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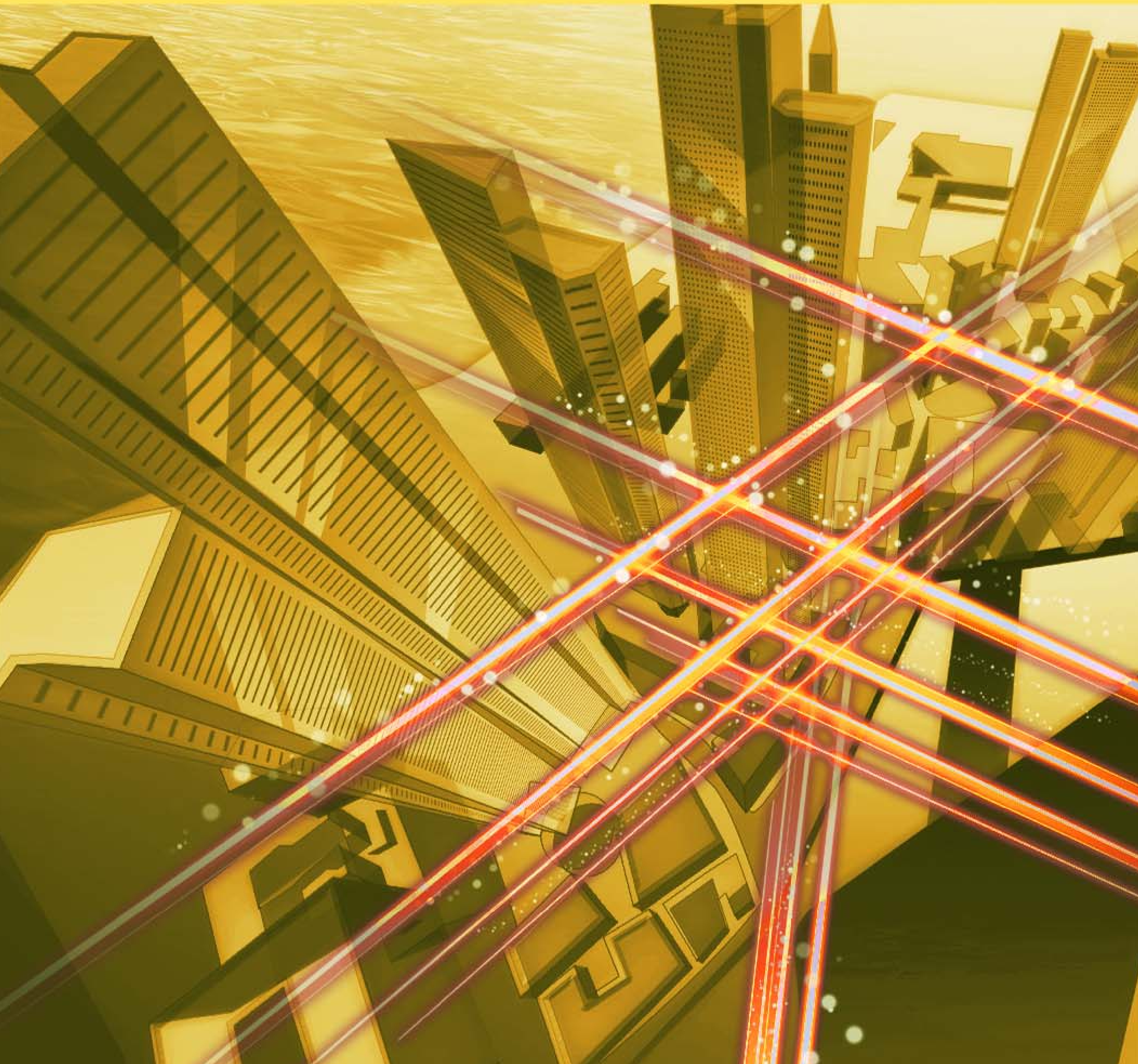

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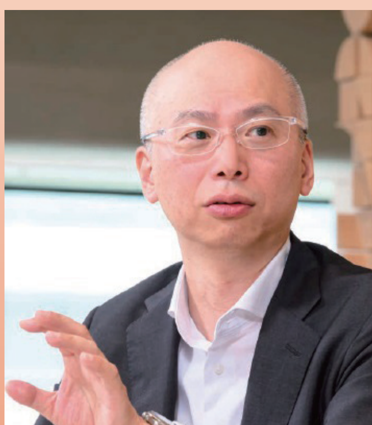
The Client's Perspective Is Essential for Creating Usable Technology. Evolving to an Asset-based Business Model and Strengthening the Capability to Use Advanced Technologies and System Development Technologies



Hidehiko Tanaka
Senior Vice President, Head of Technology and Innovation General Headquarters, NTT DATA Group Corporation

Abstract

In July 2023, NTT DATA shifted to a three-company structure consisting of NTT DATA Japan Corporation, which operates a business in Japan, NTT DATA, Inc., which operates a business outside Japan, and NTT DATA Group Corporation, the holding company that oversees the two aforementioned companies. Under the slogan "Realizing a Sustainable Future," NTT DATA is promoting a sustainable management. We interviewed Hidehiko Tanaka, senior vice president, head of Technology and Innovation General Headquarters, NTT DATA Group Corporation, about the technology strategy and vision of NTT DATA under the new structure.

Keywords: technology strategy, technology assets, technology focus areas

The Technology and Innovation General Headquarters oversees the technology development and formulates a technology strategy for NTT DATA as a whole

—NTT DATA transformed into a new organizational structure. What role does the Technology and Innovation General Headquarters play under the new structure?

In 2023, 35 years after its founding in 1988, NTT DATA made a new start by shifting to a three-company structure consisting of NTT DATA Japan Corporation, the operating company responsible for business in Japan, NTT DATA, Inc., the operating company responsible for business outside Japan, and NTT DATA Group Corporation, the holding company that oversees the two aforementioned companies. The aim of this organizational change is to expand business scale and promote agile management appropriate for the fast-changing digital era.

As an organization within NTT DATA Group Corporation (the holding company), the Technology and Innovation General Headquarters is now in a position to oversee the technology development and formulate a unified technology strategy for NTT DATA as a whole and promote the development and utilization of technology assets both in Japan and abroad.

In accordance with our Mission Statement of "NTT DATA uses information technology to create new paradigms and value that help contribute to a more affluent and harmonious society," we are supporting society through the provision of information technology (IT)-based social infrastructure and IT services to clients in government and industries such as finance, manufacturing, and distribution. In our medium-term management plan for fiscal years 2022 to 2025, we aim to further improve our ability to construct systems on the basis of our accumulated client understanding and advanced technological capabilities and ability to connect people, companies, and society by supporting various systems and infrastructures under the slogan of "Realizing a Sustainable Future." To achieve these goals, we are pursuing the following five strategies: (1) "Capitalize on the convergence IT & connectivity," (2) "Strengthen consulting with foresight," (3) "Evolve to an asset-based business model," (4) "Enhance advanced & development technology," and (5) "Be the best place to work."

With these strategies in mind, the Technology and Innovation General Headquarters is placing greater emphasis on leveraging our technological achievements. We are promoting the evolution to an asset-based business model as well as enhancing our ability to use advanced technologies and system development technologies while strengthening our perspective of global expansion.

Our assets include our knowledge of best practices of industries and businesses, software, and in-house tools that are commercially useful and reusable. The Technology and Innovation General Headquarters aims to create technology assets that can be used across the globe by defining global technology focus areas (TFAs) and developing technology assets that are independent of a particular industry.

—Could you please tell us in more details about your technology strategy?

In terms of the five strategies mentioned earlier, we at the Technology and Innovation General Headquarters are focusing on two of the strategies, namely, "Evolve to an asset-based business model" and "Enhance advanced & development technology." To pursue these strategies, I believe it is important to catch up with the many cutting-edge technologies that emerge every day and determine how we can quickly connect them to our clients and social issues.

Therefore, we selected technology themes in each of three phases that correspond to the maturity level of the technology, "emerging," "growth," and "mainstream." We then promote measures to strengthen our ability to use advanced technologies to gain a first-mover advantage and enhance our system development technologies to improve productivity and quality and expand business.

Regarding the technologies in the mainstream phase, which are the core of current business and the hottest ones already on the market, we are focusing on improving our business agility by enhancing our technological capabilities and creating technology assets and are developing technology assets that are independent of a particular field or industry in the TFAs that were defined and shared on a global basis. How to scale these mainstream technologies is another important issue. To implement such technologies on a large scale, we are developing the human resources involved in their implementation and building an ecosystem with partners. We are also managing these technologies according to their growth stage by using our technology portfolio.

The technologies in the growth phase are those that have been verified to have a certain degree of practicality and are expected to grow as a business. We had been looking at technologies in the span of three to five years; however, the speed of change in our society is increasing every year, so we need to accelerate the steps from the growth phase to the mainstream phase. To achieve this, we create use cases of technologies for each industry, work with clients to promote the technologies and broaden their application areas, and expand successful use cases with technologies in a particular industry to other industries.

The technologies in the emerging phase are new technologies, such as quantum computers, that have not been verified for their practicality. We identify technologies that will drive business growth in the future and evaluate the practicality of these technologies with our clients. Such co-creation efforts with clients also help us determine how a technology will contribute to clients when it is widely implemented.

Building trust-based relationships with our clients and steadily delivering results

—You have built a solid foundation for each phase. Could you give us some specific examples of the areas you are currently focusing on?

Let me present examples in four areas: "cloud," "application development and management (ADM)," "data and intelligence (D&I)," and "cyber security," as well as an example regarding the Innovative Optical and Wireless Network (IOWN) being

promoted across the NTT Group.

In the cloud area, we are strengthening our IT outsourcing services (managed services) for the growth area of cloud operation and maintenance. In response to the growing need for hybrid environments, we are offering the Hybrid Cloud Managed service as a technology asset that brings together the expertise and tools for developing and operating a hybrid environment consisting of a combination of public clouds, such as AWS, Azure, and Google Cloud, with private clouds and on-premises environments.

In the ADM area, we are focusing on strengthening market-leading software development technologies. We are also striving to use generative artificial intelligence (AI) technology, which has been growing rapidly. Since 2020, we have been working on applying generative AI to software development based in Japan and Spain.

In the D&I area, we are strengthening our ability to build and propose data platforms. We are also developing assets related to four technology trends namely, AI governance, AI engineering, data fabric, and decision intelligence for this purpose.

In the cyber security area, we are enhancing security-operation services—from detection to cause identification, recovery, and prevention of recurrence. In July 2023, we began providing a managed detection and response service in Japan. To launch this service, we turned the expertise we have accumulated through NTT DATA's global governance of 56 locations and 190,000 people into business. We are also training the human resources who will deliver this service to clients to roll it out globally.

Regarding IOWN, in April 2024, we conducted field trials in the U.K. and U.S. for connecting datacenters owned by the NTT Group via the IOWN All-Photonics Network (APN). In these trials, datacenters separated by approximately 100 km were connected using an IOWN APN line, which enabled communication between datacenters with latency less than 1 ms. These trials demonstrated that connecting datacenters with the IOWN APN enables them to be used as an integrated IT infrastructure as if they were a single datacenter and suggested its applicability to distributed, real-time AI analytics and the financial sector. Together with our operational departments around the world, we are planning field trials with clients in sectors that could be use cases for distributed datacenters, such as in the financial sector, with the aim of quickly launching business. We plan to work with our clients to confirm that distributed datacenters connected via the IOWN APN can adequately meet the requirements for actual business operations.

—What do you think are the strengths of NTT DATA, which is expanding its business worldwide?

Our strengths are having deep knowledge of various industries and having global reach. As I mentioned, we capitalized on the long-term relationships that we have built with our clients to forge partnerships for innovation. Such partnerships are essential because business and technological development cannot be achieved from a single perspective.

The same as with the four TFAs mentioned above, we have defined business focus areas (BFAs) to consider technology development from a business perspective rather than just from a technology perspective. We have established the dedicated team Tech Advisory Team to accelerate the creation of business that uses advanced technology in line with the innovation process. It is pointless if the developed technology is not actually used; therefore, we simultaneously emphasize technology development and distribution/implementation of our assets in Japan and abroad. What is needed to achieve this is to democratize a technology so that it can be used across industries. Internationally, in fiscal 2023, we established the Global Repository, a mechanism for sharing our assets across NTT DATA as a whole. In Japan, in addition to creating a framework for the distribution of information, the Technology and Innovation General Headquarters is taking the lead in identifying assets that should be focused on while linking with the industry-specific strategies possessed by the operational segments, i.e., the Public & Infrastructure, Financial, Enterprise, and Technology Consulting and Solution segments. We are striving to expand and upgrade assets that are expected to be used more widely in the future.

We, NTT DATA, have been recognized for the high level of implementation capability, but by strengthening the proposal capability, we hope to become a group of engineers with consulting capabilities as well. We are more concerned than ever about "results" in terms of how much we have contributed to satisfying our clients' goals. Rather than simply making proposals and implementing them, we want to build relationships of trust with our clients and steadily deliver results. Results are an important indicator for both the consultants who make proposals and the engineers and experts who implement them, and we want to be a company that does not stop at providing services but also delivering concrete results and value.

Hosting training camps to bridge the gap among departments

—What do you value in your work?

I joined NTT DATA in 1995 and started my career in the research and development department. I then gained experience in the practical application of technology through project management in the field. Specifically, I have been involved in a wide variety of projects, including smart-meter systems for NTT DOCOMO and an electric-power company. The knowledge that we acquired in the process of constructing such systems with our clients is the basis of our current technology strategy.

Needless to say, when providing technology, it is important to see things from the client's perspective. For example, rather than receiving detailed instructions and specifications, clients want a system that they can operate safely and securely without having to read instructions and specifications. Moreover, various types of failures, both big and small, inevitably occur, and it is fair to say that at least one server breaks down somewhere every day; however, we cannot stop our clients' systems or lose their important data, thereby interrupting their businesses. In light of this reality, I always keep in mind how to ensure that our clients can keep operating their systems safely and securely and place great importance on creating technology that will enable us to provide that assurance.

Although not particularly popular these days, we hold training camps and other events to provide opportunities for exchanging ideas to strengthen communication both inside and outside one's organization. For example, even when the same client needs and markets are considered, there will inevitably be gaps in the perceptions of those in the field and those in the supervision and management departments. Accordingly, we will work intensively with around 30 employees at department-manager level to communicate in a way that bridges such gaps. Participants in the training camps may at first be apprehensive and feel each other out, but they gradually get used to each other, begin to understand each other's thinking, and start talking about things other than work. Seeing such situations, I realize the importance of direct communication.

Formulating a specific action plan with milestones is also important to align the sense of time and the direction of the entire organization.

—Finally, please tell us about the future prospects for the Technology and Innovation General Headquarters and your message to engineers and clients.

We call ourselves "the world's strongest group of system engineers plus something extra" and we intend to use the experience we have cultivated to strengthen our system development and operation capabilities. NTT DATA has set 2025 as the "Global 3rd Stage," and we aim to become a company trusted by clients worldwide and obtain the "Global Top 5" status in IT services. To acquire this status and beyond, we cherish the spirit of taking on challenges without fear of failure.

To all our engineers, researchers, and developers, it goes without saying that technological innovation requires flexible responses and rapid action, so always maintain a positive attitude. I've been told this in the past, "If you're not sure which direction to go, just move forward." Even if the path you have chosen turns out to lead to failure, you can correct your course as soon as you realize that and use that experience of failure to lead to your next success. Let's grow together with our clients while enjoying the evolution of technology without forgetting the clients' viewpoint. Let's also continue to challenge ourselves by taking a start-up mindset.

Finally, to our clients and partners, we want to be your trusted partner as your first choice. Let's solve social issues through co-creation and create business opportunities together.

Interviewee profile

■ Career highlights

Hidehiko Tanaka joined NTT DATA in 1995. He became head of Platform Engineering Department of System Engineering Headquarters in Technology and Innovation General Headquarters in 2017, head of Production Engineering Department of System Engineering Headquarters in Technology and Innovation General Headquarters in 2018, and head of System Engineering Headquarters in Technology and Innovation General Headquarters in 2020. He has been in his current position since June 2023.

Pursuing Fundamental Theory and Applied Technology of Cryptography That Is Secure in an Environment in Which Quantum Computers Are Widespread

Masayuki Abe
NTT Fellow, NTT Social Informatics Laboratories

Abstract

Security incidents such as data breaches and cyber attacks are being frequently reported. In the event of such an incident, cryptography protects essential information. If the information stolen or leaked was encrypted using a strong cryptography that cannot be decrypted, the information is merely a series of "1"s and "0"s and cannot be tampered with. With the spread of the Internet, cryptographic technologies are widely used in e-commerce such as online shopping and cryptocurrency. Encryption and decryption are done through computer-based computations, but as computer performance improves, they are becoming more complex to ensure robustness.

We talked with NTT Fellow Masayuki Abe of NTT Social Informatics Laboratories, who is researching cryptography, about a new method that uses cryptography for safely buying and selling information, new developments in zero-knowledge proofs, a technique for proving a certain statement is true without revealing additional knowledge, and his thoughts on creating a comfortable community where researchers respect each other.

Keywords: cryptography, zero-knowledge proofs, cryptographic protocol

Cryptographic technology based on fundamental theories that are unshakeable even in the era of quantum computers

—Could you tell us about your current research?

I became an NTT Fellow in 2022, and am researching cryptography under the new structure of the Abe Research Laboratory. Research on cryptography at NTT is roughly categorized into three areas based on periods in chronological order: "present," "near future," and "distant future" (**Fig. 1**). The critical points concerning these categorizations are whether the period is before or after the advent of general-purpose

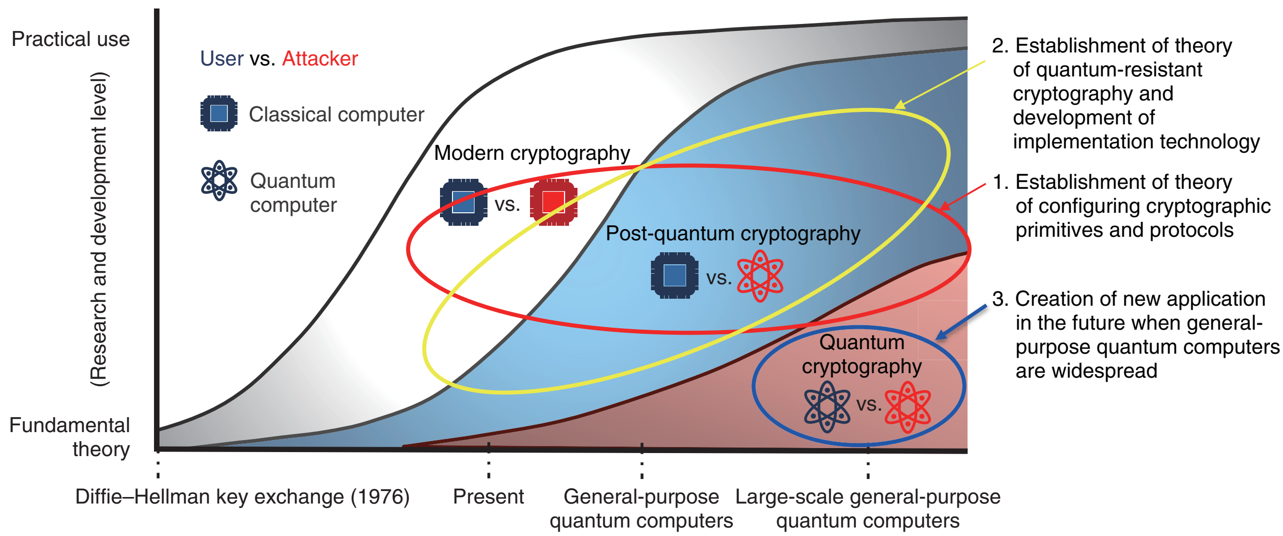


Fig. 1. Current status of NTT's cryptographic research: three research areas.

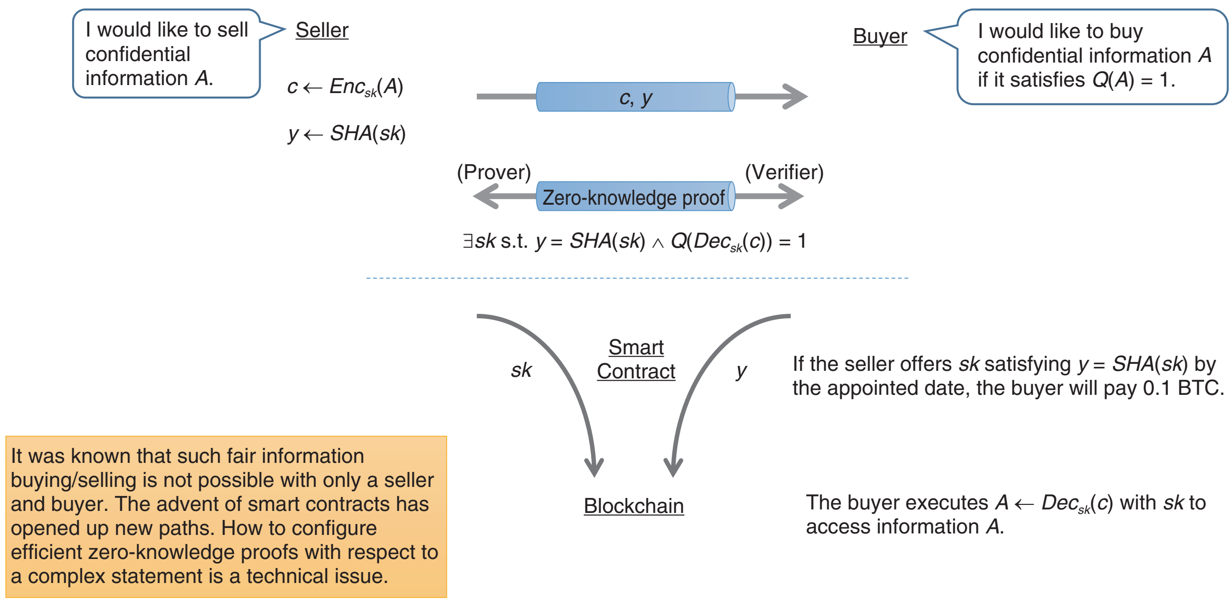
quantum computers or after such computers becoming widely used in society. Under these categorizations, the present is the period before general-purpose quantum computers are invented.

Cryptography aims to protect information from hacking or attacks by malicious individuals or from leaks due to system problems, so it is crucial to know how much computing power malicious individuals have. Improvements in the computing power of classical computers (commonly used computers) can be predicted in line with past improvements. However, quantum computers have powerful computing capabilities that are inconceivable as an extension of classical computers, and new types of attackers will take advantage of these capabilities. Accordingly, cryptography will be utterly different before and after quantum computers are put into practical use. When quantum computers become more widespread, new applications will emerge, and cryptography that can handle them will be needed. Quantum computers will, therefore, be a key factor in cryptography. It is currently unclear whether or when a large-scale general-purpose quantum computer will appear, so we are researching cryptography to prepare for its arrival.

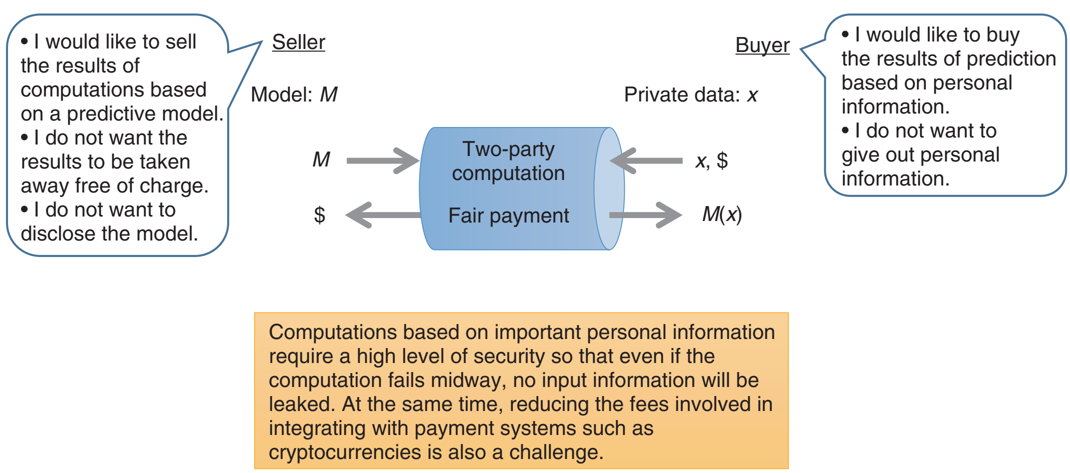
Under these circumstances, the theory of cryptography that has been researched in the world of classical computers will be an unwavering fundamental theory in the future, and the theme of the first area of our research is to continue that research and build a new theory. The second area of our research is to construct cryptography that is secure even after the advent of a general-purpose quantum computer. Being tackled primarily by young researchers, the third area of our research involves imagining what applications will emerge and what the world will be like when quantum computers become as pervasive as smartphones are today and researching the corresponding cryptography.

I am currently investigating the themes in the first and second areas. In my last interview of this journal (July 2021 issue), I discussed a method that combines zero-knowledge proofs and smart contracts as one of the mechanisms for safely and securely buying and selling information, namely, a buyer purchases (correct) information held by a seller (at the correct price) by using smart contracts on the blockchain (**Fig. 2(a)**). I am now advancing this method one step further and consider that a seller and buyer exchange information, and the buyer buys the result of that exchange. An example is that the seller has a high-precision predictive model (circuit), and the buyer wants the results of predictions made with their information using the seller's model. The seller provides the circuit, and the buyer provides the input information for the computation (prediction). Considering such a case, I am researching a mechanism for safely and securely buying and selling the computation results when both parties want to keep their respective highly confidential model and input information secret (**Fig. 2(b)**).

One method of achieving such a mechanism is to use an intermediary while using the smart contracts



(a) Safe information selling/buying using smart contracts on the blockchain



(b) Secure purchase and sale of computation results

Fig. 2. Information buying/selling.

mentioned above, but doing so would be very costly. Another method is fully homomorphic encryption, which encrypts the buyer's input information and executes the computation with that information on the seller's side. In contrast, the data are still encrypted, and the encrypted computation result is returned to the buyer. The challenge, however, is that the seller's circuit is not encrypted, yet the buyer has no idea whether the result of the seller's computation is correct.

Therefore, I came up with an approach to achieving two-party computation, with encrypted (encoded) information input into an encrypted circuit. The final result of the computation is also output as encrypted information. The correctness of the computational process is guaranteed by the pre-processing between the seller and buyer—independent of their private inputs—to create a circuit. If this pre-processing is correct, it is guaranteed that the actual computations can only be executed correctly. If an error occurs during the pre-processing, the information between the two parties at that stage is simply computed as random numbers, and the original information is not tampered with or leaked, so the processing can simply be aborted. We are currently using this two-party computation to develop a secure mediation system for computation results. Artificial intelligence-based prediction and other services have become popular, and I expect that selling the results of computations will emerge as a business.

—Besides technology for safely buying and selling information, what other themes are you working on?

Another research theme is cryptographic protocols, which securely combine several components for a particular purpose. I am particularly focusing on composition technology for zero-knowledge proofs. A zero-knowledge proof is a technique for proving that a certain statement is true without revealing additional knowledge beyond the statement itself. For example, the technique enables one party to prove to another party the fact that a particular sheep named Dolly is present in a flock without revealing specific information about where Dolly is in the flock. Therefore, a person who has a public key only needs to inform the other party of the fact that they have the corresponding private key, the public key can be used for authentication through zero-knowledge proofs. The concept of zero-knowledge proofs was developed in 1985 but has recently been recognized as a very effective technique in the blockchain field. With the rapid development of applied technology in the last few years and the entry of startups and other companies, zero-knowledge proofs are now being used in the Web3 and blockchain fields. That being said, not all relevant theories have been created, and as the development of zero-knowledge proofs advances, new areas of research have emerged, so my current theme is to theoretically establish technologies to address these areas.

The point of this theme is how to prove, by zero-knowledge proofs, for example, that a person knows "private key corresponding to the public key" and that "I have more than 1000 bitcoins." In the case of proving the former fact *and* the latter fact, it is only necessary to prove that two individual facts are both true simultaneously; however, in the case of proving the former fact *or* the latter fact, if one party does not want to give the other party information about which fact is true, it is not enough to prove one of them. That is, if these two zero-knowledge-proof systems are not combined effectively, information about which fact is true will be leaked. Consequently, proving the former fact *or* the latter fact cannot be successfully done without an internal composition (zero-knowledge-proof composition).

The study of zero-knowledge-proof composition has rapidly progressed since 1994; however, the method of composing two zero-knowledge-proof systems has been changing in accordance with the properties of each system. In contrast to the traditional, well-known style of zero-knowledge proofs, known as "three round zero-knowledge proofs," a new, more-efficient style of zero-knowledge proofs—which is unsuitable for three round zero-knowledge proofs—has emerged. This progress has made it possible to execute zero-knowledge proofs efficiently with five or more rounds. However, it is interesting that a method of composition that worked well with three rounds becomes vulnerable to so-called "attacks" when the number of rounds reaches five. For example, it becomes possible to create a proof that verifies the statement "(A and B) or (C and D)" even though only A and C are valid, which means the proof becomes incomplete and information will be leaked or security not being properly proven. It has therefore become necessary to develop a method of composition that is compatible with newly emerged zero-knowledge proofs. Given that necessity, I and co-researchers have proposed a method for safely combining multi-round zero-knowledge proofs such as five round and seven round ones. The results of our proposal will be presented at Crypto 2024, the most prestigious conference concerning cryptography, to be held in Santa Barbara, CA, August 18–22, 2024 (as of the time of this interview).

By applying our method to the areas where conventional zero-knowledge proofs are used, it should be much easier to use zero-knowledge proofs. I believe that our method will contribute not only to the Web3 and blockchain fields but also to broader fields that require efficient zero-knowledge proofs.

To create a comfortable community where researchers respect each other

—What do you keep in mind as a researcher?

I have always wanted to contribute to NTT's research and development through cryptographic research, but becoming an NTT Fellow has given me a broader perspective and a stronger desire to nurture the successors and younger generations in the cryptography community as a whole. Research and development can blossom precisely because it has theoretical seeds, but if you admire the flower and eat the fruit, it will end there. It is therefore necessary to train successors and younger generations. At the same time, the soil (fundamentals and theory) that supports the flower (application) must be constantly supplied with nourishment, so I want to work hard to make the soil strong while finding enjoyment in doing that. Since applied fields are fast-paced and results will not last forever, I strive daily to use fundamentals to produce results one after another.

I currently have two positions: the director of the Abe Research Laboratory and a researcher. As a laboratory director, since the members of my lab are outstanding, independent researchers, I am aware that my job is to respect their independence and create an environment in which they can do what they want to do. I grew as a researcher watching the example of my seniors, but the research styles and lifestyles of today's researchers differ from those of researchers in the past, so I ask myself whether I can be a good role model for my fellow researchers. My style is not everything, and we are equals as researchers regardless of age, so I try to set an example to young researchers as one model.

Connecting and discussing ideas with a wide variety of people at international conferences is a direct opportunity for collaboration, so I want to maintain this style. Nothing is more satisfying than having people want to conduct research with me after seeing the discussions and presentations I gave at conferences.

—Do you have a message for younger researchers?

Terms, such as Millennials and Generation Z, are used to lump together behavioral and lifestyle characteristics on the basis of year of birth and generation. The world of researchers has also seen significant change in the research environment. Research styles, lifestyles, and ways of thinking of young researchers, mid-career researchers, and their superiors differ, and those of mid-career researchers and their superiors have also changed compared to when they were young researchers. Ways of thinking also vary from individual to individual.

When such members form a research community or team, each member tends to impose their way of doing things, and because it takes time to understand each other, disagreements tend to occur. The community or team will never feel comfortable. I believe a sense of comfort is important to grow as a community and team and achieve results. To create a comfortable environment, it is best to take the time to understand each other, and the first step to that is to be relaxed and respect each other regardless of age, position, etc. Each generation has different problems, and each is searching for a way of life and direction to go amid those problems. Your experienced colleagues can offer advice or provide examples that are based on their experiences, so please do not hesitate to talk to us if you need assistance.

During the COVID-19 pandemic, I found researching challenging because I could not meet people in person. However, now that the various restrictions have been lifted and the research environment has improved significantly, face-to-face communication has become more active. I'm happy about this situation, and I want to seize this opportunity to engage in more face-to-face communication—necessary to make the community more comfortable—while preserving the benefits of remote work. Let's continue to research together in a comfortable community.

■ Interviewee profile

Masayuki Abe received a Ph.D. from the University of Tokyo in 2002. He joined NTT Network Information Systems Laboratories in 1992. He engaged in developing fast algorithms for cryptographic functions and their software/hardware implementation as well as the development of a software cryptographic library. From 1996 to 1997, he was a guest researcher at ETH Zurich, where he studied cryptography, specifically multi-party computation, supervised by Professor Ueli Maurer. From 1997 to 2004, he was with NTT Information Sharing Platform Laboratories (now NTT Social Informatics Laboratories), where he worked on the design and analysis of cryptographic primitives and protocols, including electronic voting, a key escrow system, blinding signatures for digital cash systems, message recovery, and publicly variable encryption schemes. He also engaged in efficient multi-party computation based on cryptographic assumptions and zero-knowledge proofs in multi-party computation. From 2004 to 2006, he was a visiting researcher at IBM T. J. Watson Research Center, NY, USA, working with the Crypto Group, where he researched hybrid encryption, zero-knowledge proofs, and universally composable protocols.

He served as a program chair for the 7th Cryptographers' Track at the RSA Conference on Topics in Cryptology in 2007, Aisa CCS'08: the 2008 ACM Symposium on Information, Computer and Communications Security, and ASIACRYPT 2010: the 16th Annual International Conference on the Theory and Application of Cryptology and Information Security. His research interests include digital signatures, zero-knowledge proofs, and design of efficient cryptographic protocols.

Developing a Theory for a Quantum Internet for Global Quantum Communication

Koji Azuma
Distinguished Researcher, NTT Basic Research Laboratories

Abstract

Quantum mechanics emerged a century ago. It abandoned the deterministic worldview that underlies classical mechanics for a more general theoretical system. It is now believed that everything should be described by quantum mechanics. Furthermore, in our efforts to rethink the theoretical system for information processing based on the classical worldview within the framework of quantum mechanics, it has become clear that even information processing tasks that were previously considered intractable can now be performed within the framework of quantum mechanics. For this issue, we interviewed NTT Distinguished Researcher Koji Azuma, a leader in the field of quantum network research at NTT, about his current research and his mindset as a researcher.

Keywords: quantum network, quantum internet, quantum repeater

A new method that overturns conventional wisdom will bring the future of the "all-optical quantum internet" to life

—First of all, what does it mean to develop a quantum network theory?

My research is about developing a quantum network theory. It is aimed at identifying a future vision of the "quantum internet," the ultimate type of a communication network allowed in the framework of quantum mechanics.

One of the roles of theory in physics is to predict the future with a high degree of certainty. Classical mechanics, as typified by Newtonian mechanics, gives a 100% correct prediction of the "in principle, this will always happen" sort. But in the microscopic world of atoms and elementary particles, there are phenomena that cannot be explained by classical mechanics. That is where quantum mechanics comes in. This is a broader theoretical system than classical mechanics in that, like weather forecasting, it only goes so far as to say the probability that a phenomenon will occur. It provides highly accurate explanations for phenomena at various levels, from the microscopic world to the universe. Quantum mechanics is now considered to be the theory of everything, and even when a theory has worked well in classical mechanics, for example the theory of gravity, it remains one of the fundamental efforts in modern physics to rethink it, or "quantize" it, in the broader framework of quantum mechanics.

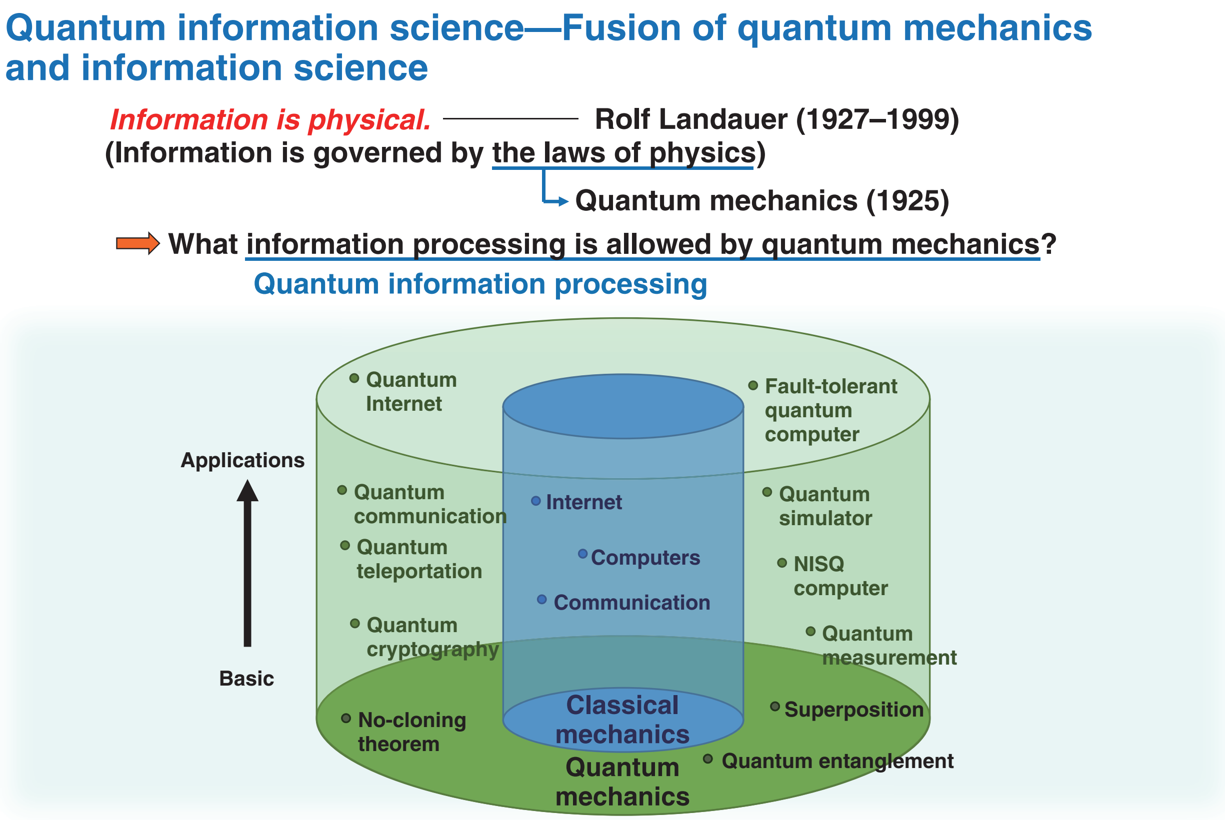


Fig. 1. Background of the research: fusion of quantum mechanics and information science.

At the same time, physics also underlies information processing technologies such as telecommunications and computers, which were invented in the last century and have influenced modern society. This idea was popularized in the 1990s by Rolf Landauer (then an IBM Fellow) with his slogan "Information is physical" (**Fig. 1**). For example, when we communicate information in our brain in an online meeting, the information in our brain is converted into sound, the sound is picked up by a microphone and converted into an electrical signal, and so on... In general, information processing is done through physical systems and physical processes, which means that information processing follows physical laws. However, current information processing technologies such as computers and telecommunications are only built on a classical mechanistic worldview.

Quantum information science was born out of the attempt to "quantize" this information processing, and within this field, I am working on developing the theory for a "quantum internet." If we consider the current internet as the largest information processing network on Earth, the quantum internet, a quantum version of it, should be the ultimate information processing network (**Fig. 2**). The term "quantum internet" was originally introduced by H. Jeff Kimble, a professor at the California Institute of Technology, as the title of a 2008 review article in *Nature*. At that time, however, it was only an abstract concept of a "quantum information processing network" in which quantum information processing nodes such as quantum computers and quantum memories were connected by quantum communication channels such as optical fibers and free space. My research aims to give shape to the quantum internet, which at the time was only an abstract concept.

—What kind of research are you working on to realize the quantum internet?

In order to instantiate and realize the quantum internet (which was an abstract concept), a quantum communication channel is first needed to transmit the quantum systems that carry quantum information. In

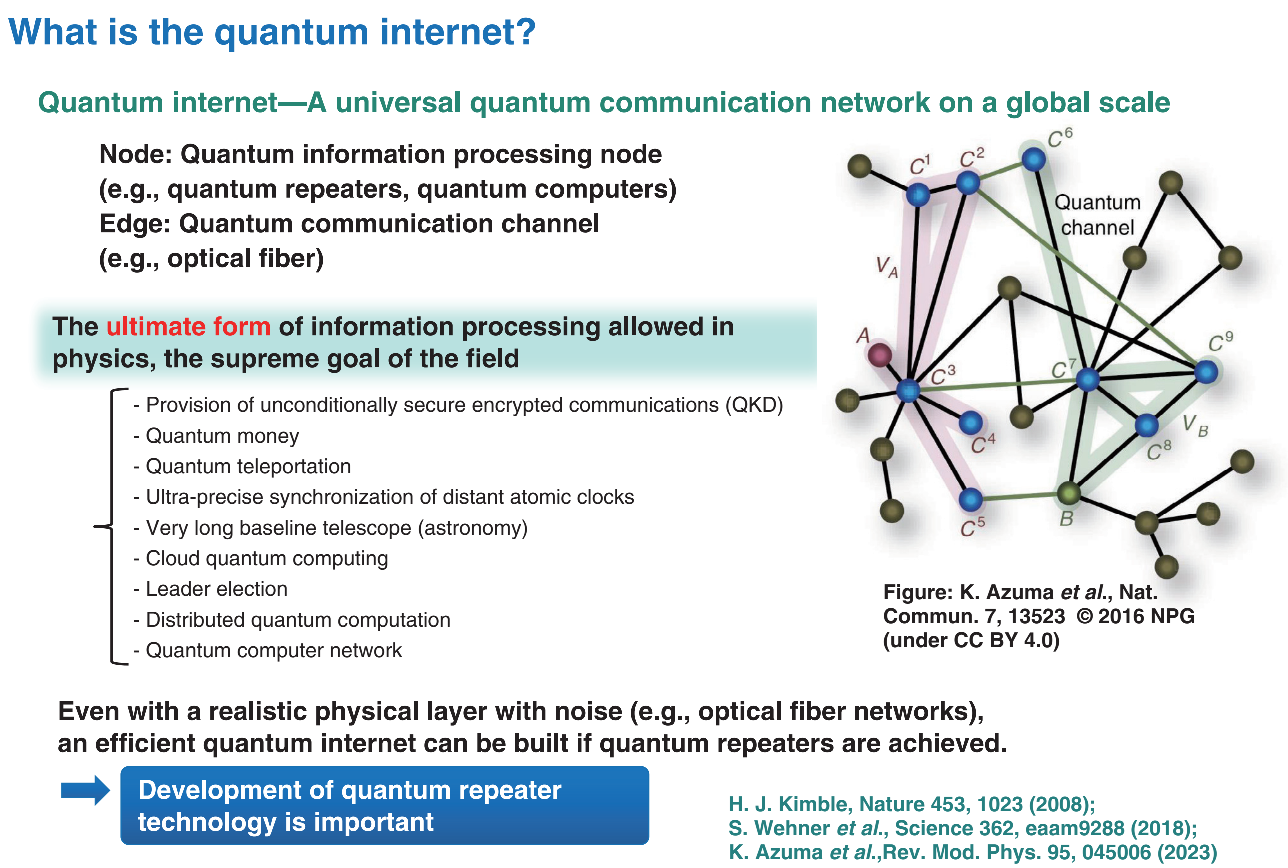


Fig. 2. Overview of the quantum internet.

conventional communications, optical fiber and free space are used as communication channels, and signals are amplified using repeaters and amplifiers to counter the noise and loss they have. However, since quantum information cannot be duplicated or amplified in principle (no-cloning theorem), signal amplification cannot be used in the transmission of quantum information. The "quantum repeater" was proposed in 1998 as a method to solve this problem. This method works by placing multiple special devices called "quantum repeaters" between the sender and receiver and connecting them with each other via quantum communication channels, enabling faithful and efficient quantum communication regardless of the distance between the sender and receiver, even if the quantum communication channels have noise or loss.

Around 2010, when I started my research, it was a well-established theory that quantum repeaters are equipped with "quantum memory" to store quantum information, and I don't think anyone had any doubts. However, a quantum repeater using conventional quantum memory requires time-consuming transmission of quantum information, and also requires quantum memory to have a quantum interface with light, which is the medium for delivering quantum information. Not only that, but there was a risk that the transmission itself would fail if the quantum computation by the repeater failed during the process, resulting in extremely high demands on the device.

What led to the creation of the research that turned the situation around was a conversation with Professor Hoi-Kwong Lo at the University of Toronto, where I was accompanied by my colleague and mentor Kiyoshi Tamaki, who was then a member of the same laboratory as me. When I presented my theory of a quantum repeater based on quantum memory, I was asked a simple question: "Is quantum memory necessary for a quantum repeater to begin with?" This single remark made me rethink the conventional wisdom, and what emerged was a new quantum repeater method, "all-optical quantum repeater,"

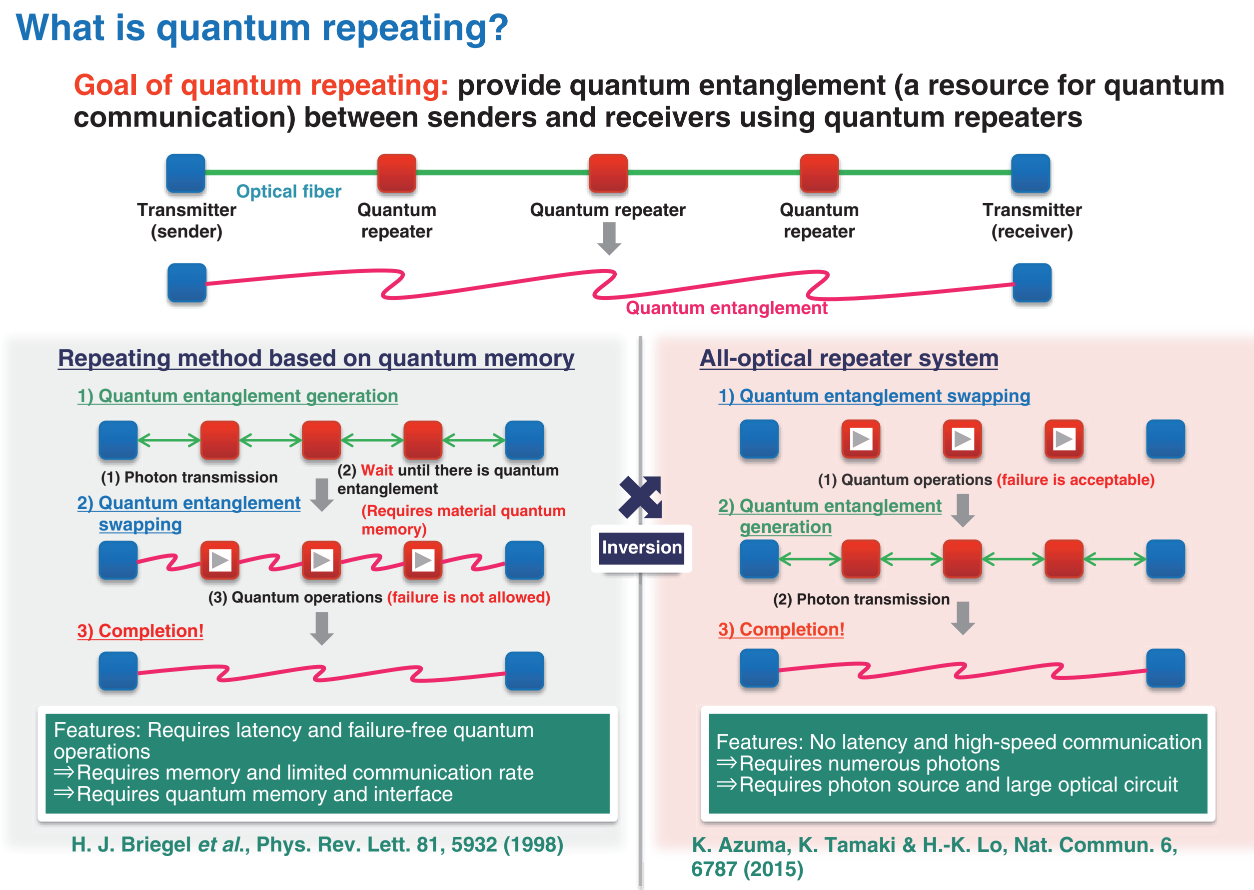


Fig. 3. Comparison of two quantum repeater methods.

which we pioneered and announced to the world in 2015. This showed that a quantum repeater was possible simply by combining optical devices, and overturned the conventional wisdom. This method was not immediately accepted by the public at the time, when quantum memory development was being vigorously pursued for a quantum repeater. However, the situation changed drastically after a talk at the international conference QCrypt 2015, and it is now recognized as one of the two major approaches to realize a quantum repeater (quantum memory-based repeater and all-optical repeater) (**Fig. 3**). This all-optical quantum repeater is a milestone in the development of an "all-optical quantum computer" that realizes quantum computation using only optical devices. Furthermore, it presents the possibility of an "all-optical quantum internet" realized by connecting all-optical quantum computers with all-optical quantum repeaters. I was personally convinced from the outset that it would be significant.

—What other research are you involved in?

In order to implement the all-optical quantum repeater announced in 2015 as per theory, I felt that the research would be very lengthy, requiring a special mechanism called "quantum error correcting code," and that the field might "run out of breath." In that context, I wanted a research subject that would be a milestone in the realization of an all-optical quantum repeater. I set out to find a method that would bridge the technical and conceptual gap between an all-optical quantum repeater, which has no communication distance limit, and the point-to-point quantum key delivery method, which, although limited in communication distance, was already in the practical application stage.

The distance limit for point-to-point quantum key delivery, which directly links the sender and receiver via fiber without using any relay points, was estimated to be about 400 km in fiber distance. To overcome this, I proposed with William J. Munro, the group leader at the time, and others the idea of placing only one measurement device in the middle of the sender and receiver. This has revealed the possibility of doubling the communication distance without requiring quantum memory or a quantum error correcting code, while maintaining the communication rate of the point-to-point quantum key delivery method, and thus enabling communication up to 800 km. Among them, the twin-field quantum key delivery method that I proposed in 2019 with Marcos Curty and Professor Lo from the University of Vigo is now called the CAL19 method and has been adopted by various teams around the world for their quantum key delivery implementation.

After discussions with Akihiro Mizutani, who was resident with Professor Lo's group, we initiated research to extend the theoretical limits of the point-to-point method, which had just been derived at that time. We were the first to present the limits of "quantum communication capacity" and "secret communication capacity," which are the capacity for communication that any quantum network has. This has helped to lay out a theoretical framework for properly handling the previously ambiguous "quantum internet" and has provided a road map for the design of efficient quantum internet protocols. In fact, inspired by this, Professor Go Kato (who belonged to NTT Communication Science Laboratories at the time) and I proposed a communication method in which quantum repeaters are run in parallel between two parties on a quantum network. We have even found that the efficiency of this method is consistent with the theoretical limit when the communication channel consists of optical fibers. These results show that a quantum repeater can play a fundamental role in the development of a high-performance quantum internet at or near the theoretical limit.

I believe that this series of studies on quantum networks contributed to the linking and substantiation of the concept of a quantum repeater (which had existed since 1998) and the abstract concept of quantum internet (proposed by H. Jeff Kimble). In fact, we were able to compile these findings into a review paper titled "Quantum repeaters: From quantum networks to the quantum internet" with leading researchers from around the world, which was published last year in *Reviews of Modern Physics*.

A beautiful theory with "simplicity" will be passed down to future generations

—What are your future research prospects?

The quantum internet has many potential applications. One of them is to enable quantum key delivery between arbitrary users on a network. Quantum key delivery, a type of quantum cryptography, can provide information-theoretically secure cryptographic communications even if an eavesdropper commits any eavesdropping act allowed by quantum mechanics (e.g., eavesdropping with a quantum computer). Therefore, it is likely to be applied in situations that require a high level of security, such as referendums, summit meetings, financial transactions, and the exchange of genetic and biometric information. Other applications include quantum teleportation to faithfully transfer information about quantum systems to distant points at the speed of light, precise and covert synchronization of atomic clocks to enable stable, accurate, and secure sharing of world clocks, and very long baseline telescope arrays.

In addition, research on quantum computers is spreading beyond academia to companies, and there is accelerating development toward commercialization. Unlike quantum computers, which are primarily for personal use, quantum communications, and hence the quantum internet, is an infrastructure whose value increases with the number of users, and therefore must be built and expanded at the national level based on a scalable grand design. Therefore, I believe that research to articulate the design of scalable middleware and software, as well as standardization, will be important efforts.

—What is your impression of NTT laboratories?

NTT Basic Research Laboratories has been conducting research on quantum information since the dawn of the field in the 1990s and is a center of quantum information research in Japan. In fact looking back, there were many people around me from NTT Basic Research Laboratories. Professor Nobuyuki Imoto (currently a specially-appointed professor at the University of Tokyo), who was a professor in the Quantum Information Laboratory at Osaka University, which I belonged to, and Professor Masato Koashi (currently a professor at the University of Tokyo), who was an associate professor at Osaka University, belonged to NTT Basic Research Laboratories before they transferred to the university. Professor Masahiro Kitagawa (currently a specially-appointed professor at Osaka University) had been in close contact with the Imoto Lab at Osaka University and was also conducting pioneering research in the field of quantum information. And what I found when I actually joined NTT is that even if a field is currently in its budding stage (like quantum information research 30 years ago), NTT has an environment that will support your research over the long run if it is intrinsically important. This is a rare laboratory in the world, and I feel blessed to have it.

—Finally, do you have a message for researchers, students, and business partners?

What I value in my research is to pursue theories that, even if they are not understood at the time of publication, will be recognized over time and become "the norm" in the future. Personally, I believe that is the kind of research that will endure, and I think it is very important to explore the possibilities of this kind of research, especially with basic research. What I always keep in mind is to what degree the impact of our research will remain over a longer time frame. While it is important for an ordinary product, for example, to affect many people at the same time, this is not necessarily the case for research. Some of Einstein's papers have become more widely cited since his death, and on a related note I am always mindful of the question of how long research can captivate many people.

I also note that such an enduring theory always encompasses simplicity. If the theory is correct and valuable, and if it is published and recognized by the public, it will then spread on its own without any arbitrary intervention. I still look for puzzles and their pieces, always asking myself questions such as, "What conception of nature and what technologies will become standard in the future?" and "What is a fundamental problem that I would be elated to solve?" While it can be a struggle, it can also be an incomparable joy when you find a problem and solve it. I hope that this article will make some of you think, even if only a little, that you should "value your own sensibilities" in your research and work, and that you should "devote yourself to what you, not others, believe is valuable."

■ Interviewee profile

Koji Azuma received a Ph.D. from the Department of Materials Science, Graduate School of Engineering Science, Osaka University in 2010. In the same year, he joined Nippon Telegraph and Telephone Corporation. Since joining NTT Basic Research Laboratories, he has been engaged in theoretical research on quantum information theory, especially quantum repeaters and quantum internet. He was a visiting scholar at the University of Toronto from 2012 to 2018; a visiting scholar at the University of Cambridge in 2019; and a JST PRESTO (concurrent) researcher from 2018 to 2022. He has been an invited associate professor at the Graduate School of Engineering Science, Osaka University since 2019 and an editor of *Optica Quantum* since 2023.

Social Well-being Achieved through Social Infrastructure That Is Friendly to People and the Planet

Sachiko Oonishi

Abstract

With the emergence of generative AI (artificial intelligence), the world is becoming more convenient; however, electricity consumption is increasing, and environmental problems are becoming more serious. By personalizing products and services to meet diversifying needs from a market-in perspective, while using energy-saving technologies and IOWN (Innovative Optical and Wireless Network) access networks as new human and Earth-friendly industrial and social infrastructure, we can achieve social well-being. This article is based on the keynote speech I presented at Tsukuba Forum 2024 held in May 2024.

Keywords: generative AI, IOWN, marketing

1. Delivering desired value: From information and communications infrastructure to industrial and social infrastructure

The global situation and social issues are becoming increasingly serious. Food loss is also a major issue; 2.5 billion tons of food, or 40% of the world's annual food production, is wasted, and 1.5 billion of the 2.9 billion garments produced in Japan each year are discarded. Environmental and energy issues are becoming increasingly severe on a global scale, and Japan's declining birthrate, aging population, and labor shortages are also becoming more serious. In this environment, people's values are diversifying. In the past, people sought an abundance of material goods, but this pursuit has gradually shifted to spiritual values, intangible qualities, and satisfying experiences. Put another way, people's present mindset is to minimize loss and possess only what is necessary rather than an abundance of goods.

In response to such diverse values, NTT has combined research and development with marketing, and in June 2023, we launched the Research and Development Market Strategy Division within the holding company. In addition to the Research and Development Planning Department, which manages the research laboratories, Market Planning and Analysis Department and Alliance Department were established in a manner that unified the three departments into a single headquarters. We want to continue to evolve and develop our research technologies while aligning with the market and considering research and development of technologies on the basis of requirements from a market-in perspective. In addition to research and development, we will pursue customer experience (CX) in all business processes, ranging from service development to operations and service quality. We will also continue to improve our services from the customer's perspective by taking into account how our corporate and individual customers feel. To achieve these goals, we are building a marketing infrastructure that will enable us to digitize and visualize customer feedback and other information and strengthen our system for promoting CX.

Our product-out research and development has evolved from "connect" and "communicate" technologies, starting with telephones, to optical-fiber technology and more recently, IOWN (Innovative Optical and Wireless Network). From a market-in perspective, we look at things from the viewpoint of people, society, and the Earth as if we were imagining them with our senses. Therefore, "product-out" is

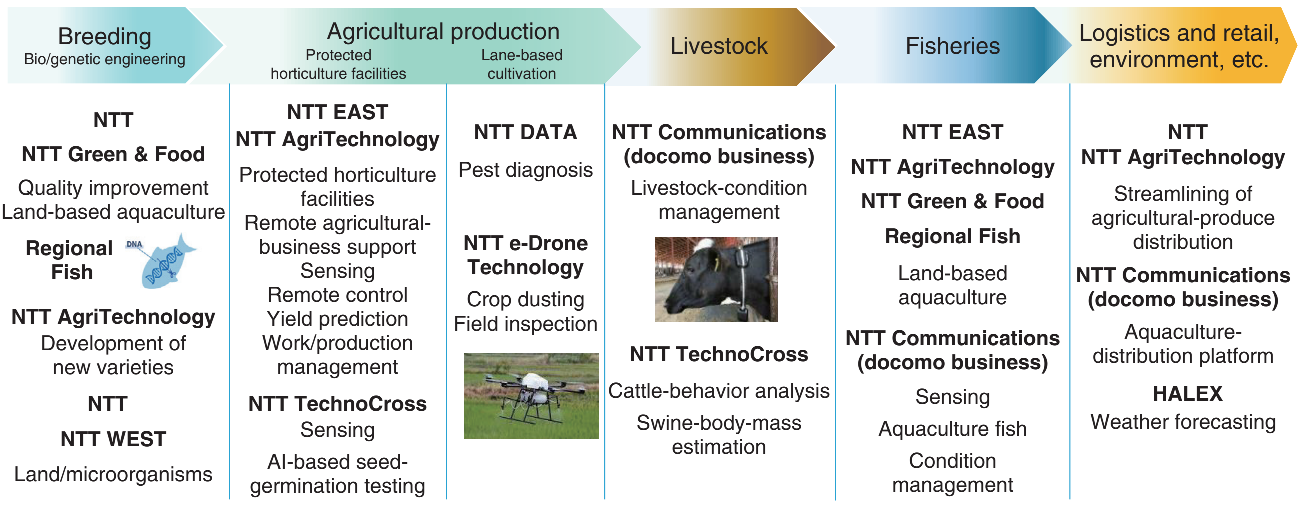


Fig. 1. How innovation is transforming food: from breeding, agricultural production, livestock and fisheries to distribution.

more of a functional approach that focuses on connection, digitalization, data generation, and artificial intelligence (AI) analysis. In contrast, "market-in" is more of a value approach that involves using a variety of technologies to visualize, optimize, improve efficiency, save energy, and personalize. By combining these two approaches, we can respond to diverse values and work towards social well-being. The products that we have been developing through our traditional product-out research and development focused on connecting and communicating have played a role as an information and communications infrastructure for corporate and individual customers; however, from now onwards, we hope our products and services will play a role as an industrial and social infrastructure in relation to people's values, which cover food, clothing, shelter, lifestyle, education, healthcare, energy, and entertainment.

2. Food and healthcare play a role as an industrial and social infrastructure

How can we make food more abundant and sustainable? The livestock industry, fisheries, forestry, and the recycling of waste produced by these industries are all related to food production but have not been directly related to the industry supporting information and telecommunications infrastructure. I will give examples of how we are using our technology for sustainable food production. As we all know, the risks to a stable food supply are severe. In 2024, food costs have increased by about 1.5 times compared with those in 2023, and this trend is starting to affect eating habits. Japan's food self-sufficiency rate is 38%, which is the 12th lowest among the 13 major developed countries [1]. The agricultural workforce in Japan has decreased by 70% compared with that in 2000, and the average age of an agricultural worker has increased to 68 [2]. Thus, the amount of abandoned farmland has increased by 70% compared with that in 1995 [3]. The Netherlands and the UK also faced similar challenges, but through innovation, they now have food self-sufficiency rates of over 60%. To achieve such innovation in Japan, many NTT Group companies are working in various areas such as breeding, agricultural production, livestock, fisheries, and distribution (**Fig. 1**). I will introduce one of these areas, greenhouse horticulture.

NTT AgriTechnology is building one of Japan's largest lettuce greenhouses in Yamanashi prefecture (**Fig. 2**). The area enclosed by the greenhouse is 1.5 times the size of a soccer field. In this greenhouse, natural light is used instead of artificial light, and the spraying of water and nutrients is done automatically. With only half the workforce required, the greenhouse has achieved a 10-times-higher yield than that of conventional greenhouses. As Japan's population of agricultural workers declines and the general population ages, we are making good use of a combination of manual labor and technology. Thus, we were commissioned to design and build a bell-pepper greenhouse (right-side image in Fig. 2), which has also been a great success.

Another food-related area of interest is fisheries.

Japan's largest lettuce greenhouse

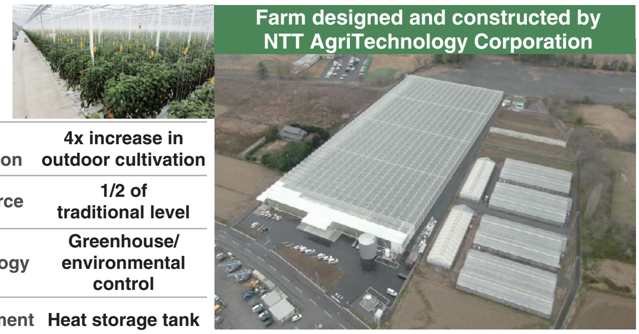
Area: equivalent to 1.5 soccer fields

Vegetables (sunny lettuce) grown at the farm are being delivered to cities and local supermarkets.

Japan's largest bell-pepper greenhouse

Area: equivalent to 3 soccer fields

Using the expertise and ICT skills that we have acquired at our own farms, we are designing and constructing farms for our customers.



Lettuce greenhouse		Bell-pepper greenhouse
10x increase in outdoor cultivation	Yield prediction	4x increase in outdoor cultivation
1/2 of traditional level	Workforce	1/2 of traditional level
Fully-automated cultivation/ environmental control	Technology	Greenhouse/ environmental control
100% water recycling	Environment	Heat storage tank

*Due to the need to prevent pests, requests to conduct tours of the facilities are not currently being accepted.

Fig. 2. Reduced environmental footprint due to 100% water recycling.

Japan's fisheries industry is in a situation in which it is no longer possible to catch as many fish as before. Increased amount of atmospheric carbon dioxide (CO_2) is warming the oceans and reducing the regions of the oceans that can be inhabited by fish. Although ocean acidification has led to a decrease in phytoplankton and zooplankton, which fish feed on, global production of marine products, including aquaculture, is increasing. Japan, however, is the only country where seafood production is declining. Japan's fishing industry was ranked number one in the world in 1980, but it has now fallen to seventh [4, 5]. In light of this situation, we decided to start land-based aquaculture, and in collaboration with NTT and a startup from Kyoto University, called Regional Fish, we established NTT Green & Food to promote land-based aquaculture. Although fish change gradually in the natural world, by scientifically modifying them at an earlier stage and making them meatier, we have succeeded in breeding fish with 60% more edible parts. The algae that fish feed on are modified to absorb as much CO_2 as possible from the ocean, and that CO_2 is thus adsorbed into the bones of the fish that eat the algae. The NTT Group is building land-based aquaculture plants for flounder, white-leg shrimp, and salmon. The first flounder farmed at the plant located in Kyushu, Japan is now available for shipment under the name "Hirameki Hikari."

We are also engaged in various initiatives in the fields of health, healthcare, and medicine. In one such initiative, we are investigating which foods, for example, a banana or cookie, cause a greater rise in blood-glucose level after eating. The glycemic index (GI) determines how much a person's blood-glucose level rises after eating. According to the GI [6, 7], cookies raise blood-glucose level more. However, the level varies from person to person, even if they eat the same food [8]. When we asked 1089 people at risk of developing diabetes to eat a banana and a cookie then measured their blood-glucose level after eating each one, 445 of them experienced an increase in blood-glucose level after eating the banana, but their blood-glucose level did not change after eating the cookie. For the remaining 644 people, their blood-glucose level increased when they ate a cookie but remained unchanged when they ate a banana (**Fig. 3**). As biometric devices in the form of wristwatches and pedometers become available to measure blood-glucose level, people will be able to eat whatever food they like while checking whether it raises their blood-glucose level. NTT's biometric wristwatch device irradiates radio waves onto the skin and measures glucose concentration by analyzing the reflected signal (**Fig. 4**). We will continue investigating this type of personalized support for promoting health.

3. Entry of generative AI

The next area concerning NTT Group companies is generative AI. Hardly a day goes by without someone

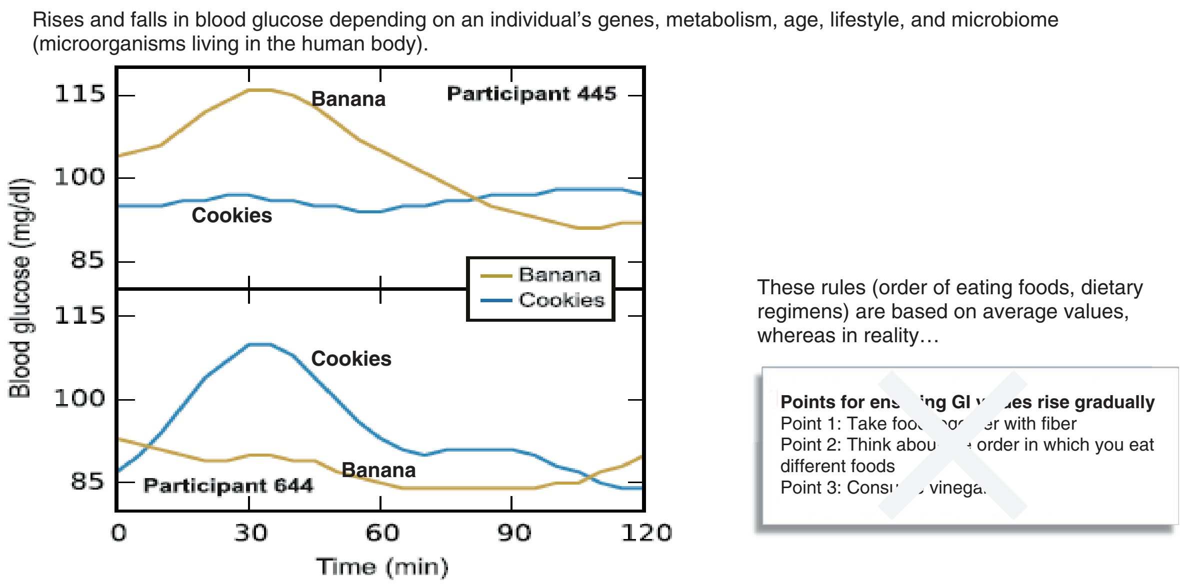


Fig. 3. Changes in blood glucose among individuals after eating the same foods.

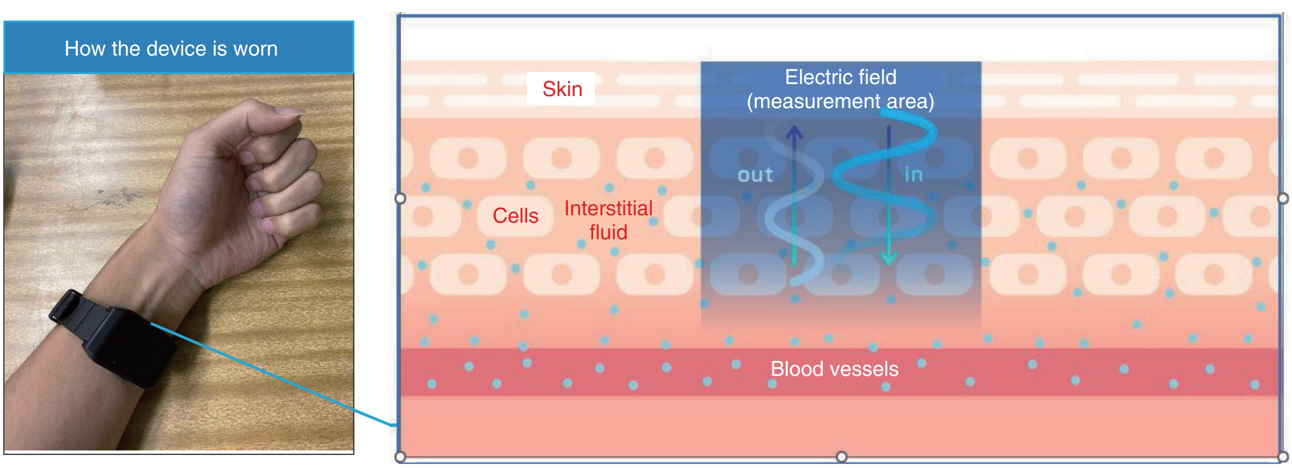


Fig. 4. Analysis of signal of reflected electrical wave passing through the skin.

talking about generative AI [9, 10]. Let's think about the size of generative AI. The size is determined by multiplying two factors: the amount of text data to train generative AI and the size of the neural network that connects the data. As the size increases, the number of graphics processing units (GPUs) used for training the AI increases, and more GPUs means increased electricity consumption, increased processing time, more operations, and higher cost. It is thus essential to determine the appropriate neural network and suitable data. OpenAI's ChatGPT-3.5 has 570 GB of training data, and the number of parameters for the size of the network that connects these data is said to be 175 billion. This amount of data is roughly the amount of words spoken by an adult male per day, which is said to be 7,000 words (20,000 words for women), and when converted to annual character count and bytes, it comes to 5.11 million bytes. In other words, the training data for ChatGPT-3.5 are equivalent to the number of words uttered by 110,000 adult men in a year. Whether this amount feels like a lot or a little depends on the individual, but it is the

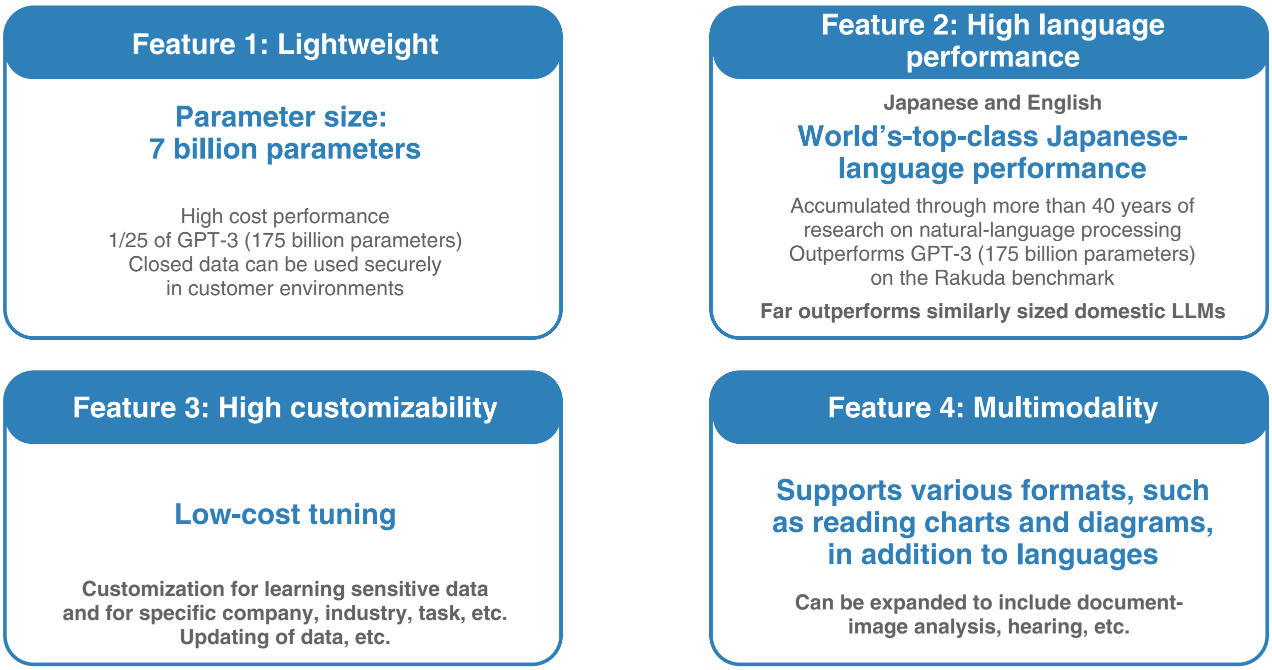


Fig. 5. Features of tsuzumi.

actual amount of data that ChatGPT-3.5 learns from.

The other factor is the size of the neural network that connects data. A neural network is structured in a similar manner to the human brain, and humans recognize things by connecting over 100 billion nerve cells and 100 trillion synapses from input to output. The size of the ChatGPT-3.5 network, estimated to be 175 billion parameters, means that the network connects up to 1/600th the functions of the human brain. In other words, ChatGPT-3.5 must learn a lot of data, and that learning incurs high costs. Given these issues, we released NTT's version of a large language model (LLM) called "tsuzumi."

The tsuzumi LLM has four key features (**Fig. 5**). The first feature is it being lightweight. Both the amount of training data and number of parameters connecting the data are small. ChatGPT-3.5 has 175 billion parameters, but tsuzumi has only 7 billion, which is 25 times fewer. Thus, tsuzumi is easy to train on closed company data because of its low number of parameters. The second feature is its high language performance. NTT has been researching natural-language processing (NLP) for over 40 years. Therefore, we can effectively connect various NLP parameters and neurons for training LLMs, making it possible to attain high language performance. Despite being lightweight, tsuzumi has been evaluated as having language performance exceeding that of ChatGPT-3.5. The third feature is customizability. Training ChatGPT-3.5 on closed data from companies, etc. requires a huge number of parameters and GPUs, which requires high power consumption. However, tsuzumi can be easily customized with a small number of GPUs, so it can be tuned with low power consumption and at low cost. The fourth feature is multimodality. That is, tsuzumi can be trained on not only text data but also various figures and tables. "Lightweight = high cost performance" means that tsuzumi can be trained in 1/25th of the time it takes to train ChatGPT-3.5, which results in lower hardware, electricity, and operating costs. Despite it being lightweight, tsuzumi gives better answers than the top-ranked AI in Japan and ChatGPT-3.5, so it is currently ahead of its rivals.

4. Response to tsuzumi

Since the launch of tsuzumi in November 2023, we have received inquiries from more than 500 customers, mainly from corporate customers. Taking advantage of tsuzumi's features, 60% of customers want to train tsuzumi with their personal information and highly confidential information in their environments in a closed and secure manner, and about half the

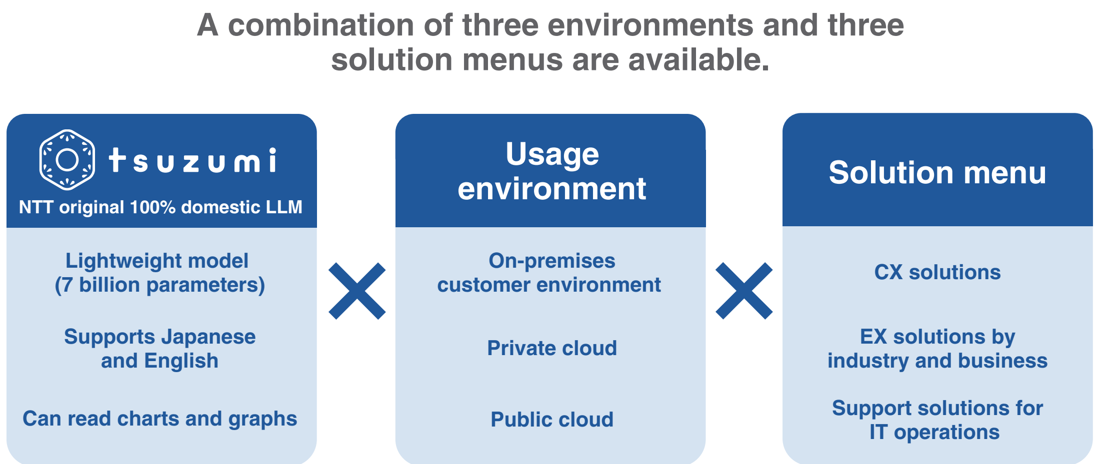


Fig. 6. Commercialization of tsuzumi.

customers are in the manufacturing, municipal, financial, and information technology (IT) industries. Many customers want to use tsuzumi for improving CX and customer response, improving employee experience (EX), and IT and automating operations. Given these customer requests, we started providing three commercial "solution menus" from March 2024 (**Fig. 6**).

I will now give examples of using tsuzumi in the healthcare field. Does drinking coffee rejuvenate blood vessels or constrict them? In fact, it depends on the genes that each person possesses: it will have a positive effect on some people and a negative effect on others [11]. Similarly, the effectiveness of the drug "warfarin" for dissolving blood clots varies by up to 20 times depending on an individual's constitution and medical history [11]. In other words, for some people, one tablet is effective, and for others, 20 tablets are required. The current average dosage is considered 10 tablets. Consequently, some people may end up taking too much, but others may find that the drug has no effect at all. Given these issues, we are using tsuzumi to structure and analyze electronic medical records (information) in a way that makes it possible to personalize such medications. Electronic medical records have been introduced in over 90% of large hospitals in Japan [12]; however, they are written qualitatively, so they cannot be collected and analyzed. Although we have a system in place for structuring and formatting the data (records), we want to be able to transcribe the data automatically (since they are currently transcribed manually). For example, it takes one person a day to input various test data into a medical record; however, by using tsuzumi, it is possible to transcribe electronic-medical-record data and analyze them automatically in a manner that personalizes healthcare.

5. Energy-saving technology that supports the benefits of AI

Although using AI will make many things more convenient, the total amount of data generated and used in the world will increase. The electricity consumed by one training session for ChatGPT is greater than the amount of electricity generated by a single nuclear power plant in one hour; put another way, the more convenient it becomes to train it, the closer we get to the limit of the Earth's energy capacity. The power consumption of datacenters is also increasing rapidly, and building more datacenters poses the risk of power shortages for the general public. With that power issue in mind, some countries, such as the Netherlands and Singapore, have temporarily halted construction of datacenters.

IOWN is a technology that uses the power of light to reduce electricity consumption. Looking for ways to compensate for the shortage of datacenters, we are using optical technology—from transmission to data processing—and incorporating the features of IOWN, namely, low power consumption, large capacity, and low latency, into datacenters and networks. We launched the All-Photonics Network (APN) IOWN1.0 in March 2023 and the APN leased-line plan powered by IOWN in March 2024.

Building many large datacenters would significantly impact electricity use in everyday life. We thus believe that this impact can be lessened by (i) building smaller, distributed datacenters or datacenters in locations where natural renewable energy can be used and (ii) connecting them with the APN to enable them to be used without delay as if they were a single datacenter. In fact, although the previously mentioned training of tsuzumi is being researched at our Yokosuka R&D Center, because space to install a GPU was not available there, we trained tsuzumi by connecting the Yokosuka R&D Center to a GPU installed at the Musashino R&D Center in Musashino City, 100 km away, via the APN. We are thus able to use the training data as if they were in Yokosuka.

In our overseas datacenters, we have experimentally connected datacenters 100 km apart via the APN. NTT currently possesses 98 global datacenters and 148 buildings. NTT's datacenters are ranked as the third most abundant in the world. We have also achieved a leading position in a market evaluation by IDC [13]. Demand for datacenters is forecast to grow at an average annual growth rate of 13.5%. With both hyperscalers and enterprises growing at the same rate, adding expected demand for generative AI will add a further 20% growth in demand for datacenters. Due to the above-mentioned issue of power consumption, supply is not enough to meet such high demand, so we hope to use the APN globally to resolve the supply shortage. We plan to double the current total power supply to each of our global datacenter locations (1100 MW) by FY2026 [14].

We are also considering using the APN for dynamic control of mobile base stations, that is, reducing power consumption by turning antennas on and off in accordance with the number of people covered by each antenna. In collaboration with Sony, we are also promoting remote production. We have been using temporary lines to stadiums each time a game is held, and people have been going to the stadiums to edit video of the game on the spot. However, we are considering a set up by which APN lines are connected to all the stadiums from the beginning, and the game video can be edited remotely simply by using those lines.

The construction industry now has a serious labor shortage, and to cope with this situation, we developed a system that allows construction equipment to be controlled remotely. At EXPO 2025 Osaka, Kansai, Japan, we will connect the NTT Pavilion and NTT's datacenter via the APN, which will make it possible to transmit the "Expo space" to the datacenter and analyze in real time what kind of people are visiting the NTT Pavilion and the emotions on their faces. From the analysis results, we will create a "living pavilion" that reacts to visitors' reactions in real time.

6. Aiming for social well-being

We eventually hope to make even the wiring inside a chip optical, thereby lowering power consumption from transmission to processing. I believe that changing only a part of the social infrastructure will be ineffective, that is, the entire society must change to create a low-consumption infrastructure. We are looking forward to working with you to achieve this change. OpenAI has created very large LLMs. We are considering an "AI constellation" that combines many lightweight, small, expert LLMs connected by IOWN. In this AI constellation, multiple LLMs—each with a different specialty—are connected in the form of a constellation so that they can "discuss" questions with each other and come up with answers. Those answers are then compiled to elicit better answers that are deeper and more diverse than those that can be elicited from larger LLMs. We plan to achieve sustainable transformation (SX) by using optical transmission and optical transmission processing and dramatically reduce the power consumption of technology by improving the power efficiency, processing efficiency, and training efficiency of AI models. To achieve this, we hope to work with you to build a social infrastructure that will eventually enable personalization of not only food and healthcare but also entertainment. Through SX by using AI and IOWN, we aim to achieve "human and Earth-friendly social well-being" that allows a variety of people to live healthy, happy lives.

References

[1] Ministry of Agriculture, Forestry and Fisheries (MAFF), "Food Self-sufficiency Rate," aff, Feb. 2023 (in Japanese). https://www.maff.go.jp/j/pr/aff/2302/spe1_02.html

[2] MAFF, "Statistics on Agricultural Labor Force (2022)," 2022 (in Japanese).

[3] MAFF, "2020 Agriculture and Forestry Census," 2020 (in Japanese).

[4] MAFF, "White Paper on Fisheries," 2022 (in Japanese).

[5] Food and Agriculture Organization of the United Nations (FAO), "The State of World Fisheries and Aquaculture Production," 2022.

[6] GI value of banana (in Japanese), https://www.gi-gl.com/kudamono-50/

[7] GI value of cookies (in Japanese), https://www.gi-gl.com/keisyoku-118/

[8] D. Zeevi, T. Korem, N. Zmora, D. Israeli, D. Rothschild, A. Weinberger, O. Ben-Yacov, D. Lador, T. Avnit-Sagi, M. Lotan-Pompan, J. Suez, J. Ali Mahdi, E. Matot, G. Malka, N. Kosower, M. Rein, G. Zilberman-Schapira, L. Dohnalova, M. Pevsner-Fischer, R. Bikovsky,

Z. Halpern, E. Elinav, and E. Segal, “Personalized Nutrition by Prediction of Glycemic Responses,” Cell, Vol. 163, No. 5, pp. 1079–1094, 2015.
[9] Nikkei XTECH article, Jan. 10, 2024 (in Japanese). https://xtech.nikkei.com/atcl/nxt/column/18/02683/011000015/
[10] Nikkei XTECH article, Feb. 2, 2024 (in Japanese). https://xtech.nikkei.com/atcl/nxt/news/24/00170/
[11] NHK, “Special Program on The Human Body (Jintai),” May 2021.
[12] Ministry of Health, Labour and Welfare, “Trends in the Spread of Electronic Medical Record Systems, etc.,” 2020 (in Japanese).
[13] IDC, “IDC MarketScape: Worldwide Datacenter Colocation and Interconnection Services 2021 Vendor Assessment,” June 2021. https://info.equinix.com/rs/180-SLL-021/images/ar_idc_datacenter_and_colocation_vendor_assessment.pdf
[14] NTT, “Growth Strategy of NTT Global Data Centers,” 2023. https://group.ntt/en/ir/library/presentation/2023/pdf/231003_1.pdf

Sachiko Oonishi

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She joined NTT in 1989 and became vice president of Regional Economy Vitalization, Strategy Business Development Division in 2016. In her career at NTT Communications, she became a member of the board, head of the Third Business Solutions at the Business Solution Division in 2020 and senior vice president, head of the Third Business Solutions at the Business Solution Division in 2021. She has been in her current position since 2023. She has also been an executive member of the board, chief customer experience officer, and co-chief artificial intelligence officer, NTT Corporation since June 2024.

Creating "Connections to the Future"

Riaki Hoshino

Abstract

In this article I introduce a sense of society (creating connections to the future) targeted by the NTT EAST Group as a Social Innovation Partner toward a prosperous society through the social implementation of advanced technologies. With this goal in mind, I also introduce NTT EAST Group efforts in "self-enhancement" and examples of initiatives for creating new regional value in collaboration with other companies and society. This article is based on the keynote speech I presented at Tsukuba Forum 2024 held in May 2024.

Keywords: Social Innovation Partner, invisible wall and red line, creating connections to the future

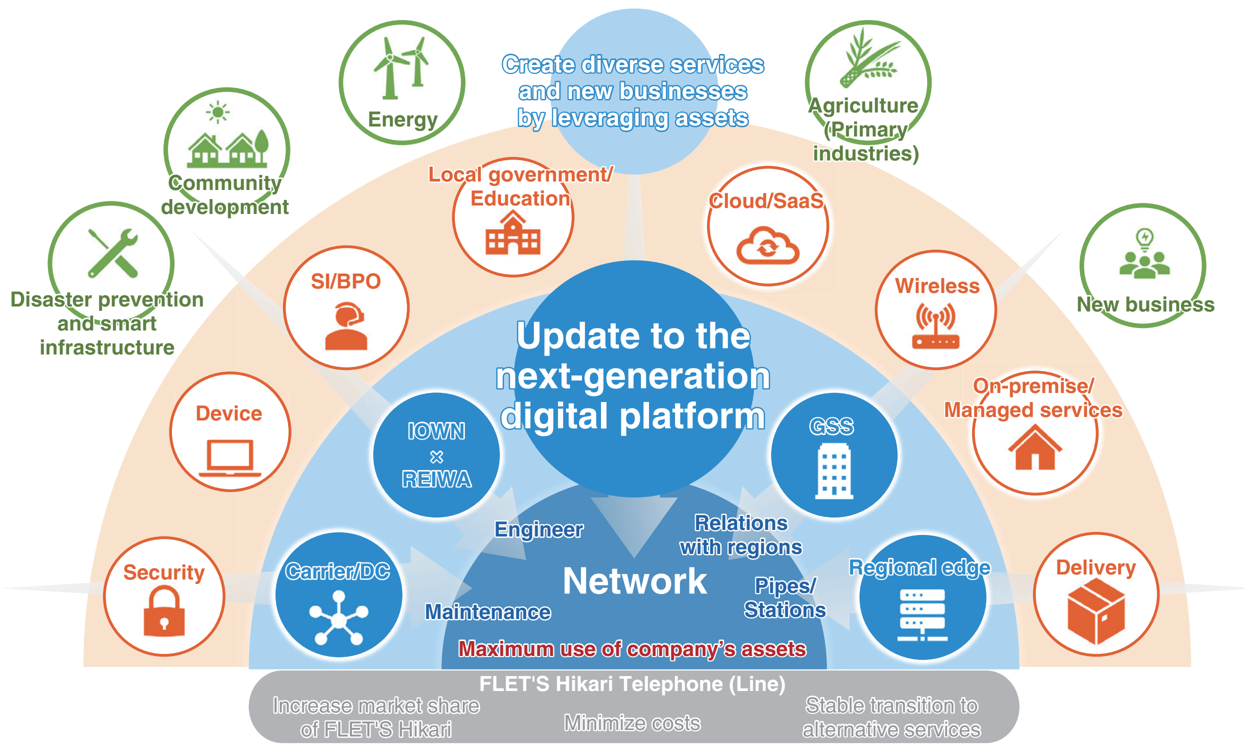
1. Towards the next-generation NTT EAST Group

At NTT EAST, we are working to implement new technologies that are truly beneficial to all our customers and society to become a Social Innovation Partner. While we have thus far been providing a variety of services centered around communications networks, there is a need to update these services into a next-generation digital platform. We are also making a transition from an era that had been providing only a network to an era that can change the lives of even more customers. NTT EAST has also contributed to areas peripheral to communications such as the cloud and devices, but I wonder if we could also contribute to new areas beyond that such as energy, agriculture, and community development (**Fig. 1**). What are our strengths at NTT EAST? Up to now, it has been our engineering capabilities in maintaining and providing many facilities. The number of metallic lines stands at several million while there are more than 10 million optical lines. Every year, we open up and discontinue more than a million lines putting more than 4000 persons to work on on-site maintenance. Going forward, I would like to provide these engineering capabilities to peripheral areas and new areas using wireless and satellite technologies, which used to be limited to only offices, at even places like factories and farms where it is difficult to provide wired services.

For this reason, we set up a new system in October 2023 that assigned more than 1000 members of NTT EAST to work in peripheral and new areas while working to raise efficiency in existing areas. We also established the Innovation and Technology Department and Open Innovation Center. It is not our intention to use the technologies developed by NTT laboratories just for us but to also provide our customers with useful technologies. To become a company that can contribute to society, I would like to pursue our activities on the three axes of "self-enhancement," "collaboration with other companies," and "collaboration with society."

2. Self-enhancement

We have strived continuously for "self-enhancement." We have made improvements by incorporating advanced technologies such as a mobile mapping system (MMS) and sensing technologies using optical fiber. However, "invisible walls" exist when introducing new technologies. I think that the concept of invisible walls is something that all companies talk about, not just NTT EAST. While it can be said that we have reached a certain level of improvements in our operations, we must change the way we work when introducing new technologies. When attempting to do so, the risks that can arise become worrisome. We can break through such an invisible wall by addressing the problem within a new field or making changes to the organization. Such an approach may be inefficient for a while, but it can eliminate worry



BPO: business process outsourcing
DC: datacenter
GSS: government solution service
IOWN: Innovative Optical and Wireless Network
SaaS: software as a service
SI: system integration

Fig. 1. Aiming to be a Social Innovation Partner.

and break through the wall. However, not everything works out in the same way. This is because existing objectives remain fixed, preventing any progress or having those objectives be too vague. Another way of breaking through a wall is to solve a problem and set new objectives so that we can then walk along a new red guiding line toward those objectives (**Fig. 2**). In this way, I believe that we can break through a wall without even realizing it.

3. Understanding the early impact of failures and improving processing efficiency (using digital technology)

We are not a unique company in that we have problems the same as other companies and local governments. It is important that we solve those problems within our company. It is because we have a proven track record in solving problems on our own that we would like others to choose us as a Social Innovation Partner.

The reforms that we are promoting involve the basic business of protecting communications. Up to now, we have promoted a mechanism that analyzes alarms and executes automatic recoveries. Since we construct facilities to enable services to continue, we have been conducting operations trying to avoid any

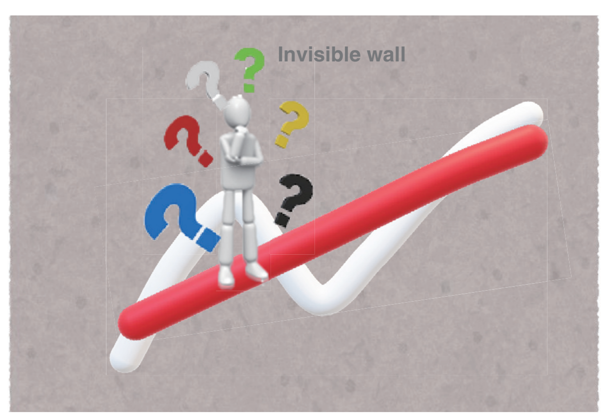


Fig. 2. Invisible wall and new red line as a guiding principle.

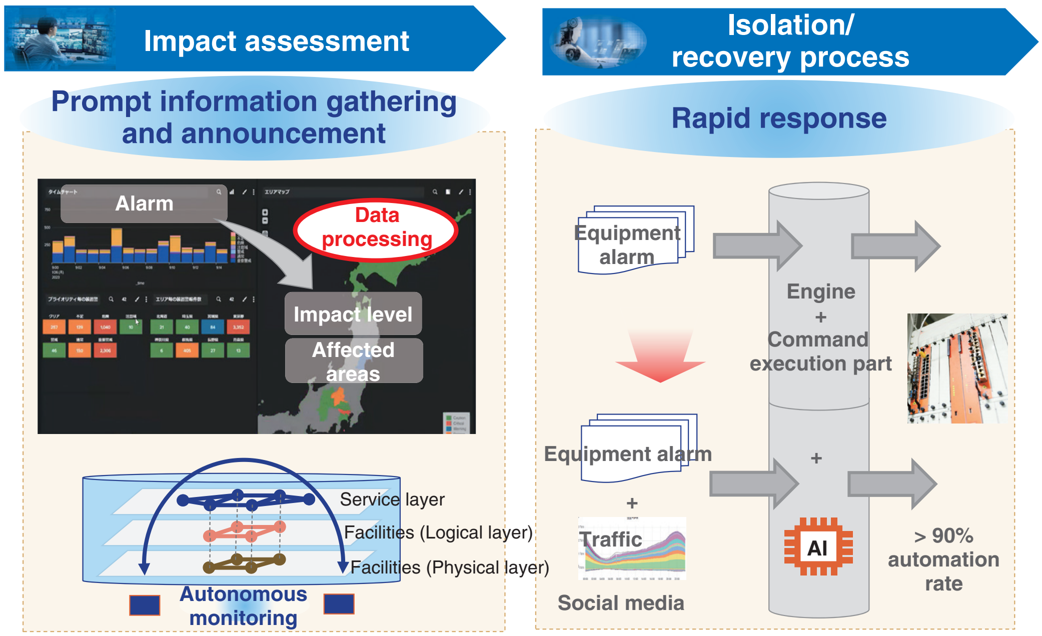


Fig. 3. Understanding the early impact of failures and improving processing efficiency (using digital technology).

impact on our customers even in the event of an equipment alarm. However, network-quality objectives have been vague.

So, what did we do? We automated processes to achieve prompt information dissemination and failure response. Taking a large-scale failure that occurred on April 3, 2023 as an impetus to make changes, we began an initiative for announcing a large-scale failure to the public within 30 minutes. We came to understand certain things during the course of this initiative. To make a public announcement, it is essential that we have mechanisms for gathering and analyzing a large number of alarms and gathering and analyzing traffic and social-media information. Fortunately, many techniques are available for gathering and analyzing data. The need for such techniques is simply common sense, but up to then, we had a different viewpoint on gathering and analyzing data, so we just didn't pursue those techniques.

Similarly, we defined our guiding principle to be that increasing the automation rate of failure response improves quality. There are many situations in which automating a response is difficult such as complex system failures and failures that had not been experienced before. However, once a failure has been experienced, a response can be automated. We also noticed that artificial intelligence (AI) for analyzing massive amounts of data is essential for increasing the automation rate of failure response (**Fig. 3**).

4. Construction of a data-utilization platform (OASIS)

It is also necessary to undertake the construction of a new data platform. All customer data are stored together since they are the same type of data, but facilities-related data are optimized separately depending on the type of operations, thus stored in a distributed manner. To analyze facility data, therefore, it is necessary to develop an application programming interface (API) for multiple systems simultaneously and upgrade servers for each facility objective, all of which can incur enormous development expenses. Assuming the secondary use of data, we have achieved the collection of data through meticulous planning and incorporated improvements tailored to individual system developments without incurring expenses. Let me give an example. By combining behavior history and data on work processes, we can identify the person working closest to the equipment that has failed within a specific NTT building. Additionally, data integration between systems has enabled more detailed analysis.

5. Efforts to redefine business content (on-site fusion)

In October 2023, we implemented an organizational restructuring toward the integrated management of inside and outside on-site operations. A major challenge for NTT EAST is determining how to expand our range of general knowledge without losing the specialized knowledge we have accumulated to date. We are also dividing our efforts into specialized technology and multi-target technology while taking on challenges in both peripheral and new fields.

In the process of taking up these challenges, there will, of course, be temporary inefficiencies. However, this will create a foundation for accepting new technologies that provide remote support. The inheritance of skills from one person to another has its limits. The use of AI can be effective in facilitating skill inheritance, but data must be accumulated to train an AI system. I think that accumulated data can be used to train AI by converting remote support work traditionally provided, for example, by telephone to text data and converting on-site work to video data. An important point when working to increase the efficiency of existing operations is how to deal with large-scale disasters considering that improvements in efficiency are accompanied by a decrease in personnel. In past typhoons, failures occurred at 50 times the normal rate, requiring a support system of about 600 people.

One measure in this regard is to focus on technology. For example, the work of inspecting utility poles that is needed when a disaster occurs can be made more efficient by using an MMS. However, machinery may stop running when a disaster hits, so there is a need to secure support personnel for such times.

At a forum held by NTT EAST on improving on-site capabilities, we conducted a competition on climbing up utility poles at the time of a disaster targeting people who work away from the field. From this competition, we learned that the number of people who could no longer safely climb up utility poles to perform maintenance work was higher than expected. We will continue to take advantage of various opportunities to secure and train personnel who can provide support in emergency situations including personnel to handle the front desk for inquiries regarding failures.

6. CX initiatives

The entire NTT Group is promoting activities to improve customer experience (CX). We learned from these activities that improving CX is beneficial to both our customers and employees. That is to say, improving CX provides an opportunity for achieving digital transformation (DX) and improving employee experience (EX). By making our customers fans (F) of NTT EAST through business (B), we obtain an ongoing flow in the form of “B, C, D, E, and F.” Using front desks as an example, we are working to improve CX by turning the speech of customers from several hundred thousand calls per month into transcription data, summarizing those data by generative AI, and classifying the results into negative and positive calls. The final step is analysis, and although this is done manually, it is still analysis that could not be done in the past.

Of importance in this initiative is that members of the Corporate Strategy Planning Department are the ones who conduct this analysis on their own while studying AI and asking engineers for help. This is certainly an example of making effort to walk along a red guiding line. Members of facility design are likewise undertaking a CX initiative. The quality of experience in the network, which used to be vague, has now been quantified. In analyzing quantified quality, we found that the quality of experience had been ensured in terms of the usage level of web services when using a fair control function. However, some changes occurred in the process of quantifying the quality of experience. One was that the members involved in this initiative started searching for evaluation technology on their own and began using technology from NTT laboratories. Even members who had previously said that they didn’t understand the process began to act on their own the instant they drew a red guiding line. I believe that it is exactly actions like these that are needed to break through a wall.

7. Initiatives to expand business areas with other companies

There are limits as to what a company can do alone, so we are starting “collaboration with other companies.” To give a concrete example, let me discuss a network initiative. In our REIWA project, we aim to link the mobile network, cloud, and other elements to provide an efficient network and regional edge and carry a variety of applications on that infrastructure.

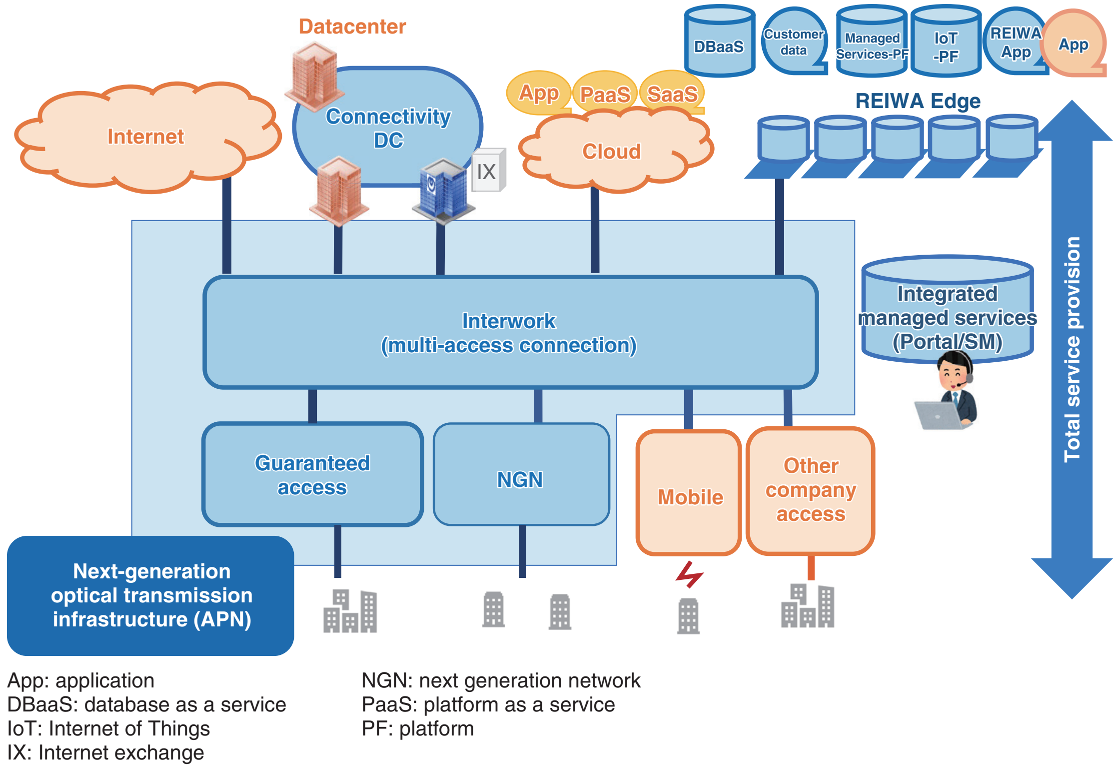


Fig. 4. REIWA project.

Making this a reality will require collaboration with other companies (**Fig. 4**).

We would also like to create an efficient and low-latency nationwide network based on the All-Photonics Network (APN). However, a network created by us alone would be unusable. Datacenter operators demand a shortest-path network, so we would like to create a connectivity datacenter network that includes datacenters.

More than simply being entrusted with the network, our objective is to create the next-generation network together with everyone. This is because the demand for datacenters in Asia is growing and it's important that Japan be chosen and not just NTT. For this reason, we aim for optimal network construction toward the construction of datacenters in cooperation with many companies. We have also started offering consulting services to business partners who wish to use our constructed cable infrastructure (**Fig. 5**).

We pioneered private 5G (fifth-generation mobile communications system) and started out with the No. 1 market share. However, in the wireless field as well, this is naturally something that we could not have done by ourselves.

We are now beginning an initiative called the "co-creation project." Our aim is to intensify our collaboration with other companies providing base stations, devices, software, and other products across the industry. This type of collaboration is important, especially overseas given the use of different radio-wave frequencies.

What we can do is make infrastructure investments and train engineers in advance. We will therefore train engineers and engage in a variety of initiatives while asking NTT Group companies for assistance.

8. Initiatives on solving social-infrastructure problems in collaboration with society

We are exploring new areas together with NTT Group companies including NTT Anode Energy, NTT InfraNet, and NTT FACILITIES. In the course of this effort, we have come to understand that this means "collaboration with society."

A case study with NTT AgriTechnology is typical example of this effort. Up to now, we have been in charge of constructing agricultural greenhouses, and among our members involved in this work, there is

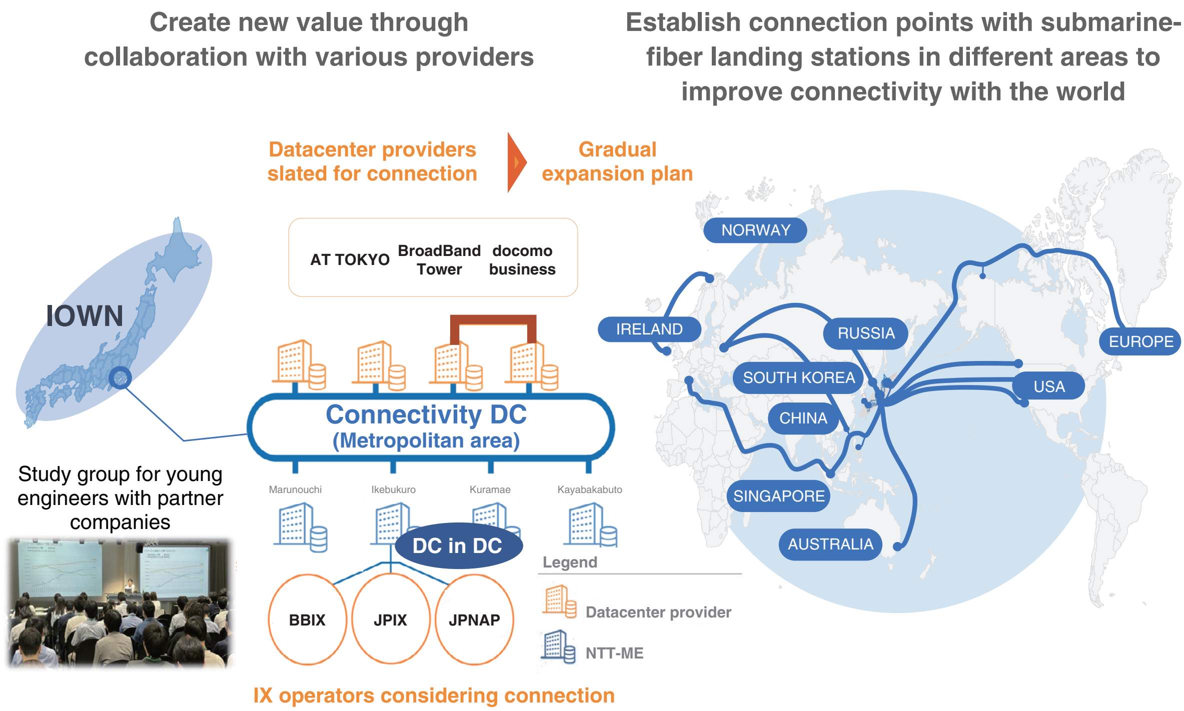


Fig. 5. Network toward datacenter construction.

one who has been continuously recognized as a Maintenance Master over a ten-year period for the number of circuit-failure repair cases handled. He quickly became a leader. While this is a different business, it was my feeling that our essential expertise and skills could be put to use here in such a way. On entering this business, we provided NTT Agri-Technology with an in-house developed system called Digital Farmer. This system was selected as one of the top ten most promising software products. In the same manner, we are providing remote-cultivation support and production guidance and making agricultural robotics a reality. I believe that it's because we get involved with farmers and execute AI-type fine-tuning that we have been chosen as the No. 1 company attracting the attention of the farming community (**Fig. 6**).

We have also been putting much effort into disaster prevention. On the basis of our experiences with the 2024 Noto Peninsula Earthquake, we are making social contributions as one of our goals. We are working in collaboration with professors at the University of Tokyo to assess disaster countermeasures in local governments. Through this assessment, we have uncovered a variety of issues related to the operation of evacuation centers and stockpile management. Making a decision on when to open an evacuation center is a particularly difficult issue. Taking the heavy rainfall that occurred in the Okitama area of Yamagata prefecture in 2022 as an example, an evacuation center was opened up five hours after heavy rain began to fall. Some people wondered whether this was too much of a delay.

We have begun providing information by collaborating with Weathernews Inc. and organizing regional operation centers. We are also exploring collaborations with software companies in such areas as electronic locks for evacuation centers and river monitoring. We are a company that creates a variety of partnerships to grow together. I would like to expand this initiative to other regions with the aim of making further contributions to society.

Renewable energy initiatives are difficult, but we have received many requests. We are introducing a power purchase agreement (PPA) model* with TNcross Corporation, a joint venture with TEPCO, but this in itself is not a real contribution. We are therefore launching initiatives in this field such as

* PPA model: A model for introducing solar-power equipment in public facilities, etc. in which the power seller and power purchaser directly conclude a PPA.

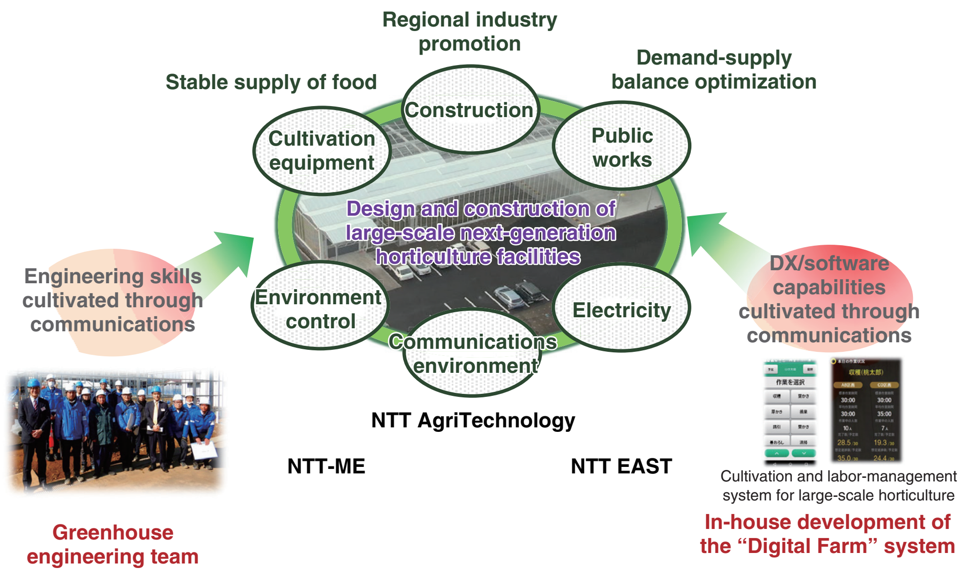


Fig. 6. Contribution to solving problems in the agricultural industry.

providing consultation on a variety of power-generation methods including wind power and consultation services for the regional power company and retailers in the Yonezawa area of Japan.

Through such activities, we have gained the trust of our customers while also being able to expand our goals together.

9. Toward the creation of new value

In the video field, we began by making videos of safety education and technical expertise starting out with only two people. Later, with a team of several hundred people, we turned to social issues such as the preservation of cultural assets and the video distribution of e-sports. More recently, we addressed the social issue of theft of copper cables at solar power plants by developing AI that can analyze video of those sites. We have been making similar efforts in the fields of drones and software. On recruiting drone pilots from within the company, about 500 employees have taken up the challenge of pesticide spraying and becoming drone-school instructors. In the software field, we established a company called NTT e-MOI in Vietnam. Although starting from scratch, about 150 employees are fully committed to developing software products and implementing them in society.

10. Creating "connections to the future"

We aim to implement advanced technologies in society by undergoing self-transformation and growing together with society. It is exactly this type of effort that is necessary for NTT EAST to be chosen as a Social Innovation Partner.

Our creation of "connections to the future" is nothing new. The metallic cables that we provided are decreasing in number every year, and we could not maintain them without the cooperation of various stakeholders such as manufacturers and construction companies. Creating "connections to the future" includes ways of making changes to connect to new things together with these stakeholders in a stress-free manner and the building of new relationships with everyone. Thank you for your ongoing support of NTT EAST.

Riaki Hoshino

Representative Member of the Board, Senior Executive Vice President, NTT EAST Corporation.

He joined Nippon Telegraph and Telephone Corporation in 1990 and became a member of the Board of Directors of NTT EAST Corporation in 2018, president and representative director of NTT-ME Corporation in 2020, and senior executive manager of NTT EAST Network Business Headquarters and president and representative director of NTT e-Drone Technology in 2022. He assumed his current position in June 2022.

Creating New Value: Access Networks to Support a Sustainable Society

Takashi Ebine

Abstract

NTT Access Network Service Systems Laboratories is undertaking research and development (R&D) on access networks, which link customers to NTT central offices. Amid these efforts, we are producing cutting-edge access network technologies that accelerate the implementation of IOWN (the Innovative Optical and Wireless Network) to create new value and promote sustainability. Our R&D on access network technologies is also leading to the diversification of service, smarter operations, and the development of new business areas. This article introduces these latest technologies.

Keywords: access networks, IOWN, R&D

1. Introduction

NTT Access Network Service Systems Laboratories (AS Lab) was established in July 1972 as the Construction Technology Development Office. For over 50 years, AS Lab has been responsible for the research and development (R&D) of access network technologies in the NTT Group [1]. In today's information and telecommunications market, cloud services and fifth-generation mobile communication systems (5G) technologies are growing, and technologies such as artificial intelligence (AI) and digital twins are making rapid progress. To support these developments from their foundations, a high-throughput, high-capacity, low-latency network infrastructure is required. Expectations for 6G, the successor to 5G, are also increasing, and stronger measures against natural disasters, which have been occurring frequently, and against network failures are in demand. At the same time, we must contribute to the reduction of the environmental burden. These trends underscore the critical importance of access network technologies.

To meet these needs, NTT has steadily advanced the R&D of the Innovative Optical and Wireless Network (IOWN) since it proposed the concept in 2019. In March 2023, NTT launched the All-Photonics Network (APN) IOWN1.0 commercial service. NTT aims to be a creator of new value and accelerator of a global sustainable society [2]. Working together as one with the rest of the NTT Group, AS Lab is moving forward with all its might to develop IOWN from its concept to implementation through R&D.

Figure 1 shows the direction of AS Lab's R&D efforts. AS Lab's mission is "taking on the challenge of creating new value through research and commercialization of cutting-edge access network technologies and contributing to building a sustainable society." As we strengthen our efforts to achieve robust networks, environmental load reduction, and a healthy and safe workplace environment, we are taking into account global perspectives and improvement in employee experience (EX). We are conducting R&D of cutting-edge elemental technologies in five areas (optical-fiber access technology, infrastructure technology, access system technology, wireless access technology, and operation technology). We use these core competences in carrying out the following three R&D policies: (1) R&D to meet extreme requirements and support diversification of services, (2) R&D to dramatically make operations smarter, and (3) R&D to use assets for new business

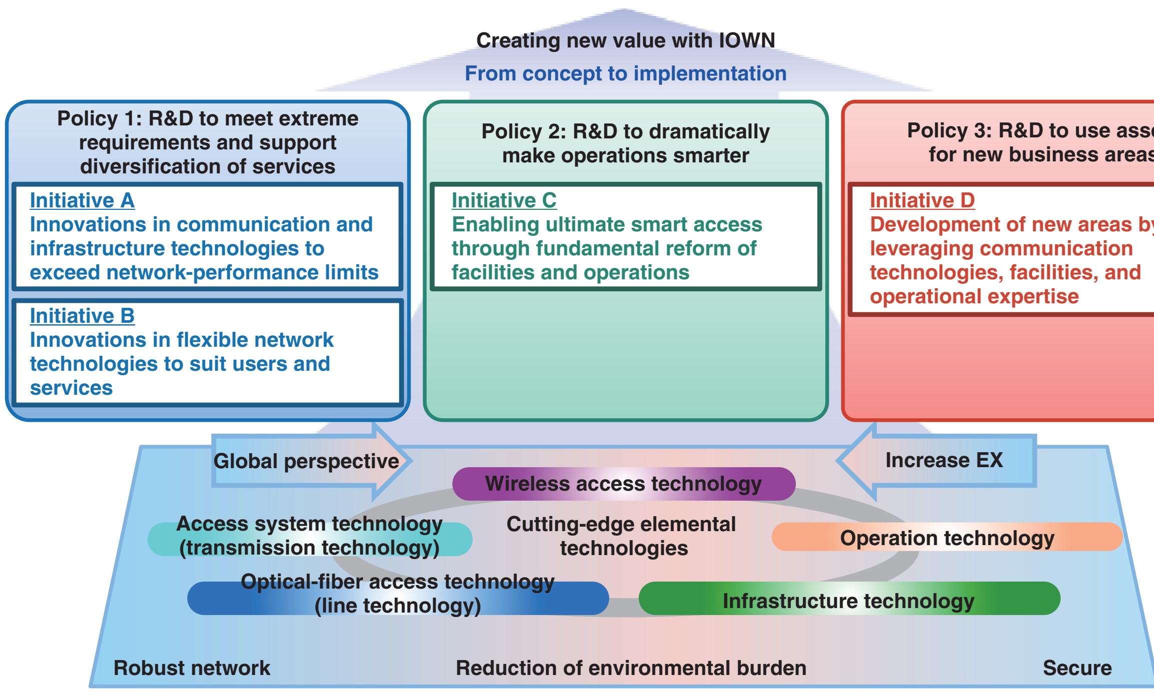


Fig. 1. Direction of R&D.

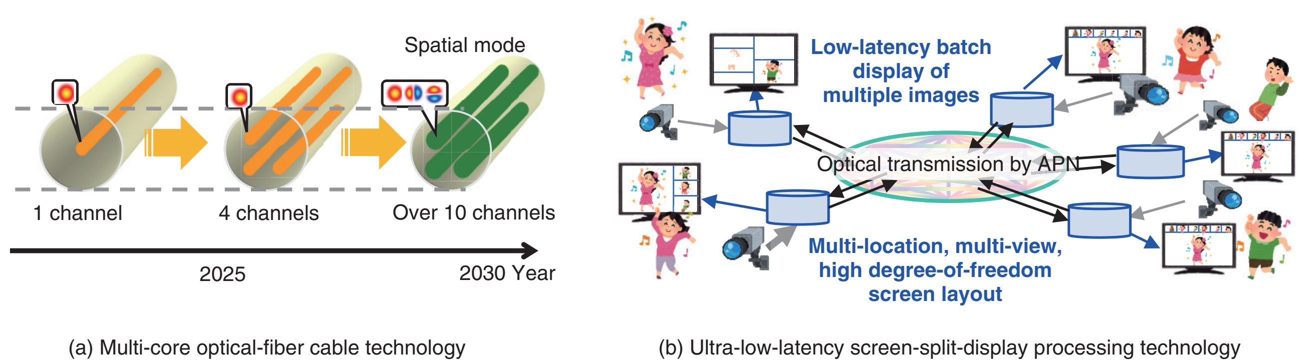


Fig. 2. Initiative A: Innovations in communication and infrastructure technologies to exceed network-performance limits.

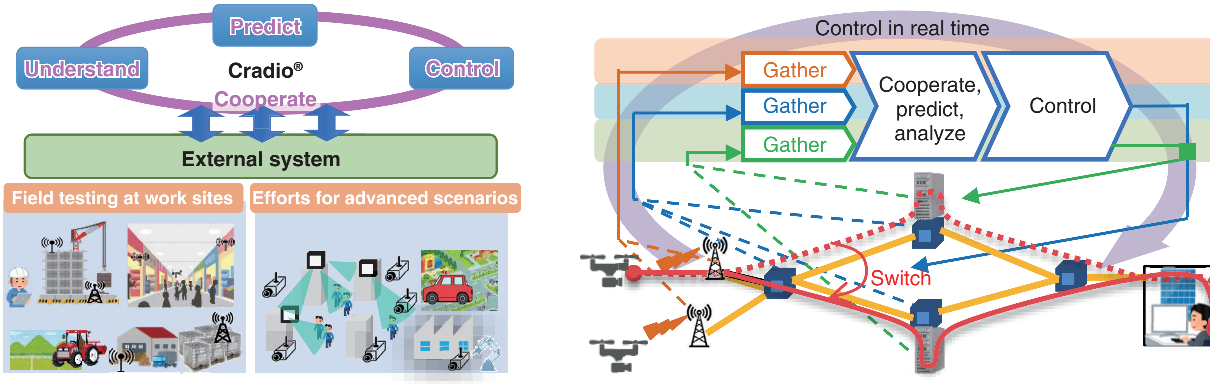
areas. The following initiatives support these three policies: Initiative A: Innovations in communication and infrastructure technologies to exceed network-performance limits, Initiative B: Innovations in flexible network technologies to suit users and services, Initiative C: Enabling ultimate smart access through fundamental reform of facilities and operations, and Initiative D: Development of new areas by leveraging communication technologies, facilities, and operational expertise.

2. Policy 1: R&D to meet extreme requirements and support diversification of services

Policy 1 is supported by Initiatives A and B.

Initiative A: Innovations in communication and infrastructure technologies to exceed network-performance limits

As shown in **Fig. 2**, Initiative A is aimed at increasing the throughput and capacity, reducing latency, and expanding the coverage of optical and wireless



(a) Cradio®

(b) Low-latency FDN technology

Fig. 3. Initiative B: Innovations in flexible network technologies to suit users and services.

communications.

The multi-core optical-fiber cable technology shown in Fig. 2(a) delivers high-capacity light through both land and sea in an eco-friendly manner. It creates optical paths at the petabit level, which is ultra-high-capacity transmission. As the demand for optical fibers in submarine and terrestrial networks expands dramatically, transmission capacity within existing facility space must be continually expanded. Using the same 125-µm cladding, this technology maintains compatibility with existing optical fibers while achieving 4x efficiency in space utilization. Taking into consideration simultaneous optimum design of fibers and cables, this initiative makes effective use of existing technologies and optical facilities, such as optical cables, and achieves high capacity and multi-core fibers between submarine networks and datacenters while also reducing facility construction costs. It also reduces the environmental burden by reducing the power consumption of transmission paths.

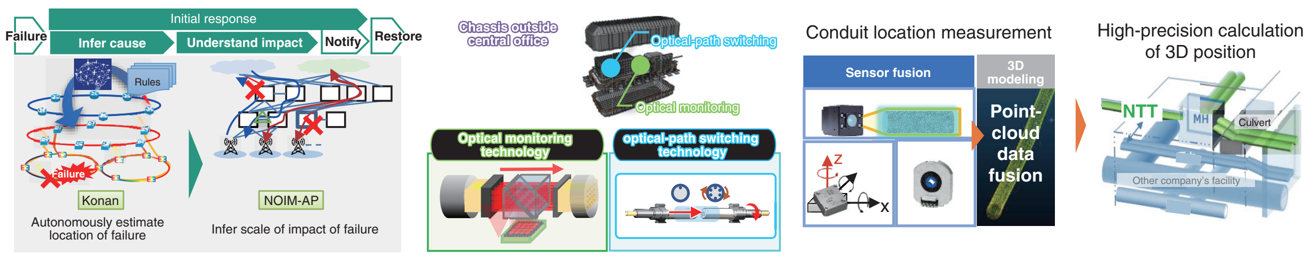
As shown in Fig. 2(b), NTT's ultra-low-latency screen-split-display processing technology enables remote lessons without time lag to be offered. By using the APN to provide multiple video and audio streams remotely without delay, the technology serves as a platform for remote ensemble performances by, for example, orchestral ensembles and dance groups. When multiple sites and perspectives are required, to keep the latency between the display of multiple sites to under 20 ms, the technology begins video display without first waiting for the videos from all the sites to be assembled together. It applies distributed processing to achieve screen layout with a high degree of freedom. The combination of the APN and this technology makes remote music and dance performances; telemedicine, such as remote surgery, remote operations and remote maneuvering; and other remote activities at multiple sites possible.

Initiative B: Innovations in flexible network technologies to suit users and services

As shown in **Fig. 3**, Initiative B is aimed at implementing networks that continuously and flexibly maintain connectivity to suit users and services.

As shown in Fig. 3(a), multi-radio proactive control technologies (Cradio®) maintain continuous connectivity through three technology groups: understanding, prediction, and control. As an era of great changes is beginning with the establishment of new wireless standards, these wireless technologies bring great promise in diverse use cases for industrial digital transformation (DX). Through field testing at business sites, Cradio® is bringing about advanced technologies to meet demand. The scope of its prediction, understanding, and control technologies are being expanded to meet the needs of use cases with diverse demands and requirements. These include high-throughput, high-capacity, and low-latency communication and the elimination of coverage holes. By providing advanced combinations of multiple wireless access technologies including Cradio®, AS Lab is working to support cutting-edge efforts such as smart cities and smart factories.

As shown in Fig. 3(b), AS Lab's low-latency function-dedicated network (FDN) technology brings about smooth remote control in locations where it is



(a) Konan/NOIM

(b) Remote optical-path switching node

(c) Technology for obtaining highly precise locations of buried conduits

Fig. 4. Initiative C: Enabling ultimate smart access through fundamental reform of facilities and operations.

difficult to work onsite. To achieve remote control, it is important to stably maintain end-to-end communication that is low latency and low jitter. For optical paths, the IOWN APN can provide low-latency and low-jitter communication. Radio paths used by wireless systems, however, are easily affected by external factors, making quality control a challenge. The FDN technology collects real-time information on optical paths, servers, and wireless systems for cooperative control, predicts end-to-end quality, selects the optimal optical path and servers, and switches to the selected optical path and servers before degradation occurs. This technology makes it possible to achieve advanced remote control for locations where working onsite is difficult. Use cases include remote facility inspection using drones and image processing.

AS Lab is working to achieve DX in factories by advancing Cradio® and the FDN technology's optical-wireless cooperative control. Real-time cooperative control has been field tested, as reported in a May 2024 press release [3].

3. Policy 2: R&D to dramatically make operations smarter

Initiative C: Enabling ultimate smart access through fundamental reform of facilities and operations

Initiative C, shown in **Fig. 4**, is aimed at enabling ultimate smart access.

As shown in Fig. 4(a), AS Lab's Konan (Knowledge-based Autonomous Failure-Event Analysis Technology for Networks)/NOIM (Network Operation Injected Model) estimates and understands the location of failure and its impact when a large-scale system failure occurs. This technology makes it possible to quickly understand the cause of a network failure and its complex effects, which have become major issues for communications providers. The impact of network failures on society has grown larger, and prompt recovery is necessary to achieve robust communication networks. However, the time required for estimating cause and analyzing impact presents a hurdle. Konan/NOIM deploys a common data model for cause estimation and impact analysis. It normalizes in a simple manner the connection relationships between resources that make up a network. It also extracts custom alarms for failures from multilayer alarms, autonomously estimates the area of failure using generated rules, and infers the scale of impact of the failure on fixed-line and mobile services from multiple perspectives. Therefore, the cause of failure and its complex impact can be rapidly understood. Planning/construction support systems can be also expanded at reduced costs by using a common data model.

Figure 4(b) shows AS Lab's remote optical-path switching node technology. It enables remote onsite work on optical facilities through switching of optical fibers without the need to dispatch workers to the site, solving the issue of the lack of field workers. There is a shortage of workers for fiber-optic facilities outside of communication central offices; however, there are also expectations for the facility business to bring new revenue sources. As a technological feature for achieving these goals, we are designing the structure of outdoor chassis to enable expansion of remote operations while being easy to maintain and waterproof. Optical monitoring technology is also applied to enable batch measurements of optical cables, and optical-path switching technology is applied to maintain communication paths even during power outages. Thus, we seek to expand remote operations for outdoor facility work and develop new services and

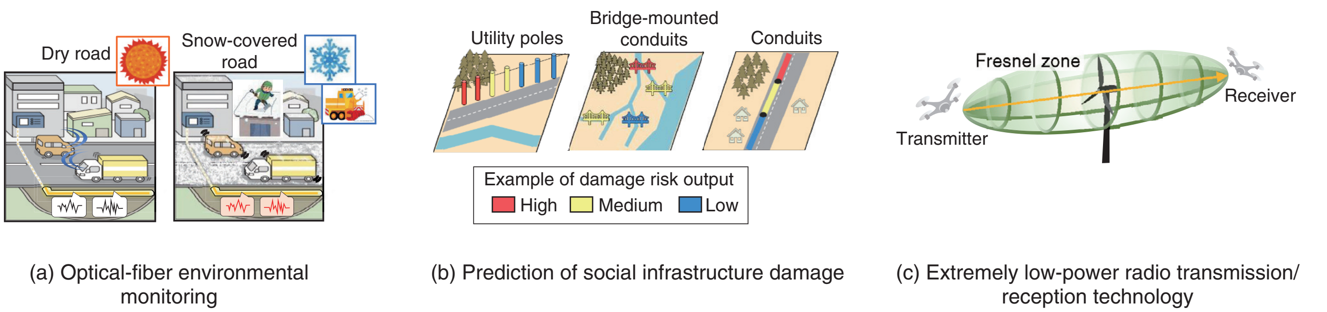


Fig. 5. Initiative D: Development of new areas by leveraging communication technologies, facilities, and operational expertise.

add value by using optical monitoring and optical-path switching technologies.

Figure 4(c) shows AS Lab's latest DX technology for improving the efficiency of outdoor facility maintenance and operation. This technology obtains highly accurate location information for buried conduits by three-dimensional (3D) modelling of the conduits' shapes, enabling buried conduits to be located without physical digging. To advance the digitization of managing underground facilities, accurate 3D location information of the facilities must be acquired.

Techniques for acquiring underground facility location information include radar measurement, but this technique is difficult to apply to deeply buried conduits and congested areas. AS Lab's technology scans inside a conduit using a measurement device equipped with multiple sensors and integrates the acquired data to calculate locations with high precision. It also calculates the absolute coordinates of the ends of conduits (ducts) through highly precise measurements of maintenance hole locations using satellite-positioning data. With this technology, it is possible to comprehensively obtain highly precise locations of buried conduits, contributing to increased efficiency of underground facility maintenance and management (design, construction, and maintenance and disaster recovery). A press release of this technology's contribution toward the creation of digital twins of social infrastructures was issued in May 2024 [4].

4. Policy 3: R&D to use assets to develop new business areas

Initiative D: Development of new areas by leveraging communication technologies, facilities, and operational expertise

As shown in **Fig. 5**, Initiative D is aimed at developing new business areas by applying AS Lab's leading advanced network technologies to non-communication fields.

Figure 5(a) shows AS Lab's optical-fiber environmental monitoring technology. This technology addresses regional issues through networks and sensing. It uses environmental vibration data collected from installed optical fibers from the surface. For example, this technology provides support for snow removal decisions in heavy snowfall regions. Because of labor shortages in the snow removal business, the transition to a sustainable model is necessary. This optical-fiber sensing technology collects and analyzes the speed and vibration frequency characteristics of passing vehicles and uses a supervised machine learning model to estimate whether snow removal is necessary. We conducted a field trial in Aomori City, and compared with the results of onsite surveys, our technology yielded a 90% correct response rate. A press release of this trial, the world's first, was issued in November 2023 [5]. We seek to continue to expand the application of DX to the snow removal business with this technology and grow NTT's facility business.

Figure 5(b) shows AS Lab's technology for predicting infrastructure damage from disasters and eliminating the unexpected through visualization of the risk of infrastructure damage. The technology learns damage trends on the basis of public data and facility data owned by NTT to visualize damage risks throughout Japan when a disaster occurs. When a disaster strikes, maintaining lifeline functions, including telecommunications, is critical. Proactive responses to predicted damage throughout society are needed. This technology uses public data and NTT facility data at a minimum 10-m mesh to enable high-precision quantitative evaluation of damage risk anywhere and at any time. By analyzing the disaster mechanism, factors effective for predicting damage risk can be identified and used. By learning damage trends in association with the disaster mechanism, disaster risk at the facility level can be visualized. A press release of this technology was issued in April 2024 [6].

Figure 5(c) shows AS Lab's technology for non-stop inspection of wind turbines. Extremely low-power radio signals are transmitted and received between two drones. This technology enables energy generated by wind turbines to be increased through inspection that does not stop their power generation and poses no harm to turbine blades. Offshore wind power generation is expected to expand to bring about a sustainable society. Because offshore wind turbine blades are larger than land-based ones, measures to prevent suspending operation, which leads to decrease in energy generated, take on greater significance. It is also necessary to prevent cost increases associated with maintenance and operation due to, for example, using ships for offshore work. The key points of this technology include the use of autonomous drones as radio transmitters and receivers and the use of extremely low-power radio without a radio station license. We have designed the technology so that the Fresnel zone, determined by the frequency and transmit/receive distance, can be easily changed and changes in received signal can be detected. Therefore, the technology contributes to carbon neutrality by increasing power generation through extreme low-power radio inspection and reducing maintenance and operational costs through the use of autonomous drones.

5. Conclusion

Taking on the challenge of creating new value and contributing to the sustainability of the Earth, the direction of AS Lab's R&D of access networks and major technologies in our R&D initiatives were presented. We will continue to conduct R&D of IOWN toward its practical implementation.

References

[1] History of NTT Access Network Service Systems Laboratories (in Japanese). https://www.rd.ntt/as/history/

[2] NTT, "Medium-Term Management Strategy: New Value Creation & Sustainability 2027 Powered by IOWN," https://group.ntt/en/ir/mgt/managementstrategy/

[3] Press release issued by NTT, "Demonstrated real-time optical and wireless cooperative control for efficient IOWN All Photonics Network utilization - Promoting optical networks in accordance with the state of radio usage that supports DX at factories -," May 15, 2024. https://group.ntt/en/newsrelease/2024/05/15/240515a.html

[4] Press release issued by NTT, "Establishing a technology for high-precision measurement of pipeline shape and buried location—Toward realization of digital twin of social infrastructure," May 14, 2024. https://group.ntt/en/newsrelease/2024/05/14/240514c.html

[5] Press release issued by NTT, "World's first vibration sensing technology using telecommunication optical networks for making road snow removal decisions in heavy snowfall area—Aiming to solve regional issues using environmental information obtained from communications infrastructure," Nov. 9, 2023. https://group.ntt/en/newsrelease/2023/11/09/231109a.html

[6] Press release issued by NTT, "Building an AI to predict infrastructure damage from disasters—Achieving infrastructure resilience and early disaster recovery," Apr. 25, 2024. https://group.ntt/en/newsrelease/2024/04/25/240425a.html

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R&D Activities to Implement an Access Network for the IOWN Era

Junichi Kawataka, Takayuki Baba, Koichi Ishihara, Ayako Iwaki, Kotaro Saito, and Katsuhisa Taguchi

Abstract

NTT Access Network Service Systems Laboratories is conducting research and development to support access networks in the fields of optical fiber access, infrastructure, access system, wireless access, and operation technologies. To advance the Innovative Optical and Wireless Network (IOWN) from concept to implementation by 2030, we introduce our vision of a future access network and our efforts to implement it.

Keywords: future access network, advanced maintenance and operations, IOWN

1. Directions in access network research and development

NTT has proposed the Innovative Optical and Wireless Network (IOWN) concept and is working toward its implementation. We at NTT Access Network Service Systems Laboratories assume the following changes in the environment and requirements for an access network in the IOWN era.

We assume that the demand for network coverage will expand from residential and commercial areas to places where industry needs it, such as in the ocean and mountainous areas, i.e., "anywhere." The need for one-way and low-resolution communication, mainly for downloading, will change to the demand for seamless real-time and bidirectional communication such as high reality and extended reality (XR), i.e., "seamless." The user had to choose the network, but this has been reversed and the network needs to be changed to automatically adapt to the user's usage, i.e., "anytime and immediately." Connection should not be disconnected in normal times, and this will be extended to in the event of a disaster, i.e., "not being disconnected." It is necessary to raise the level of implementation to further advance digitalization from the stage of merely proceeding with digital transformation (DX) to compensating for the decrease in the quantity and quality of the labor force and achieving automation, i.e., "smart operations" of business and facilities.

In addition to strengthening our efforts to improve the basic performance and operability of telecommunications networks, we believe that it is necessary to address new needs by using our extensive optical-fiber and equipment-inspection technology and expertise beyond the utilization of facilities in the telecommunications field, so that we can explore new business by taking into account recent trends in our operating companies. As shown in **Fig. 1**, we have established three research and development (R&D) policies to respond to these changing needs. Policy (1) is "achieve extreme requirements and support diversification of services," Policy (2) is "improve operations to be smarter," and Policy (3) is "use assets for new business areas." To promote these policies, we consider robust networks, reduction in environmental impact, and on-site safety as strengthening points taking into account the recent issues regarding our operating companies and society.

2. Envisioned access network in the IOWN era and its implementation technologies

In the near future, we envisage a world where wireless access networks will accommodate not only conventional mobile terminals but also diverse

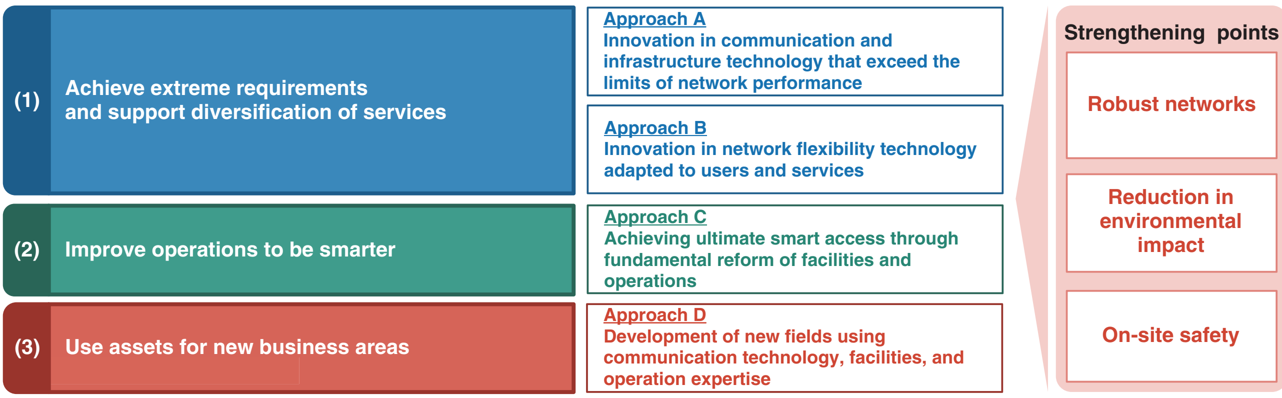

Fig. 1. R&D policies of NTT Access Network Service Systems Laboratories.

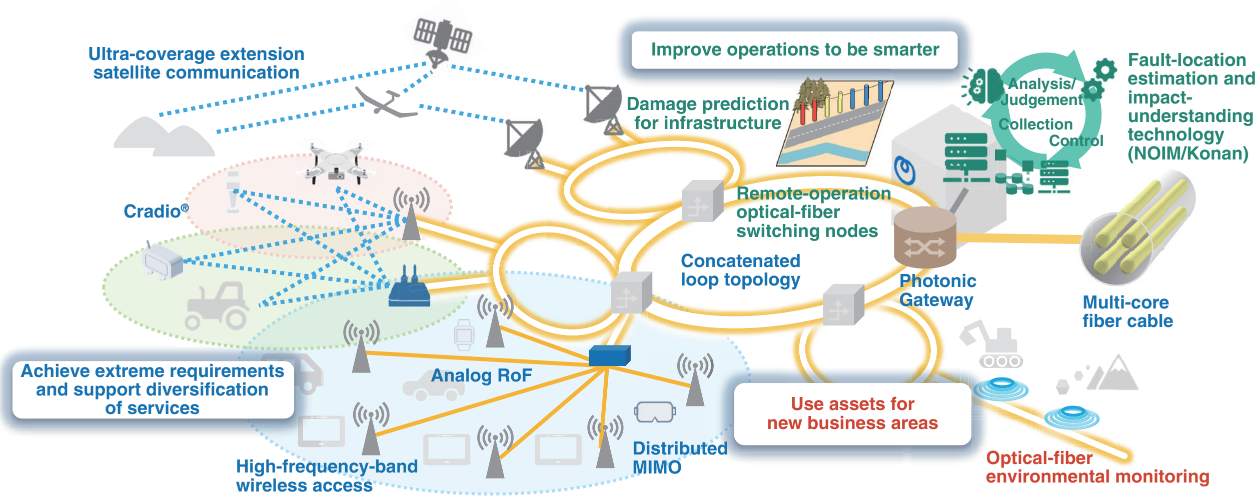

Fig. 2. Future vision of access networks.

objects such as mobility, robots, and sensor devices. We assume that the environment will change so that we can receive information and services with large capacity and low latency even when we are outside or on the move. At the same time, wired access networks are expected to be used in industrial applications such as distributed datacenters; mission-critical applications, such as telemedicine; and entertainment and education.

To achieve high speed and large capacity in wireless access networks, the utilization of radio waves of higher frequency bands than the 5th-generation mobile communication system (5G) has been discussed. However, such radio waves are too linear to pass into shadows and are vulnerable to shielding. Therefore, we are studying an architecture in which a large number of antennas are distributed so that even if the radio wave from one antenna is blocked by an obstacle, it can continue to be connected with other antennas and maintain high-speed communication. Antennas will be placed on the exterior walls of buildings, beside traffic lights, smart poles, and other places on which antennas had never been installed. To achieve this, it is necessary to simplify each antenna as much as possible and develop a technology to control multiple antennas in a coordinated manner.

Figure 2 shows the future vision of the access network based on these factors.

Analog radio-over-fiber (RoF) technology involves modulating the intensity of optical signals with radio signals in their original waveforms and transmitting them through optical fibers as analog signals. By concentrating the signal-processing units such as digital-to-analog conversion and beamforming on the central-station side, it is expected to reduce the size, power consumption, and simplification of the base station and enable cost-effective installation of the base station.

The distributed multiple input multiple output (MIMO) technology selects and controls beams from multiple distributed antennas to enable stable large-capacity communications while reducing interference between antennas and users. In addition to the technology to achieve high-speed wireless communication, technology to use wireless communication more flexibly will be required. Therefore, we are working on providing a natural communication environment that does not require the user to be aware of the wireless network by using Multi-radio Proactive Control Technology (Cradio®), which links the three technologies of understanding, prediction, and control of various information in the wireless network. There are many benefits and use scenes of Cradio®. The first use scene is the basic design of wireless network services. On the basis of the three dimensional (3D) structure of a building and the radio-wave-propagation characteristics of each frequency, it is possible to design and control the installation of antennas using public 5G, private 5G, Wi-Fi, and radio-relay devices, such as a reconfigurable intelligent surface, in a non-skilled manner to efficiently construct the wireless environment desired by the customer.

The second use scene is operation and maintenance. We are developing wireless-network quality-prediction technology, i.e., providing a wireless access network to a connected car on the basis of information, such as the radio-wave strength on the driving route learned in advance and the radio information just before, the quality of communication is predicted several seconds ahead, and the switching of the wireless network as necessary without interruption is controlled to ensure optimum operating conditions. The application of wireless sensing/visualization technology is a new application of Cradio®. Focusing on understanding changes in radio-wave conditions, we use the fact that radio waves transmitted from an antenna are blocked or reflected by people or objects to detect objects such as passing people or opening and closing doors. We are also developing a sensing technology for scenes in which the location of terminals placed in a room is automatically determined.

Radio antennas deployed in more diverse locations will need to be accommodated in optical fiber networks. Regarding the deployment of such a network to the access network, since optical facilities have been constructed mainly for fiber-to-the-home services, the service area has been developed mainly for residential areas such as houses. This will continue, but future access networks will also need to reach wireless base stations installed in various locations. It will also be necessary to provide communication lines to datacenters that require higher speed and reliability rather than best-effort IP services such as FLET'S HIKARI, which will make it difficult to predict planned demand and require mission-critical quality. To respond to such changes, we developed a configuration technology that enables us to provide flexible, reliable, and concatenated loop topology by overlaying existing access networks or constructing them using existing cables. To install base stations on signal poles and streetlights, we are developing a construction technology for cabling in grooves formed on road surfaces in situations where it is impossible to pull cables from underground pipelines or overhead lines.

Each line housed in an optical fiber cable is accommodated in an NTT building (telecom central office). In the IOWN era, an NTT building is expected to handle not only Internet signals but also uncompressed video signals, such as High-Definition Multimedia Interface (HDMI), radio analog signals, and optical signals for optical fiber sensing. It is also necessary to respond to needs by providing an end-to-end optical path that connects arbitrary points, including the turnaround point at an NTT building. To meet this requirement, we are conducting R&D on new photonic nodes, such as Photonic Gateway, which will not depend on the signal format. By providing the optical path to any point, it will become possible to provide it quickly with flexible control and efficiently accommodate various optical services. We are also developing technologies for multi-core fiber cables to achieve ultra-large-capacity transmission for a heavily trafficked network.

We are also developing technologies to improve the maintenance and operation of our services. We are constructing robust networks by using damage-prediction technology for communication facilities. By combining past disaster and weather data with data on the aging and characteristics of individual NTT facilities, we can predict areas with a high probability

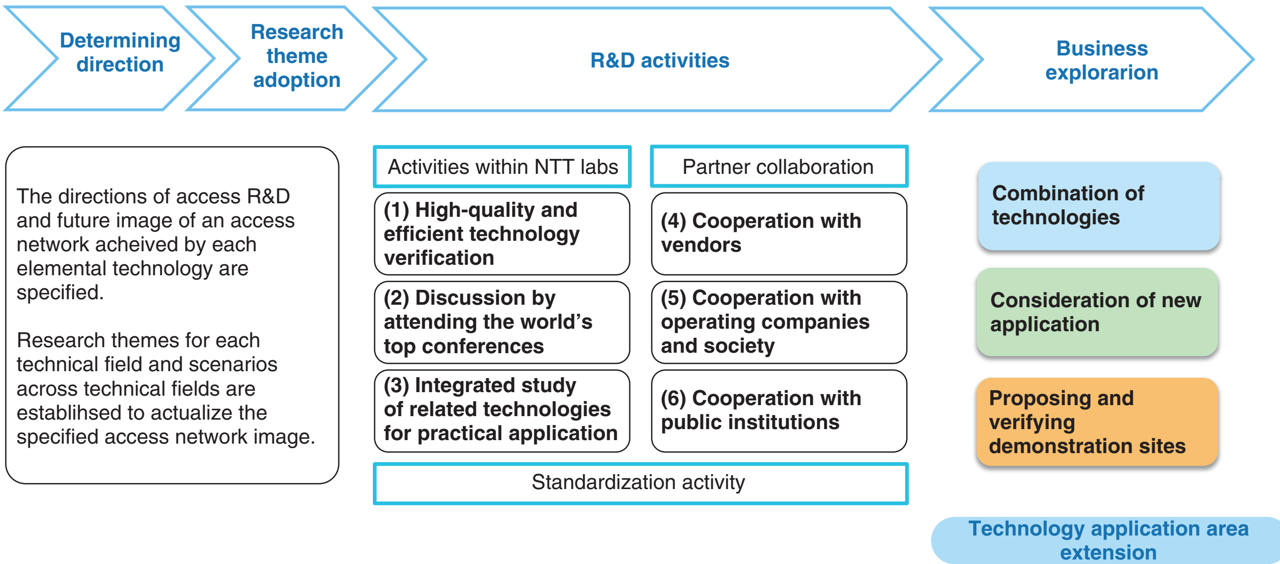

Fig. 3. Approach of R&D activities.

of damage during a disaster and take measures, such as strengthening the resistance of facilities, in advance. We are developing technology to predict damage to various communication infrastructures due to various factors such as damage to utility poles caused by heavy rain, damage to bridge-attachment facilities caused by rising river water, and damage to underground pipeline facilities caused by earthquakes.

For the response after a disaster or a large-scale network failure, Konan (Knowledge-based autonomous failure-event analysis technology for network) is used to estimate the location of the failure on the basis of the status of the alarm from the affected communication equipment. We are also developing a model called NOIM (Network Operation Injected Model), which is a data model of the entire network equipment configuration, including the service, transmission and physical layers, to understand the impact of failure and speed up the subsequent dissemination of information and planning of countermeasures.

3. Activity from technology development to social implementation

Figure 3 shows the approach of R&D activities in our laboratories.

3.1 Determining the R&D direction

From the initial determination of the R&D direction to research-theme adoption, as explained at the beginning of this article, we are devising research themes that are based on technological trends and strengths in optical fiber access, infrastructure, access system, wireless access, and operation technology.

3.2 Activities at NTT laboratories

The activities in the third phase of R&D at our laboratories are presented. In the R&D phase for social implementation, we are (1) conducting high-quality and efficient technology verification, (2) promoting discussion by attending the world's top conferences, and (3) conducting an integrated study of related technologies for practical application. A specific example of (1) is the construction of a verification environment for wireless technology [1]. To reproduce the environment we are aiming for as a future-use environment and use scene, we have built a dedicated experimental facility in Yokosuka. By having a dedicated environment, we can efficiently conduct verification with higher accuracy with more freedom in the experimental setup and fewer restrictions on use. Regarding (2), we have been actively disseminating information at international conferences and journals in optical access, such as ECOC (the European Conference on Optical Communication) and OFC (Optical Fiber Communications Conference and Exhibition), where the world's top-level researchers in the field gather, to enhance technological advancement and superiority and the appropriateness of problem setting. An example of (3) is activities in optical fiber systems. In addition to the design of the fiber structure, we are also conducting a set of verifications, such as cabling, constructability in an actual field environment, connectivity, and transmission characteristics, to improve our capabilities as a communications facility [2].

3.3 Partner collaboration

We are also promoting efforts to obtain better research results by using the schemes for collaboration with various partners such as (4) venders, (5) operating companies and society, and (6) public institutions.

Regarding (4), we are devising a scheme regarding 6G for demonstration cooperation with major vendors in Japan and overseas and advancing research [3]. To ensure that the creation of functions does not become separated from product implementation, we will promote feasibility studies, taking into account the implementation issues of the functions. Regarding (5), this approach is aimed at actively developing use cases from the research stage and establishing the necessary functions and technologies at the required level. In the robot-delivery experiment in the Shinagawa-Konan area, we are participating in an experiment from the standpoint of radio technology in cooperation with NTT Group companies investigating intelligent control in buildings [4]. Regarding (6), we are investigating technologies related to the All-Photonics Network (APN) in cooperation with public institutions. We will aim to devise research themes with a high degree of public importance and spillover potential by using national project schemes [5].

We are also promoting technology deployment through standardization activities. In the fields of radio, optical access, optical fiber, and operation, NTT has been leading discussions by submitting contributions toward the standardization of new NTT technologies and obtaining positions in standards organizations and organizations such as “de jure” and forums. Standardization activities of functions, methods, products, etc. will be carried out from the core R&D phase to promote standardization of rules and regulations that enable functions and interconnections necessary for product implementation. Through the standardization process, we are promoting initiatives for securing quality and interoperability, reducing costs, and creating business opportunities by enabling the industry and related parties to understand the content of NTT technologies and promoting the formation of partnerships.

3.4 Business exploration

Finally, we discuss an initiative in the business phase to leverage the advantages of technology. Activities are being made to expand the application use cases of technology, such as finding new value by combining multiple technologies across technology fields, examining the possibility of applying technology to areas other than traditional access areas, and creating value through demonstration experiments matched with servicers. As an example of such activities, we have applied our image-recognition artificial-intelligence technology for telecommunications infrastructures to detect and evaluate equipment, e.g., to automatically detect rust on signs and guardrails managed by local governments for facility inspections [6]. The APN’s low-latency optical transmission technology was also combined with ultra-low-latency split-screen-processing technology to demonstrate remote ensemble and chorus performances at a music event in collaboration with an NTT Group company [7].

4. Summary

We introduced the vision and technology of the future access network of our laboratories and the challenges to implementation. By setting the direction and policy of R&D to meet the changing needs of the IOWN era; promoting the development of technologies related to wireless, optical transmission, and optical fibers to achieve a high-speed, high-capacity, low-latency, and highly reliable communication environment, as well as technologies to enable advanced infrastructure maintenance and operations; and refining technologies by cooperating with partners, using demonstration sites, and improving the quality of research activities, we will develop an access network for the IOWN era around 2030.

References

[1] Press release issued by NTT, “Started the world’s first verification of radio space reproduction technology that integrates optical and radio propagations—Will contribute to accelerating new radio communication systems by accurately reproducing various usage scenarios,” May 17, 2022. https://group.ntt/en/newsrelease/2022/05/17/220517a.html

[2] Website of NTT R&D, “Multi-core Optical Fiber Cable Transmission Line Technology” (in Japanese). https://www.rd.ntt/research/AS0106.html

[3] Press release issued by NTT and NTT DOCOMO on Feb. 22, 2024 (in Japanese). https://group.ntt/jp/newsrelease/2024/02/22/pdf/240222aa.pdf
[4] Press release issued by NTT Communications, NTT, and NTT Urban Solutions, "Delivery robots using NTT Group technology demonstrated at Shinagawa Season Terrace—Robot control function with optimal path generation and radio wave quality," Mar. 26, 2024. https://group.ntt/en/newsrelease/2024/03/26/240326b.html
[5] Press release issued by NICT on Nov. 6, 2023 (in Japanese). https://www.nict.go.jp/press/2023/11/06-1.html
[6] Press release issued by Kitahiroshima City and NTT Business Solutions on Aug. 10, 2022 (in Japanese). https://www.nttbizsol.jp/newsrelease/202208101000000728.html
[7] Press release issued by NTT, "Remote chorus demonstration for ultra-low latency real-time video communication - Realizing music events that make people feel like they are in the same place even if they are far away -," Dec. 1, 2022. https://group.ntt/en/newsrelease/2022/12/01/221201a.html

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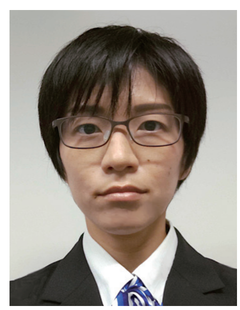

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R&D of Innovative Optical Fiber Facility Technologies

Kazunori Katayama

Abstract

NTT Access Network Service Systems Laboratories is promoting research and development (R&D) of optical fiber facility technologies that contributes to the sustainable development of communications networks. This article outlines the R&D of large-capacity and advanced optical fiber facilities for the All-Photonics Network, which is one of the three key elements of IOWN (the Innovative Optical and Wireless Network) concept advocated by NTT. This article also introduces the R&D activities of optical fiber facilities in response to social changes and demands such as the decrease in the working population, diversification of communication services, and reduction in environmental impact.

Keywords: optical fiber facilities, space division multiplexing optical fiber, IOWN

1. Situation surrounding optical access facilities

Network traffic has continued to increase [1] and this trend is expected to continue. In terms of the working population, the number of construction workers at NTT facilities is expected to decrease by about 35% over the next 10 years. We also believe that the requirements for optical access facilities will diversify as communication services diversify from person-to-person communication to object-to-object communication. In response to the demands of environmental management, NTT Group has formulated the “NTT Green Innovation toward 2040” [2] and believes that it is necessary to develop technologies that take into account environmental performance in optical access facilities. In other words, it is necessary to continue to develop optical fiber facility technologies that can respond to the demands of and changes in society.

The All-Photonics Network (APN), one of the three elements of the Innovative Optical and Wireless Network (IOWN) concept, aims to achieve the following three target performances through the introduction of photonics technology from the network to the terminal: 1) low power consumption (power efficiency 100 times), 2) high quality and high capacity (transmission capacity 125 times), and 3) low latency (end-to-end delay 1/200) [3]. From the research and development (R&D) of optical fiber facility technologies, we would like to contribute to achieving these target performances.

2. Space division multiplexing optical fiber cable technologies

We first introduce space division multiplexing (SDM) optical fiber cable technologies. The capacity of optical transmission systems has increased 1000 times in 20 years and has advanced by using time division multiplexing transmission technology and wavelength division multiplexing transmission technology. However, the transmission capacity limit of conventional single-mode fiber (SMF) is about 100 Tbit/s per fiber and soon expected to reach the transmission capacity limit. To overcome this limit, we at NTT Access Network Service Systems Laboratories are promoting the R&D of SDM optical fiber that expands the transmission capacity by setting multiple space channels (number of modes × number of cores) in a single optical fiber. **Figure 1** shows an overview of SDM optical fiber and the flow assumed for its introduction. SDM optical fibers are roughly divided into two types: multi-core fiber (MCF) in which multiple cores are arranged in one fiber, and multi-mode

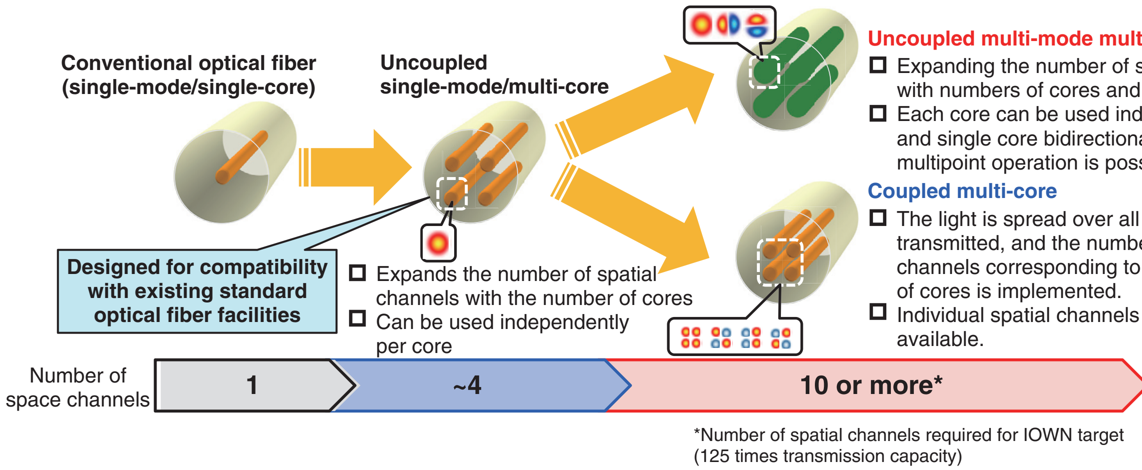

Fig. 1. SDM optical fiber.

fiber in which multiple modes are propagated as signals in one core. These types are further classified into two types: uncoupled, which does not allow signal crosstalk between cores or modes, and coupled, which actively allows signal crosstalk. To introduce SDM optical fiber, we consider uncoupled single-mode MCF as the primary target, considering the expansion of spatial channels and compatibility with existing facilities. However, to achieve the performance target of "125 times the transmission capacity" of the IOWN APN, space channel expansion of 10 or more is considered necessary. There are two types of MCF as candidates for more than ten space channels: uncoupled multi-mode MCF and coupled MCF, and we are promoting R&D on each. When considering the introduction of uncoupled single-mode MCF, by adopting the cladding diameter equivalent to current SMF (standard cladding diameter: 125 µm), it is possible to expect the same optical fiber manufacturability as the conventional one and ensure high compatibility with the current optical fiber equipment such as the use of the existing optical cable structure and optical connector interface. For standard cladding diameter uncoupled MCF, the number of cores is considered to be up to four due to the amount of crosstalk. For such MCF, we developed the design technology of the refractive index profile in accordance with the application area such as short-range network, metro/core network, and long-haul submarine network as with current SMF. **Figure 2** shows the application area of standard cladding diameter MCF and its practical application. A promising application area for such MCF is the area where demand for large capacity or multiple fiber is high such as submarine networks and datacenters in terrestrial networks. Since submarine cables have limited space for fiber accommodation due to their structure, transmission capacity expansion can be expected without increasing the number of cables laid by introducing standard cladding diameter MCF. Since the conduit space of terrestrial fiber cable is limited, transmission capacity expansion can be expected by introducing standard cladding diameter MCF without adding cables and conduits. We decided to begin the practical application of SDM optical fiber from a submarine network to reduce the facility construction cost while continuously expanding the transmission capacity.

To construct a standard cladding diameter MCF cable system, it is necessary to develop peripheral technologies, such as fiber connectors, fiber-fusion splicer, fan-in-fan-out (FIFO) devices for MCF-SMF conversion, and related products such as optical wiring racks/closures and promote technological development considering compatibility and commonality with existing and commercial technologies. A prototype standard cladding diameter MCF cable was laid in a tunnel at NTT's R&D center, and good optical characteristics (connectivity and long-term stability) have been confirmed. We also demonstrated the world's first large-capacity transmission (1.6 Tbit/s/fiber, 10 km) assuming large-capacity datacenter networks under the same field environment [4].

As an example of expanding the application area of standard cladding diameter MCF, we proposed a power-over-fiber system using MCF. A single MCF

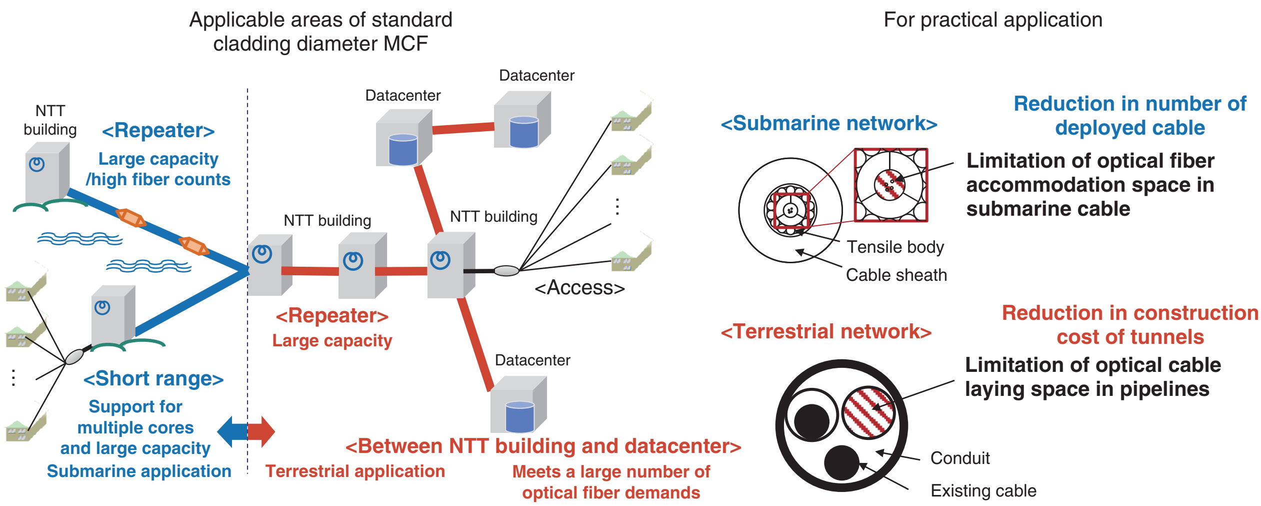

Fig. 2. Application areas of the standard cladding diameter MCF and its practical application.

can simultaneously transmit signal light and feed light and achieves the world's highest optical feeding capability (14 W · km) and optical transmission capability (140 Gbit/s · km) [5].

Uncoupled multi-mode MCF with more than ten channels uses a mode-multiplex transmission line. The technical problem with this line is the signal quality degradation caused by the optical intensity difference between modes caused by the mode deviation of the transmission line loss and that of the optical amplifier. To overcome this problem, we proposed an optical waveguide device that variably compensates for the difference in optical intensity between different modes and demonstrated wide-band compensation of the gain difference generated in a two-mode optical amplifier for the first time [6].

A coupled MCF with more than 10 channels has succeeded in 7280-km optical amplification transmission using 12-core-coupled MCF [7]. We designed and fabricated multi-core optical amplifiers for 12-core-coupled fiber transmission lines and demonstrated for the first time that power consumption can be reduced by 67% compared with conventional technologies [8].

3. Remote-operated optical-fiber-switching nodes

Figure 3 shows the remote-operated optical-fiber-switching node technology that enables remote control of optical path switching operations without any on-site manual work. The remote-operated optical-fiber-switching nodes consist of internal and external nodes, and execute path switching by remotely controlling the external node installed at the path switching point of the optical transmission line from the internal node installed in the communication building. The remote-operated optical-fiber-switching node technology is composed of three elemental technologies: 1) power-over-fiber for remote control, 2) optical cross-connect technology, and 3) optical port monitoring technology. We implemented these three elemental technologies as an optical path switching unit, optical monitoring unit, and remote control unit, respectively, and fabricated an integrated prototype of an external node that enables optical path switching by cooperating with these units. The prototype of an external node is unitized to enhance maintainability, and it is waterproof (equivalent to IPX7) due to the double structure of the inner and outer cases since use in underground maintenance hole is assumed.

4. Flexible optical line construction technologies

With the diversification of communication services, it is expected that a wide variety of terminals, such as Internet-of-Things devices, will be connected to networks. The problem is that many networks need to be built to accommodate this. As a solution to the problem, an optical coupling technology that can branch the optical fiber in communication without cutting the fiber is shown in **Fig. 4**. This technology enables the connection of the terminal to the necessary

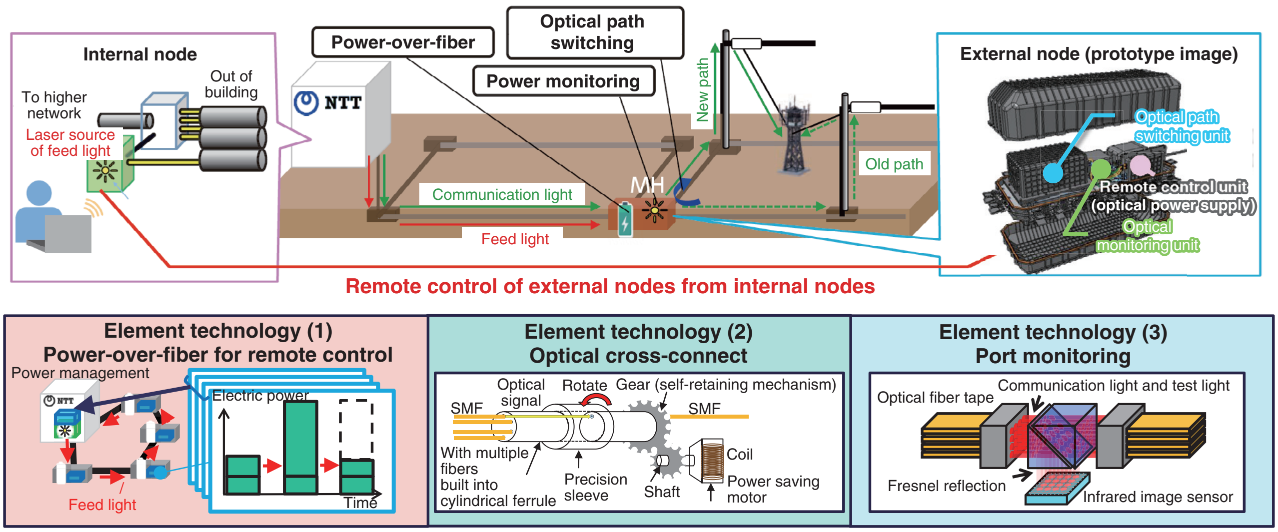

Fig. 3. Overview of remote-operated optical-fiber-switching nodes.

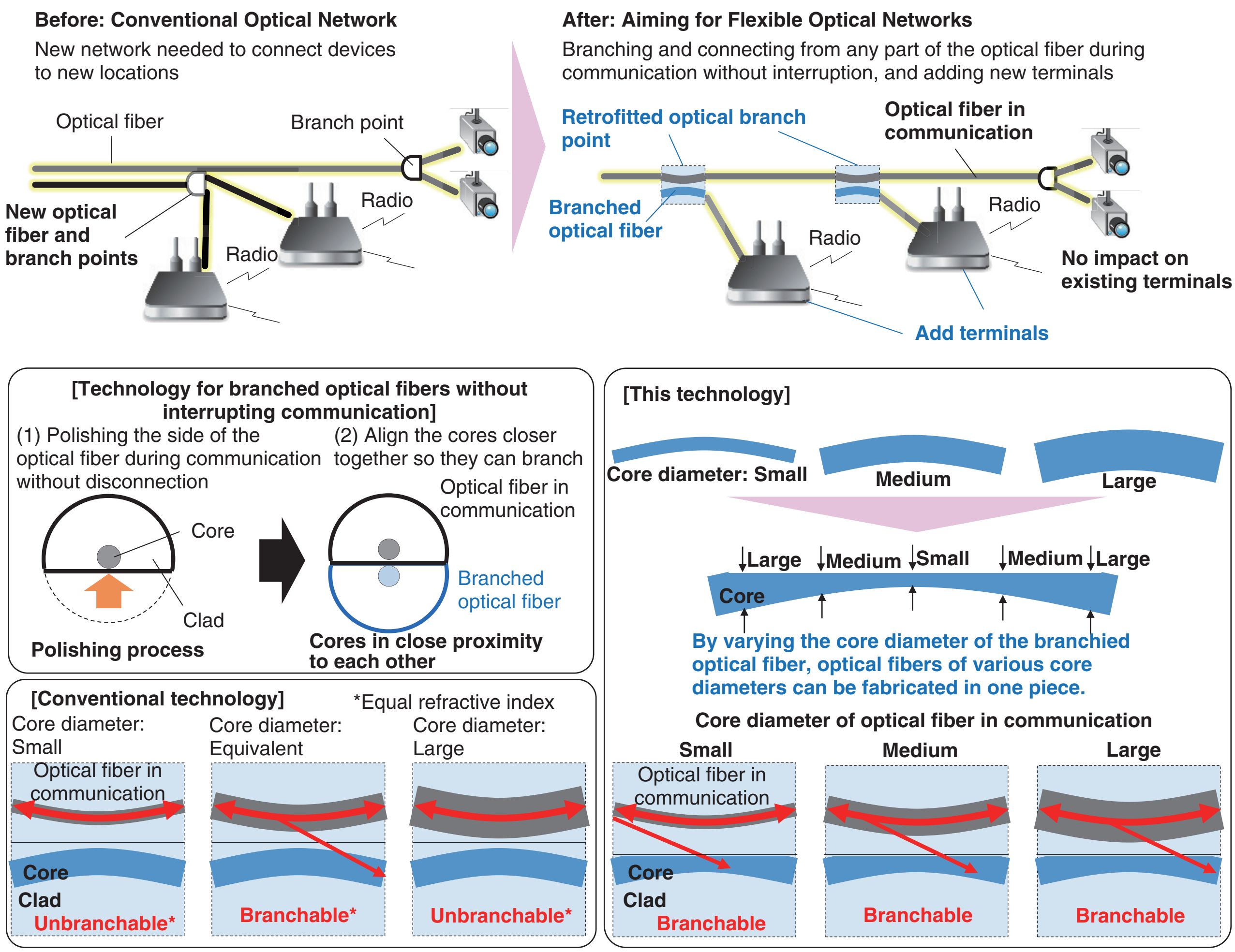

Fig. 4. Optical coupling technology.

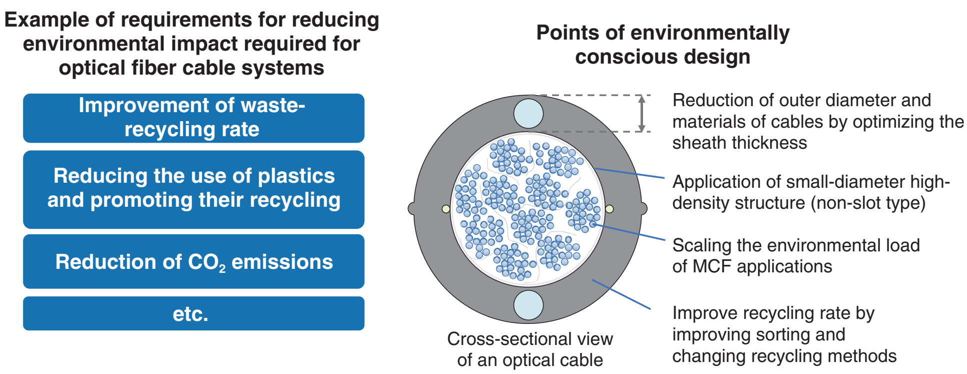

Fig. 5. Environmental considerations for optical fiber cable systems.

place in the existing network at the appropriate timing. The principle of this technology is to polish the side surface of the existing optical fiber to enable communication to the vicinity of the core without affecting communication and bring the pre-polished branched optical fiber and core close to one another to enable optical coupling. This technology has been difficult to use in commercial facilities where optical fibers with different effective refractive indices coexist since it is necessary to use optical fibers with the same effective refractive index for optical fiber in communication and branched optical fiber. To address this issue, we designed and fabricated a branched optical fiber with tapered core diameters and demonstrated for the first time that a single type of branched optical fiber can be used to couple optical fibers with various effective refractive indices [9].

We also developed an optical fiber cable technology for on-road surface wiring without using poles and conduits. Specifically, we developed an optical fiber cable that maintains the basic optical characteristics while achieving both flexibility and reduced diameter and a connector that can easily splice optical fibers. This technology enables cost-effective and rapid laying of optical fiber cables without requiring large-scale construction.

5. Environmentally friendly optical fiber cable technologies

Figure 5 shows an example of the requirements for reducing the environmental impact required for optical fiber cable systems and points of environmentally conscious design. To reduce the environmental impact of optical fiber cables, it is necessary to reduce the amount of plastic used and disposed of, improve the recycling rate, and reduce carbon dioxide (CO_2) emissions. To meet these requirements, it is important to achieve a good balance of conventional reliability, workability, economy, and environmental performance. The key point in designing optical fiber cables considering environmental impact is to examine the entire life cycle by changing the cable structure (slot structure → high-density structure), changing the fiber type (SMF→MCF), and changing the recycling method. High-density optical fiber cables with a small diameter have been developed to improve the economic efficiency and workability of cables and reduce environmental impact. From the viewpoint of reducing environmental impact, the use of plastic parts can be reduced by approximately 30% compared with conventional slot-structure fiber cables, and CO_2 emissions over the entire life cycle can be reduced by 35%. The high-density optical fiber cable has been extended from the access section (overhead and underground) to the special section (bird and insect damage section) and the repeater section (underground). By expanding the use of the high-density cable structure, the effect of high density is maximized, and the development of cables with excellent environmental characteristics and unification of peripheral parts and skills can be expected.

By using SDM optical fiber, the number of optical fibers can be greatly reduced compared with current SMF cable if the number of cores is the same as that of an optical fiber cable. In addition to saving resources, CO_2 emissions can be reduced throughout the entire life cycle by reducing energy consumption during manufacturing and disposal.

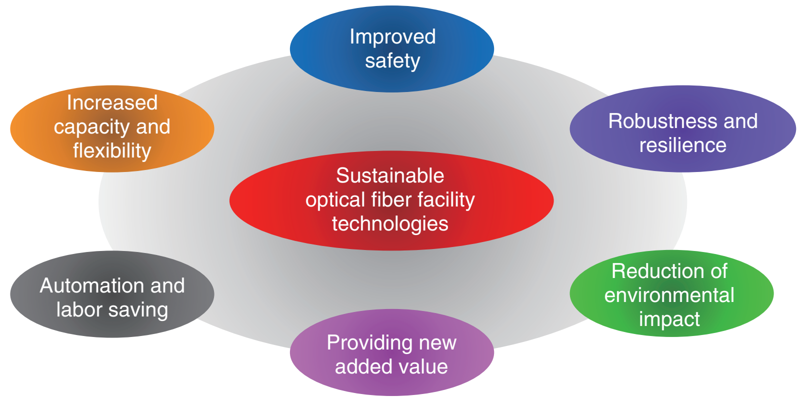

Fig. 6. Future perspectives for R&D of optical fiber facility technologies.

6. Future perspectives for R&D of optical fiber facility technologies

The future perspectives for R&D of optical fiber facility technologies are shown in **Fig. 6**. We will promote R&D to develop sustainable optical fiber facility technologies that can continue to respond to the advancement and diversification of services, maintain communications services in the face of a declining workforce and disasters, and protect resources and the environment.

A portion of these research results were obtained through research commissioned by the National Institute of Information and Communications Technology (NICT) as part of the Advanced Communications and Broadcasting Research and Development Project (adoption number 20301).

References

[1] Ministry of Internal Affairs and Communications, https://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/
[2] Press release issued by NTT, "NTT Group's New Environment and Energy Vision 'NTT Green Innovation toward 2040,'" Sept. 28, 2021. https://group.ntt/en/newsrelease/2021/09/28/210928a.html
[3] Website of NTT R&D, "What is the All-Photonics Network?", https://www.rd.ntt/e/iown/0002.html
[4] Press release issued by NTT, "World's First Successful 1.6 Tbit/s Optical Transmission Experiment with Multi-core Fiber Cable Installed in a Field Environment - Promising Technology for Achieving Large-capacity Ethernet in Large-scale Data Centers -," Oct. 5, 2023. https://group.ntt/en/newsrelease/2023/10/05/231005a.html
[5] Press release issued by NTT, "World's Highest Power over Fiber Transmission: Connect with Non-electrified Areas over 10 km Away via Optical Fiber," Aug. 29, 2023. https://group.ntt/en/newsrelease/2023/08/29/230829a.html
[6] Press release issued by NTT, "World's First Attempt at Flexible Compensation Technique for Optical Power Difference Between Spatially Multiplexed Signals: Milestone for Realizing Beyond 1-Peta-bit Class Large Capacity Optical Transmission Proposed in IOWN," June 27, 2022. https://group.ntt/en/newsrelease/2022/06/27/220627a.html
[7] Press release issued by NTT, "NEC and NTT Successfully Conduct First-of-its-kind Long-distance Transmission Experiment over 7,000km Using 12-core Optical Fiber - Progress toward Increasing Capacity of Transoceanic Optical Submarine Cables -," Mar. 21, 2024. https://group.ntt/en/newsrelease/2024/03/21/240321a.html
[8] Press release issued by NTT, "World's first transmission capacity expansion and power consumption reduction using space division multiplexing technology—Optical amplifier with multi-core structure reduces power consumption by 67%," Sept. 28, 2022. https://group.ntt/en/newsrelease/2023/09/28/230928a.html
[9] Press release issued by NTT, "World's first: Successful experiment to branch and merge various types of optical fibers without communication interruption—Toward the realization of flexible optical networks that connect from anywhere," Apr. 24, 2024. https://group.ntt/en/newsrelease/2024/04/24/240424b.html

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Wireless Technology Supporting People to Live a Fulfilling Social Life

Tomoaki Ogawa

Abstract

NTT laboratories are engaged in the research and development (R&D) on wireless communication technologies to meet various requirements for the wireless devices, communication schemes, applications, and usage scenarios that are diversifying as we enter the 6G (sixth-generation mobile communication system)/IOWN (Innovative Optical and Wireless Network) era. This article introduces NTT's Cradio®, which embodies a set of multi-radio proactive control technologies, and related advanced R&D technologies.

Keywords: 6G, wireless access, Cradio®

1. Wireless access in the 6G/IOWN era

The Innovative Optical and Wireless Network (IOWN), which is a network and information processing infrastructure concept centered on optical technology and able to provide high-speed, high-capacity communications and massive computational resources, has been advocated as a model for next-generation networks. The wireless access component can be developed in the following directions (**Fig. 1**).

- Wireless access advancement: Establish new technologies advancing the wireless access system, such as establishing new wireless formats for the sixth-generation mobile communication system (6G), exploit new frequency bands, and develop areas not yet covered, such as in space and at sea (further expanding potential). This article introduces contributions to wireless format standardization and systematization, low-latency, highly reliable communication technologies incorporating cutting-edge functionality, and wide-area reception-power estimation technologies.
- Network provision following changes in the environment: Establish technology to provide network services that integrate these wireless access formats, supporting extreme requirements of high capacity, high reliability, and low latency, and accommodating a diversity of users and services, even as conditions in the wireless environment change from minute to minute (maximizing potential). This article gives an overview of the Cradio® multi-radio proactive control technology and introduces a wireless-communication-quality estimation technology, which is a component of Cradio®, Cradio® business use cases as well as a control technology linking optical and wireless segments in real time.

2. Advanced wireless access

As the need for using wireless access increase rapidly, cultivation of radio-frequency bands suitable for wide-band use (legalization) and standardization of wireless formats are progressing to maximize use of radio waves, which are a public resource. Directions for development of wireless formats are shown in **Fig. 2**. Currently, wireless formats in wide use can be divided mainly into cellular radio (3G, 4G, 5G), which assumes public use, guaranteed connectivity, and high reliability for users, and independent formats such as Wi-Fi, which can provide high maximum throughput but only provide best-effort rates that fluctuate due to surrounding usage conditions and interference. Both have advanced year-after-year. In the coming 6G era of cellular radio, user requirements

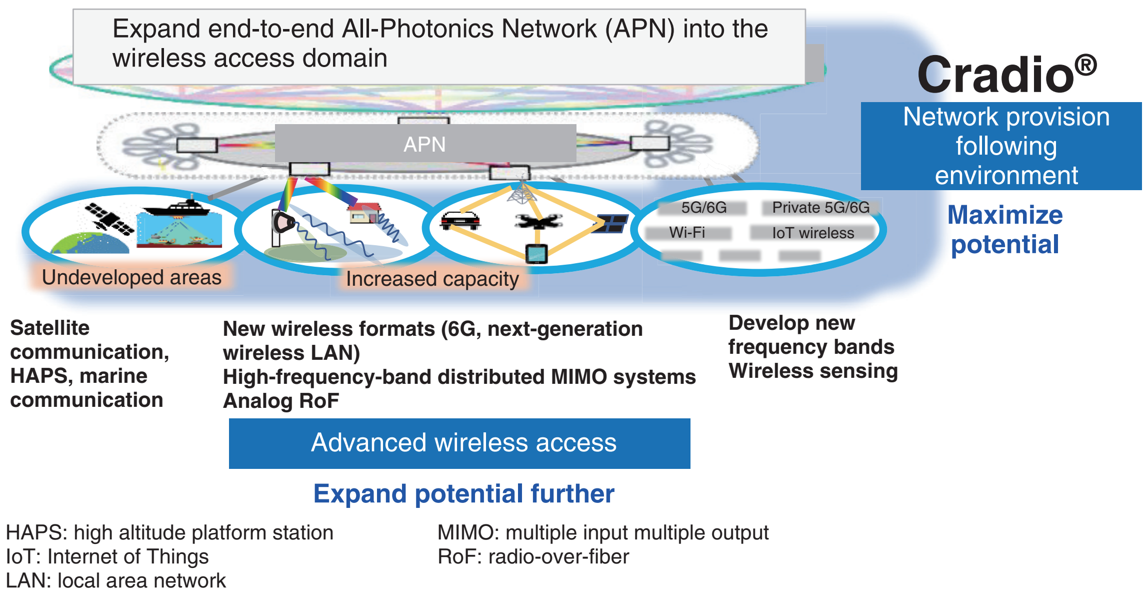


Fig. 1. Directions for wireless R&D.

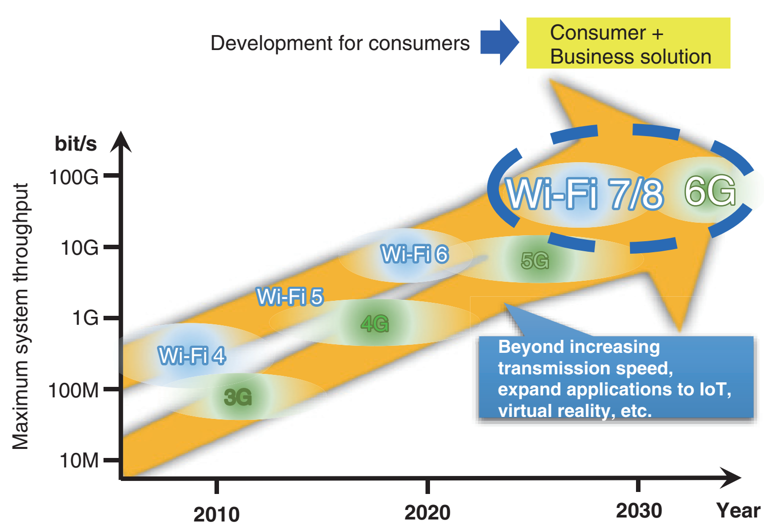


Fig. 2. Development directions for wireless formats.

for consumer and business solutions will become integrated, resulting in demand to provide a wireless access environment that satisfies all requirements by intelligently using both wireless formats. Regarding Wi-Fi standardization, high reliability is currently entering the scope of discussion for next-generation Wi-Fi. NTT laboratories' members have been appointed to important positions and are actively participating in discussion. Regarding further advances in cellular, millimeter-wave and other high-frequency bands are being cultivated and technology verification to enable stable utilization is becoming increasingly important. NTT laboratories are collaborating with NTT DOCOMO and various manufacturers to promote technical verification for 6G [1].

We are also developing technologies using the latest standardized functions. **Figure 3** shows an example of a low-latency, high-reliability technology

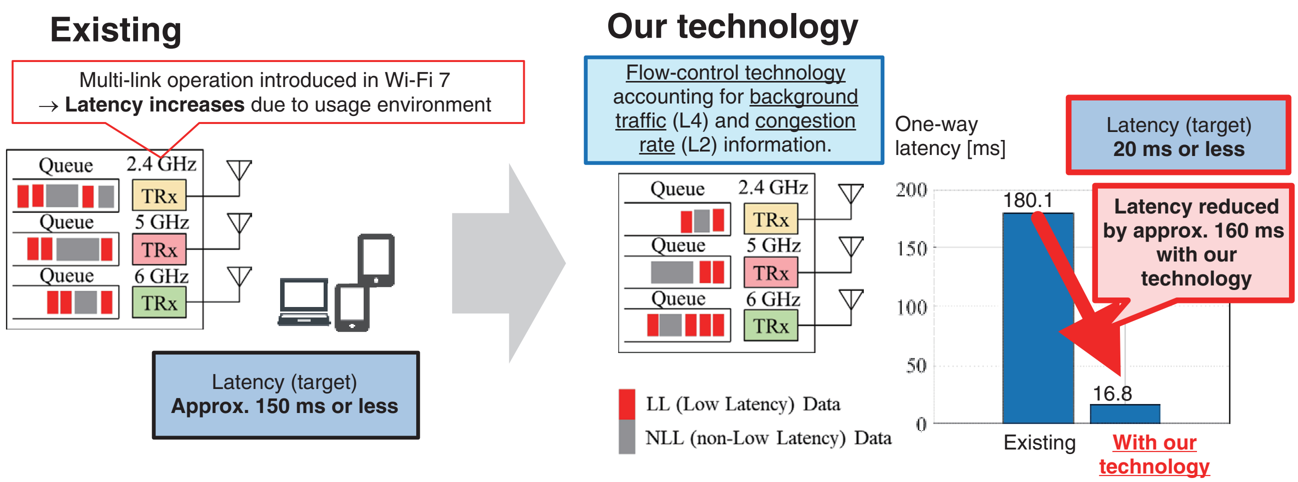


Fig. 3. Low-latency, high-reliability communication technology using unlicensed wireless.

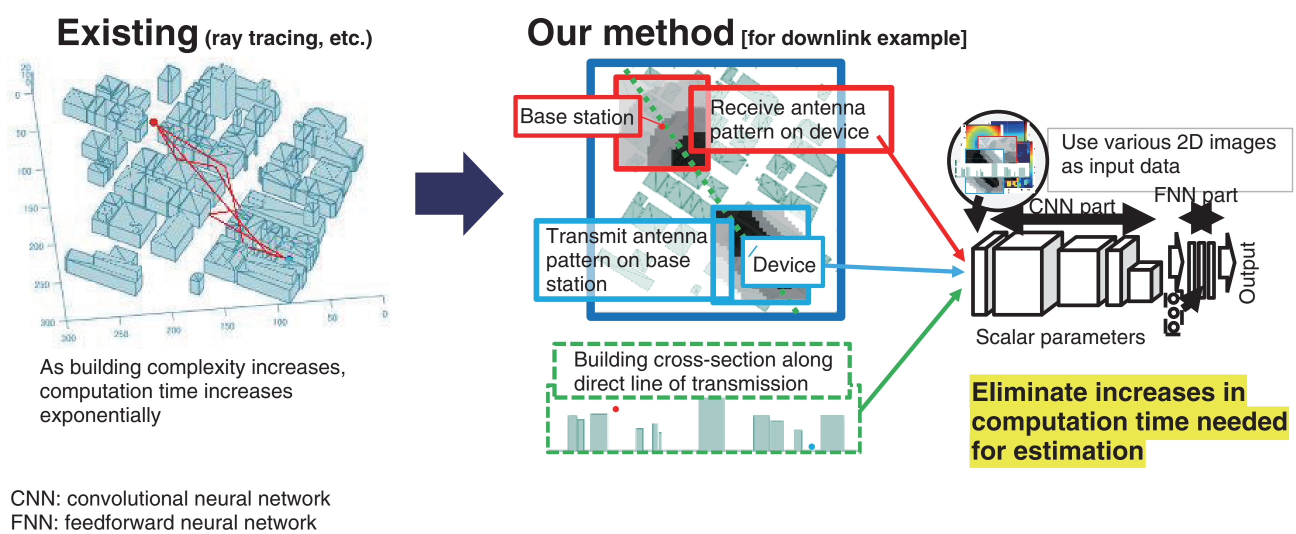
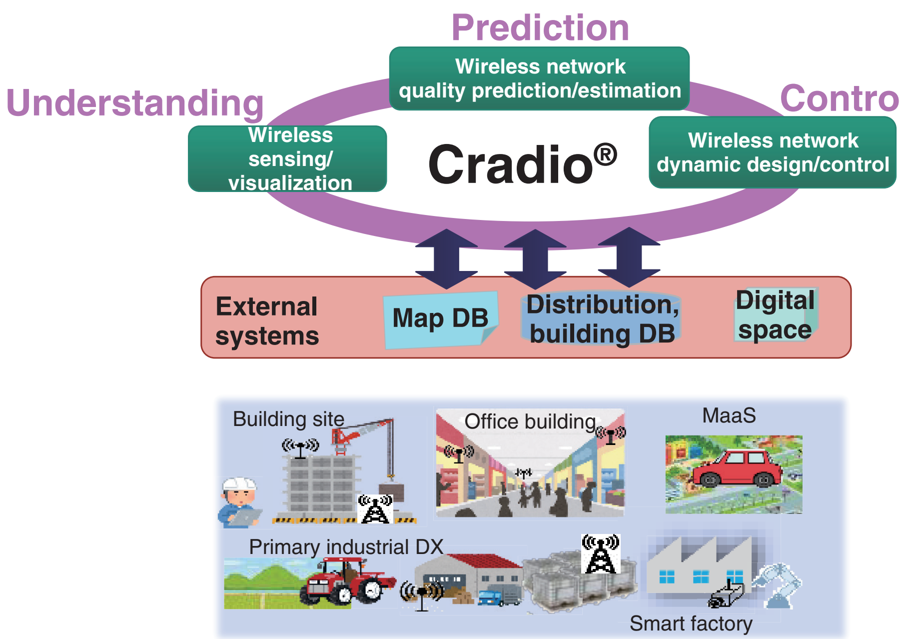


Fig. 4. Estimating reception power over large areas with deep learning.

using an unlicensed band with multi-link operation, which is part of next-generation Wi-Fi. Starting with Wi-Fi 7, a function of multi-link operation is introduced, enabling devices and access points (APs) equipped with multiple wireless interfaces to communicate using them simultaneously, but flow control linking each wireless interface as an approach to reduce latency was not implemented. Thus, we have achieved low latency by executing flow control that combines background traffic data, including data across all wireless interfaces, with wireless layer congestion information.

As the frequency of bands used is increased, the effect of obstacles will increase, making the conditions for estimating the areas reached by radio waves more complex and the computation time required to estimate signal propagation will increase. NTT laboratories therefore developed an original estimation method using machine learning. The method enables us to estimate reception power over a large area quickly by using deep learning with simple input data such as antenna patterns, cross-sections of buildings, and the height of surrounding buildings (**Fig. 4**).



MaaS: mobility as a service
DB: database
DX: digital transformation

Fig. 5. Cradio®: Multi-radio proactive control technology.

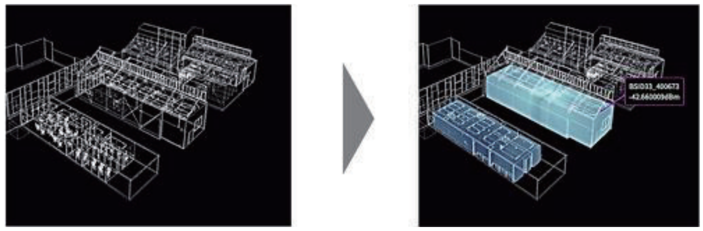
3. Network provision following changes in the environment

For network provision that follows changes in the environment, NTT laboratories are conducting research and development (R&D) on Cradio®, which is a multi-radio proactive control technology consisting of a set of technologies to enable a natural user experience without requiring them to be aware of the wireless access system, even when multiple wireless access systems are combined [2]. Cradio® links three technologies that understand, predict, and control the wireless communications environment, enabling various wireless networks to follow changes in the environment or communication state and adapt before changes occur. Cradio® can use a wide range of data beyond data that it can obtain from wireless access systems, such as map data and building data that can be obtained by linking with digital space platforms, external services, social systems, and other external databases, to maximize the potential of wireless access systems. This can also increase value by seamlessly linking with existing business systems (**Fig. 5**).

The understanding technology uses advanced analysis of the information available from wireless communication systems to understand communication-quality conditions (congestion, device usage, interference) for each end user and device. We are also investigating using the wireless data obtained with this technology for "deviceless sensing" to estimate device location and understand changes in surrounding buildings and other objects that can affect the wireless environment.

The prediction technology uses deep learning to predict wireless communication quality, as it changes due to the surrounding environment and device position, on the basis of wireless quality information obtained with the understanding technology. This enables degradation to be detected in wireless communication quality beforehand, proactively controlling devices and applications, and making adjustments such as switching to a better-quality network or changing the transmission rate for transmitting video.

The control technology is a dynamic design and control technology for wireless access networks that follows network design and operating requirements on the basis of information from the understanding and prediction technologies. For example, it can



Building data

Estimated reception-power visualization (for one base station placed in the room at the back on the right)

Fig. 6. Example of visualizing reception-power values estimated with Cradio® using building data.

design a wireless communication area dynamically on the basis of propagation estimation for the planned types of base station and antenna characteristics, or use the function for estimating wireless quality at the link layer for each wireless method to compute and control parameters of wireless devices, and implement network design and operation that avoids local congestion.

Effort on projects using Cradio® has been making progress. I introduce a trial conducted by NTT WEST and Takenaka Corporation. In this trial, Cradio® was used with 3D building information modeling (BIM), and the following was evaluated regarding whether the wireless environment could be estimated accurately and efficiently after construction was completed [3].

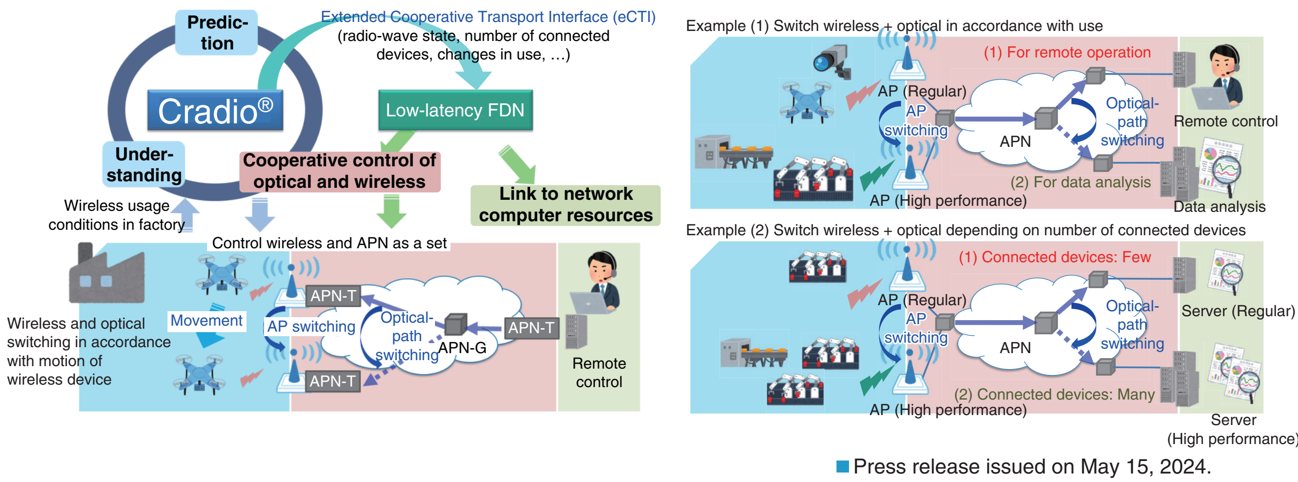
- Confirm the accuracy of estimating radio propagation with Cradio® and the accuracy of the conversion of a BIM data file format to the input file format for Cradio®
- Compare the time and cost of designing the positioning of wireless-local area network (LAN) base stations with those using the conventional method
- Visualize Cradio® simulation results using a dedicated viewer (**Fig. 6**)
- Evaluate the usefulness of radio propagation simulation for the construction industry

As a result, the median error when comparing the estimated and measured values for reception power was less than 5 dB, the design time for wireless-LAN base-station positioning when using simulation was 30% less than when using conventional methods, and the equipment placement design by simulation can reduce the amount of equipment used by 50% than the design with conventional methods.

We next introduce verification of real-time cooperative control in accordance with usage state for optical paths and wireless access (**Fig. 7**). In this verification, a Wi-Fi AP was connected to an IOWN All-Photonics Network (APN) line to simulate a wireless environment in a factory, and an environment was built in which devices connected to the Wi-Fi AP communicated with a cloud server. For the first time, a wireless controller implementing Cradio® functions that understand wireless usage state was linked to a controller able to switch at the optical path level on an IOWN APN line, using the extended Cooperative Transport Interface (eCTI) specified by the IOWN Global Forum [4]. This will enable uses such as a factory using Wi-Fi, where the Cradio® understanding function can detect when the number of user devices and amount of application traffic changes suddenly, and on the basis of this information, automatically switch the optical path connecting the application to the server. Testing has confirmed that such cooperative operations can be completed in around 100 ms.

4. Supporting people to live a fulfilling social life with wireless technology

In addition to the technical development to provide a network that follows advancements in wireless access and changes in the environment, discussion on how to use new access networks is very important. For example, NTT DOCOMO's 6G white paper [5] identifies use cases to address social issues, for human-object communication, to expand the communications environment, and advance cyber-physical integration. NTT DOCOMO is developing a haptic sharing technology called FEEL TECH® and the Human Augmentation Platform [6]. Many factors, such as body, sensation, and emotion, can be



APN-T: Open APN Transceiver
APN-G: Open APN Gateway
FDN: function-dedicated network

Fig. 7. Controlling switching between optical path and wireless access.

conveyed and shared through this platform, which could lead to entirely new unforeseen use cases.

We believe it is important to continue study, both to advance R&D, and discover new use cases to support people to live a fulfilling social life with wireless technology.

References

[1] Press release issued by NTT, “DOCOMO and NTT Expand 6G Collaborations with SK Telecom and Rohde & Schwarz - Highlighting trial progress with Nokia, Fujitsu and Keysight Technologies -,” Feb. 22, 2024.
https://group.ntt/en/newsrelease/2024/02/22/240222a.html

[2] M. Sasaki, T. Nakahira, T. Moriyama, T. Ogawa, Y. Asai, and Y. Takatori, “Multi-radio Proactive Control Technology (Cradio®): A Natural Communication Environment where Users Do Not Need to Be Aware of the Wireless Network,” NTT Technical Review, Vol. 19, No. 8, pp. 37–45, Aug. 2021.
https://doi.org/10.53829/ntr202108ra1

[3] Press release issued by NTT WEST and Takenaka Corporation, Apr. 24, 2024 (in Japanese).
https://www.ntt-west.co.jp/news/2404/240424a.html

[4] Press release issued by NTT, “Demonstrated real-time optical and wireless cooperative control for efficient IOWN All Photonics Network utilization - Promoting optical networks in accordance with the state of radio usage that supports DX at factories -,” May 15, 2024.
https://group.ntt/en/newsrelease/2024/05/15/240515a.html

[5] NTT DOCOMO, “White Paper on 5G Evolution and 6G,” Version 5.0, Jan. 2023.
https://www.docomo.ne.jp/english/binary/pdf/corporate/technology/whitepaper_6g/DOCOMO_6G_White_PaperEN_v5.0.pdf

[6] S. Miyaura and T. Amano, “Human Augmentation Platform for New Styles of Communication,” NTT DOCOMO Technical Journal, Vol. 25, No. 3, Jan. 2024.
https://www.docomo.ne.jp/english/corporate/technology/rd/technical_journal/bn/vol25_3/004.html

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Transponder Aggregator for 64-degree CDC-ROADM Nodes

Keita Yamaguchi, Kenya Suzuki, and Osamu Moriwaki

Abstract

Colorless, directionless, and contentionless reconfigurable optical add/drop multiplexing (CDC-ROADM) nodes will require throughputs exceeding 8 Pbit/s by 2035, and transponder aggregators supporting high-degree and multi-band functionality will be crucial devices. We demonstrated a low-loss multicast switch capable of supporting a 300-nm bandwidth and 64 degrees, a suitable device for this purpose. The prototype's insertion loss was less than 8.0 dB in all paths, and the extinction ratio exceeded 40 dB.

Keywords: ROADM, MCS, WSS

1. Introduction

Colorless, directionless, and contentionless reconfigurable optical add/drop multiplexing (CDC-ROADM) has been widely deployed in core and metro networks due to its high flexibility [1–5]. Due to the rapid growth in network traffic at a rate of 30% per year, the handling granularity and node throughput at ROADM nodes have increased by approximately 10 times over the last decade (**Table 1**). Extrapolating this trend, it is anticipated that in 2035, signal handling granularity will reach 10 Tbit/s, and node throughput will be required in the order of 8 Pbit/s. In contrast, the frequency-utilization efficiency is approaching saturation [5]. Instead of increasing capacity per band, it is essential to increase the wavelength bandwidth and number of connected degrees of nodes, which is equivalent to the number of connected transmission fibers. For example, on the basis of a 16-degree node using the C+L bands currently in practical use, a configuration that triples throughput by 2030 can be achieved by combining a 1.5-fold increase in bandwidth (utilizing the S-band) and a doubling of the number of fibers (supporting 32 degrees). By 2035, a configuration could achieve eight times the throughput by doubling the bandwidth and quadrupling the number of fibers (supporting 64 degrees).

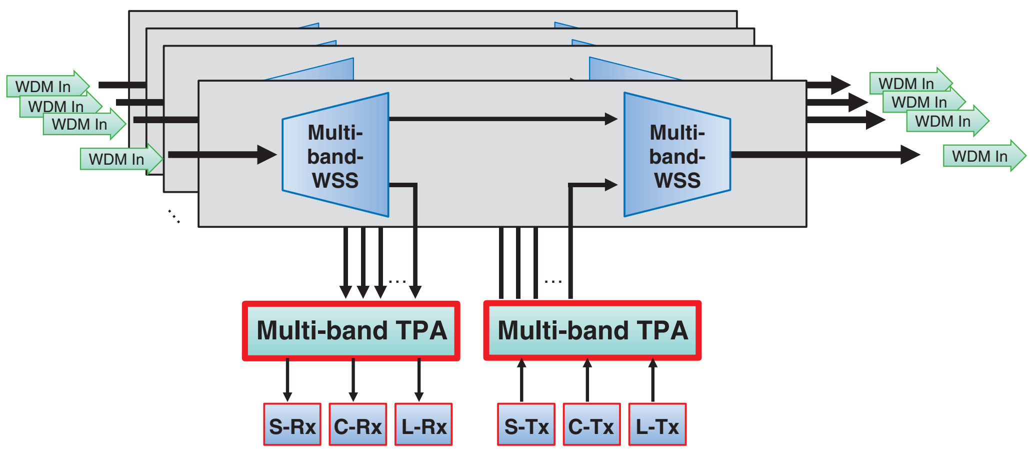
Even within such high-throughput nodes, the functionality of CDC to interconnect transponders in any direction at any wavelength remains important. To fulfil this requirement, transponder aggregators (TPAs) supporting increasingly wide wavelength bands and an extended number of degrees are necessary. We analyzed the requirements for TPAs in this context and their impact on switching characteristics and developed multicast switches (MCSs) as suitable enablers. We also developed a prototype 64×4 MCS, based on a planar lightwave circuit (PLC) platform for 64-degree links, and demonstrated its operation with less than 8-dB loss from the S- to L-bands and a high extinction ratio at a bandwidth of 300 nm.

2. TPA for future CDC-ROADM nodes

A conceptual diagram of a CDC-ROADM node supporting multi-degree and multi-band functionality is shown in **Fig. 1**. It consists of a wavelength cross-connect [6–8] and transponder aggregation [9–12]. The typical configuration consists of a pair of wavelength-selective switches (WSSs) for each link degree and wavelength-path routing. Therefore, the expansion of link degrees is accompanied by an increase in the number of WSSs. WSSs with multi-band support can also accommodate signals over a wide wavelength band [13, 14]. TPAs, however, offer

Table 1. Configuration of CDC-ROADM nodes and various requirements.

Year	2013	2019	2024	2030	2035
Handling granularity	100 Gbit/s	400 Gbit/s	800 Gbit/s	**3.2 Tbit/s**	**~10 Tbit/s**
Node throughput	77 Tbit/s	200 Tbit/s	820 Tbit/s	**2.5 Pbit/s**	**~8 Pbit/s**
Capacity/Band	9.6 Tbit/s	25.6 Tbit/s	25.6 Tbit/s	25.6 Tbit/s	25.6 Tbit/s
Node degree	8	8	16	**> 32**	**> 64**
Band	Single (C/L)	Single (C/L)	Dual (C+L)	Dual plus extra waveband (S-L)	**More waveband (S-U)**



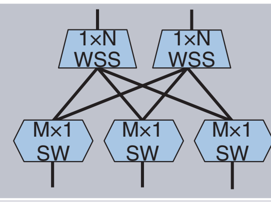
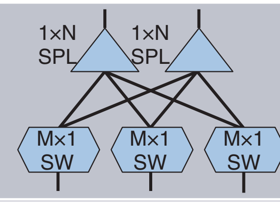
Rx: transmitter antenna
Tx: receiver antenna
WDM: wavelength division multiplexing

Fig. 1. Schematic of a CDC-ROADM node supporting multi-degree and multi-band functionality.

CDC functionality, namely the capability to connect transponders to all link degrees regardless of wavelength. Thus, two qualitative changes are required: an increase in the number of ports on the side connecting to the WSSs and support for a wider wavelength range.

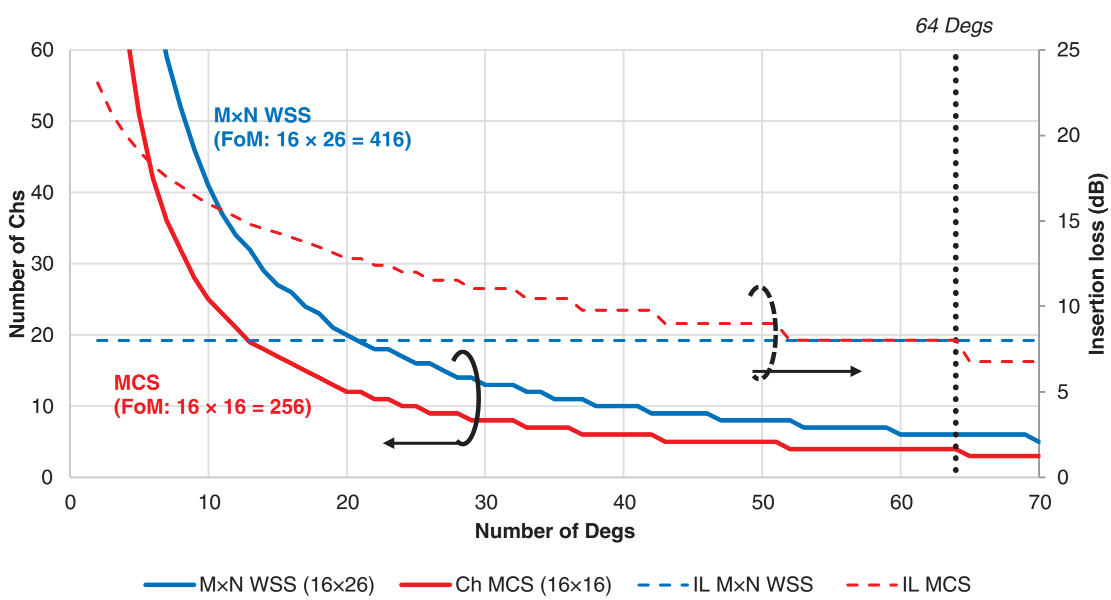
Two types of switches are currently in practical use as TPAs, the characteristics of which are summarized in **Fig. 2**. One type is the contentionless M×N WSS with multiple 1×N WSSs and M×1 switches facing each other. This type of switch can independently switch each wavelength channel, resulting in no intrinsic loss and achieving an insertion loss as low as 7 dB even when accommodating numerous transponders [10]. However, the integration of multiple WSSs into a single module with spatial optics leads to relatively high size and cost. The other type is an MCS with 1×N splitters and M×1 switches facing each other [11]. This switch can be built using only waveguides, reducing size and cost. However, as the number of channel ports increases with the number of transponders to be accommodated, branching losses occur at the splitter. For example, the branching losses when the number of channel ports is 4 and 8 is 6 and 9 dB, respectively.

For both types of switches, the figure of merit (FoM) of the switching scale is the product of the number of degree ports, which are the ports connected to the WSS in each degree, and the number of channel ports [9]. The same FoM can be achieved at a similar size and cost on the same platform. To accommodate an increase in the number of link degrees of nodes, the number of degree ports in the TPA is increased, and the number of channel ports is reduced accordingly, assuming the same FoM. The graph in **Fig. 3** shows the relationship between the number of channel ports and insertion loss of the TPA in relation to the number of link degrees. The FoM is

	Contentionless M×N WSS	PLC-MCS
		
Waveband	C or C+L	S+C+L
Insertion loss	7 – 8 dB	Intrinsic splitting loss +2 dB
FoM: Deg # × Ch #	8×24 / 16×24	16×16
Wavelength filter	Yes	No
Cost	High	Low
Size	Large	Small

SPL: splitter
SW: switch

Fig. 2. Types and characteristics of TPAs.



Ch: channel port
Deg: degree port
IL: insertion loss

Fig. 3. Varied numbers of channel ports of a TPA switch with number of node degrees.

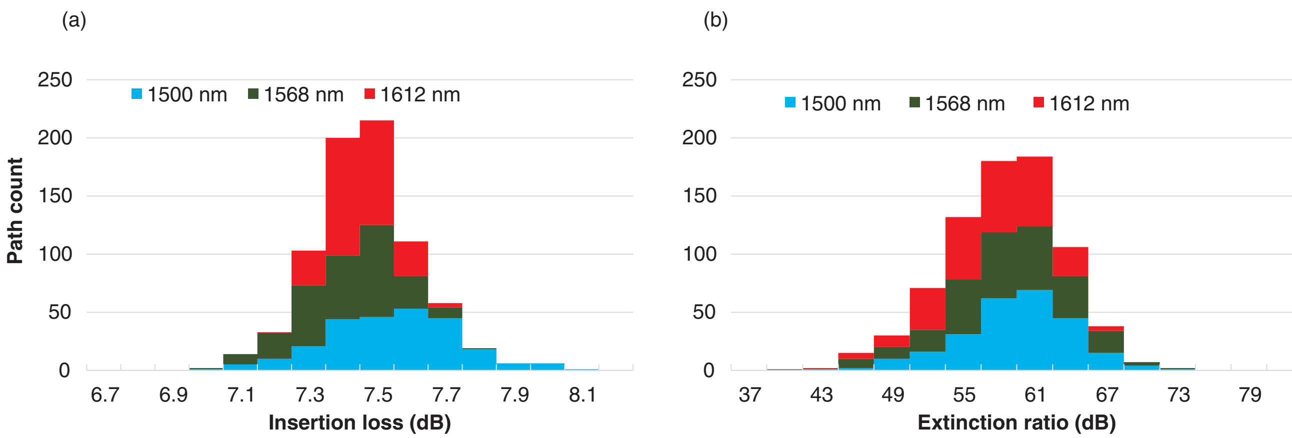


Fig. 4. Histograms of (a) insertion loss and (b) extinction ratio experimental values for the 64×4 MCS prototype.

assumed to be 16 × 26 = 416 for the M×N WSS [14] and 16 × 16 = 256 for the MCS [15]. Note that the insertion loss of the MCS decreases with the number of channel ports, and the number of link degrees of the nodes increases. The loss of the M×N WSS remains constant at around 8 dB regardless of the number of node degrees, while the loss of the MCS decreases to the same level as the number of node degrees increases to 64. The number of channel ports corresponding to 64 degrees is 6 for the M×N WSS and 4 for the MCS, which is not a significant difference. This indicates that in a CDC-ROADM node in 2035, when the number of node degrees will increase to 64, the disadvantages in terms of optical characteristics of the MCS caused by losses due to branching are almost eliminated, and the size and cost advantages become more prominent. The number of transponders that can be connected to the TPA is reduced to 6 or 4, which is inconsistent with expanding node capacity, but considering the trend of increasing handling granularity, parallelization can solve the mismatch.

3. 64×4 MCS based on PLC

A prototype 64×4 MCS with a silica-based PLC was demonstrated to verify low-loss operation across multiple bands and support for high-order links. The PLC uses a 2%-Δ core and was fabricated through a combination of flame hydrolysis deposition and reactive ion etching [16]. The circuit configuration comprises a combination of a 16-in-1 4×4 MCS and 4-in-1 1×16 switch circuits. The chip size is 85 × 50 mm, and the Mach–Zehnder interferometer switch and splitter/coupler are designed for the wide wavelength bandwidth, as previously reported [17].

The evaluation results of the optical properties from the S- to L-bands on the prototype are as follows. The average insertion losses in the S-band (1500 nm), C-band (1568 nm), and L-band (1612 nm) were 7.49, 7.37, and 7.40 dB, respectively. **Figure 4(a)** shows histograms of the insertion loss in each band for all connection paths, including the connection losses at the single-mode-fiber-waveguide interface at two locations. All connection paths and wavelength bands exhibit insertion losses below 8 dB, which is almost equivalent to the M×N WSS over a wider wavelength band. **Figure 4(b)** shows the extinction ratio in each band for all connection paths, demonstrating a robust extinction ratio of over 40 dB under all conditions.

The transmission spectra are shown next. **Figure 5(a)** shows the extinction-ratio spectrum for the connection between a single degree port (Deg #22) and all channel ports (Ch #1, #2, #3, #4). Similarly, **Figure 5(b)** shows the extinction-ratio spectrum for the connection between a single channel port (Ch #1) and four degree ports (Deg #1, 22, 43, 64). In both cases, the extinction ratio remains above 40 dB across the wide range of 1400–1700 nm, equivalent to more than a four-band wavelength range from the S- to U-bands. These results indicate that PLC-based MCSs supporting 64-degree links can operate with low losses and high extinction ratios over a wide bandwidth of 300 nm and beyond. As the number of links increases in future CDC-ROADM nodes, the size and cost advantages of PLC-MCS will become more prominent, rendering this type of switch a suitable TPA.

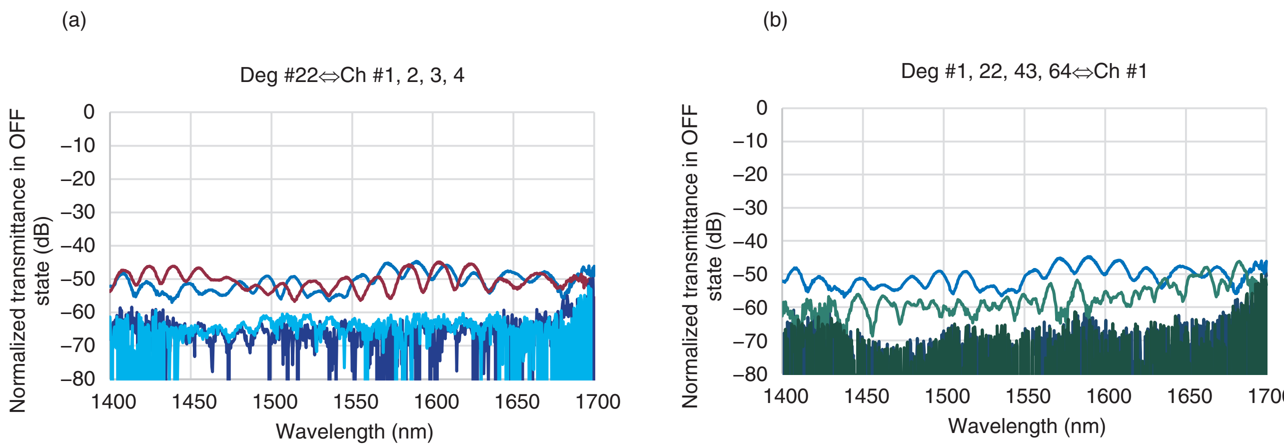


Fig. 5. Extinction-ratio spectra between (a) a single degree port and all channel ports and (b) a single channel port and four degree ports.

4. Summary

In contrast to the CDC-ROADM node configuration of 16 degrees using the C+L bands, which is currently being implemented, in 2035, a configuration with 8 times the throughput can be envisaged by supporting 4 bands and 64 degrees, corresponding to double the bandwidth and 4 times the number of fibers. To provide CDC functionality in such a node, a TPA corresponding to the increased bandwidth and number of degrees is required. In this context, we developed an MCS as a suitable enabler. We also developed a prototype 64×4 PLC-MCS supporting 64 degrees and demonstrated its operation with less than 8-dB loss from the S- to L-bands, alongside a high extinction ratio at a bandwidth of 300 nm.

References

[1] P. N. Ji and Y. Aono, "Colorless and directionless multi-degree reconfigurable optical add/drop multiplexers," Proc. of the 19th Annual Wireless and Optical Communications Conference (WOCC 2010), Shanghai, China, pp. 1–5, 2010. https://doi.org/10.1109/WOCC.2010.5510664

[2] S. Yamamoto, H. Taniguchi, Y. Kisaka, S. Camatel, Y. Ma, D. Ogawa, K. Hadama, M. Fukutoku, T. Goh, and K. Suzuki, "First demonstration of a C+L band CDC-ROADM with a simple node configuration using multiband switching devices," Opt. Express, Vol. 29, No. 22, pp. 36353–36365, 2021. https://doi.org/10.1364/OE.433383

[3] K. Suzuki, O. Moriwaki, K. Hadama, K. Yamaguchi, H. Taniguchi, Y. Kisaka, D. Ogawa, M. Takeshita, S. Camatel, Y. Ma, and M. Fukutoku, "A Transponder Aggregator With Efficient Use of Filtering Function for Transponder Noise Suppression," J. Lightw. Technol., Vol. 41, No. 10, pp. 3074–3083, 2023. https://doi.org/10.1109/JLT.2023.3240252

[4] Y. Ma, K. Suzuki, I. Clarke, A. Yanagihara, P. Wong, T. Saida, and S. Camatel, "Novel CDC ROADM Architecture Utilizing Low Loss WSS and MCS without Necessity of Inline Amplifier and Filter," Proc. of the 42nd Optical Fiber Communication Conference (OFC 2019), M1A.3, San Diego, CA, USA, 2019. https://doi.org/10.1364/OFC.2019.M1A.3

[5] K. Suzuki, M. Ota, Y. Morimoto, K. Yamaguchi, F. Hamaoka, S. Sugawara, T. Sasai, T. Kobayashi, M. Nakamura, S. Katayose, T. Umeki, D. Ogawa, Y. Ma, S. Camatel, M. Fukutoku, Y. Miyamoto, and O. Moriwaki, "Double-decker CDC-ROADM node for multi-band network with wavelength band granularity," Proc. of the 47th Optical Fiber Communication Conference (OFC 2024), Th1I.2, San Diego, CA, USA, 2024. https://doi.org/10.1364/OFC.2024.Th1I.2

[6] K. Yamaguchi, Y. Ikuma, M. Nakajima, K. Suzuki, M. Itoh, and T. Hashimoto, "M×N Wavelength Selective Switches Using Beam Splitting By Space Light Modulators," IEEE Photon. J., Vol. 8, No. 2, 0600809, 2016. https://doi.org/10.1109/JPHOT.2016.2527705

[7] R. Hashimoto, S. Yamaoka, Y. Mori, H. Hasegawa, K. Sato, K. Yamaguchi, K. Seno, and K. Suzuki, "First Demonstration of Subsystem-Modular Optical Cross-Connect Using Single-Module 6×6 Wavelength-Selective Switch," J. Lightw. Technol., Vol. 36, No. 7, pp. 1435–1442, 2018. https://doi.org/10.1109/JLT.2018.2800082

[8] N. Nemoto, Y. Ikuma, K. Suzuki, O. Moriwaki, T. Watanabe, M. Itoh, and T. Takahashi, "8×8 Wavelength Cross Connect with Add/Drop Ports Integrated in Spatial and Planar Optical Circuit," Proc. of the 41st European Conference on Optical Communication (ECOC 2015), Tu.3.5.1, Valencia, Spain, 2015. https://doi.org/10.1109/ECOC.2015.7341950

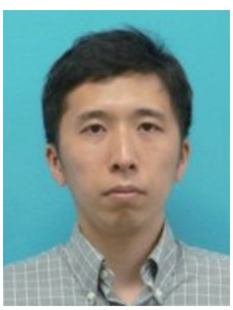
[9] Y. Ikuma, K. Suzuki, N. Nemoto, E. Hashimoto, O. Moriwaki, and T. Takahashi, "Low-Loss Transponder Aggregator Using Spatial and Planar Optical Circuit," J. Lightw. Technol., Vol. 34, No. 1, pp. 67–72, 2016. https://doi.org/10.1109/JLT.2015.2464673

[10] P. D. Colbourne, S. McLaughlin, C. Murley, S. Gaudet, and D. Burke, "Contentionless Twin 8×24 WSS with Low Insertion Loss," Proc. of the 41st Optical Fiber Communication Conference (OFC 2018), Th4A.1, San Diego, CA, USA, 2018. https://doi.org/10.1364/OFC.2018.Th4A.1

[11] T. Watanabe, K. Suzuki, and T. Takahashi, "Silica-based PLC Transponder Aggregators for Colorless, Directionless, and Contentionless ROADM," Proc. of the 35th Optical Fiber Communication Conference and Exposition and National Fiber Optic Engineers Conference (OFC/NFOEC 2012), Los Angeles, CA, USA, OTh3D.1, 2012. https://doi.org/10.1364/OFC.2012.OTh3D.1

[12] Press release issued by Lumentum, "Lumentum Recognized in Three Optical Communications Product Categories at 2024 Lightwave

Innovation Reviews," Feb. 22, 2024. https://www.lumentum.co.jp/ja/media-room/news-releases/lumentum-recognized-three-optical-communications-product-categories-2024
[13] K. Seno, K. Yamaguchi, K. Suzuki, and T. Hashimoto, "Wide-Passband C+L-band Wavelength Selective Switch by Alternating Wave-Band Arrangement on LCOS," Proc. of the 44th European Conference on Optical Communication (ECOC 2018), We1C.6, Rome, Italy, 2018. https://doi.org/10.1109/ECOC.2018.8535452
[14] GlobeNewswire, "Finisar Australia Releases World's First C+L-band Wavelength Selective Switch," Aug. 2020. https://www.globenewswire.com/news-release/2020/08/31/2086099/0/en/Finisar-Australia-Releases-World-s-First-C-L-band-Wavelength-Selective-Switch.html
[15] A. Yanagihara, K. Yamaguchi, T. Goh, and K. Suzuki, "Surface Mount Technology for Silica-Based Planar Lightwave Circuit and Its Application to Compact 16×16 Multicast Switch," IEICE Trans. Electron., Vol. E103-C, No. 11, pp. 679–684, 2020. https://doi.org/10.1587/transele.2019OCP0008
[16] K. Okamoto, "Recent progress in high-silica planar lightwave circuits," Proc. of Integrated Photonics Research, ThE1, Monterey, CA, USA, 1991. https://doi.org/10.1364/IPR.1991.ThE1
[17] T. Goh, K. Yamaguchi, and A. Yanagihara, "Multiband Optical Switch Technology," Proc. of the 45th Optical Fiber Communication Conference (OFC 2022), W4B.1, San Diego, CA, USA, 2022. https://doi.org/10.1364/OFC.2022.W4B.1



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Report on the 36th Asia-Pacific Telecommunity Standardization Program Forum (ASTAP-36)

Kazuhide Nakajima

Abstract

The 36th Asia-Pacific Telecommunity Standardization Program Forum (ASTAP-36) was held on May 20–24, 2024 in Bangkok, Thailand. More than 150 experts (including 39 remote participants) from 18 nations/regions gathered for four days of standardization discussions and industry workshops. This article outlines the key points of ASTAP-36.

Keywords: APT, ASTAP, industry workshop

1. Overview and structure of ASTAP

The international organization Asia-Pacific Telecommunity (APT) was established in 1979 to promote information and communication technology (ICT) development in the Asia-Pacific region. At present, 38 nations and/or regions participate in APT [1]. In 1998, APT established the APT Standardization Program (ASTAP) as a standardization sector meeting. Since its inception, ASTAP has continued to be held once or twice a year. ASTAP's two main objectives are as follows [2]:

- to construct a harmonized discussion scheme in the Asia-Pacific region,
- to effectively propose the region's perspectives and policies to the international standards.

Table 1 shows the meeting structure of ASTAP, which comprises three Working Groups (WGs) and eleven Expert Groups (EGs) reporting to each WG.

1.1 WG Policy and Strategic Coordination

WG Policy and Strategic Coordination (PSC) investigates and shares member policies and strategies with respect to telecommunication technology. It comprises the following four EGs:

- EG ITU-T addresses topics related to the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T),
- EG Bridging the Standardization Gap (BSG) supports developing countries by promoting telecommunication technologies,
- EG Policies, Regulatory, and Strategies (PRS) investigates policy and strategy issues,
- EG Green ICT and Electro-Magnetic Field Exposure (GICT&EMF) handles green of/by ICT and EMF exposure issues.

1.2 WG Network and System

WG Network and System (NS) comprises the following three EGs:

- EG Future Network and Next Generation Networks (FN&NGN) investigates next-generation networks,
- EG Disaster Risk Management and Relief System (DRMRS) considers disaster risk reductions,
- EG Seamless Access Communication Systems (SACS) investigates telecommunication technologies in access networks.

1.3 WG Service and Application

WG Service and Application (SA) comprises the following four EGs:

- EG Internet of Things Application/Services (IOT) handles Internet of Things (IoT) services,
- EG Information Security (IS) considers security

Table 1. Structure of ASTAP.

Working Group (WG)	Expert Group (EG)
Policy and Strategic Coordination (WG PSC) Chair: Vietnam Vice-chair: Japan, China	ITU-T Issues (EG ITU-T)
	Bridging the Standardization Gap (EG BSG)
	Policies, Regulatory and Strategies (EG PRS)
	Green ICT and EMF Exposure (EG GICT&EMF)
Network and System (WG NS) Chair: South Korea Vice-chair: Japan	Future Network and Next Generation Networks (EG FN&NGN)
	Disaster Risk Management and Relief System (EG DRMRS)
	Seamless Access Communication Systems (EG SACS)
Service and Application (WG SA) Chair: Japan Vice-chair: South Korea	Internet of Things Application/Services (EG IOT)
	Information Security (EG IS)
	Multimedia Application (EG MA)
	Accessibility and Usability (EG AU)

Table 2. Major outcomes of ASTAP-36.

WG	EG	Type	Title
PSC	ITU-T	Liaison	Proposal for establishing of new SG13 regional group for Indian ocean rim countries
	BSG	Report (Revision)	Handbook to introduce ICT solutions for the community in rural areas
	GICT&EMF	Report (Revision)	Asia-Pacific regional activities on human exposure to EMF
		Report (Amendment)	Standardization activities for e-waste and rare metals
		Report (New)	Best practices and environment friendly policies for effective ICT deployment methods
NS	FN&NGN	Report (New)	Guidelines for 5G network sharing and co-construction
		Questionnaire (Re-circulate)	Survey the problems and requirements to future network services in beyond 5G era
SA	IOT	Report (New)	Requirements and framework of IoT older person care solution
	IS	Guideline (Revision)	Guidelines for security use of IT devices and services
	MA	Questionnaire (Re-circulate)	Problems and requirements on CDN services in Asia-Pacific region in covid-19
		Questionnaire (Re-circulate)	Metaverse use cases in Asia-Pacific region
		Liaison	ITU focus group on metaverse
	AU	Questionnaire (Re-circulate)	Status of the APT countries' mobile accessibility
		Questionnaire (Re-circulate)	Current status of the APT countries' relay services for accessible emergency communication

issues,

- EG Multimedia Application (MA) handles multimedia topics,
- EG Accessibility and Usability (AU) considers information accessibility and usability.

During an opening plenary session held on the first day of the 36th ASTAP Forum (ASTAP-36), all participants shared the program's overall direction, progress updates, and main objectives for each WG. Individual EG meetings were then held separately over the two days.

2. Major outcomes of ASTAP-36 and action plans for ASTAP-37

Table 2 summarizes the major outcomes of ASTAP-36. WG PSC issued a new APT Report titled "Best practices and environment friendly policies for effective ICT deployment methods," which highlights experiences on environmental protection using ICT technology. WG PSC also revised or amended three existing APT Reports: "Handbook to introduce ICT solutions for the community in rural areas,"

Table 3. Objectives for ASTAP-37.

WG	EG	Type	Title
PSC	ITU-T	Report (Continue)	Practical experience in combating counterfeit and stolen mobile device
		Report (Continue)	Technical solutions for optical cable rural backhaul connectivity together with relevant ITU-T standards and its implementation
	BSG	Guideline (Continue)	Guideline on setting up national ICT standardization regime
	GICT&EMF	Report (Continue)	The status report of RF-EMF exposure assessment from mobile phone base stations in Asia Pacific region
NS	FN&NGN	Report (Continue)	Guidelines on application of ICT Trust index to APT members countries
		Report (Continue)	Future network services in beyond 5G era
		Report (New)	Low-altitude network and its key technologies
	DRMRS	Report (Continue)	Local-area resilient information sharing and communication systems
	SACS	Report (Continue)	Cascaded free space optical and millimeter-wave communication system for small-cell access networks
		Report (Continue)	Seamless access systems for wideband THz services
		Report (Continue)	Fiber-wireless bridge system for seamless access network in high-frequency band
SA	IOT	Report (Continue)	Guidance for emergency medical services in the digital age
		Report (Continue)	IoT ecosystem development activities in APT member countries
	IS	Guideline (Continue)	Guidelines for IoT security (for manager)
	MA	Report (Continue)	Guideline of decentralized identity (DID) technology and its application
		Report (Continue)	Problems and requirements on CDN services in COVID-19 in Asia-Pacific region
		Report (Continue)	Metaverse use cases in Asia-Pacific region
	AU	Report (Continue)	Relay services for accessible emergency communication
		Guideline (Continue)	Guide on developing accessible mobile application for the APT countries
		Report (Continue)	Accessible IoT applications and smart city services in the AP region
		Report (Continue)	Framework for evaluating usability of natural user interactions

"Asia-Pacific regional activities on human exposure to EMF," and "Standardization activities for e-waste and rare metals," as scheduled.

WG NS issued one new APT Report titled "Guidelines for 5G network sharing and co-construction." Chinese and South Korean experts provided extensive comments and proposals to this new report, implying their strong interest in sharing wireless infrastructures to facilitate effective construction and operation.

WG SA issued a new APT Report titled "Requirements and framework of IoT older person care solutions." This WG also accomplished the revision of the existing APT Guideline "Guidelines for security use of IT devices and services."

Table 3 summarizes the main objectives of each WG and EG toward ASTAP-37. Discussions will continue on 21 topics related to new or revised APT Reports/Guidelines. Among these 21 topics, 11 documents are planned to be approved and issued at ASTAP-37. During ASTAP-36, EG FN&NGN agreed to start discussions on a new APT Report titled "Low-altitude network and its key technology" in accordance with the proposal from China and strong support from Vietnam. In this new work item, various applications of social infrastructure management using drones will be investigated, including related key technologies. This new APT Report is expected to be issued at ASTAP-39.

3. Industry workshop

ASTAP-36 included an industry workshop with its program outlined in **Table 4**. Three sessions were held consecutively. Session 1 focused on supply chain cybersecurity, showcasing seven experiences from Japan and China that highlighted harmonized activities among industries and governments as well as unique trials in each industry. Session 2 featured nine individual experiences on the effective use of ICT by small and medium enterprises in Japan, China, South Korea, and Malaysia. This session investigated three key aspects: sustainable development goals (SDGs), wireless infrastructure construction in

Table 4. Program for industry workshop.

Session 1: Supply Chain Cybersecurity
1.1 Industry-Government collaboration initiative
• Supply-chain security of auto industry in Japan (Japan)
• Introduction of Transportation ISAC (Information Sharing and Analysis Center) Japan (Japan)
• DNP's Supply Chain Security Initiatives and Issue Recognition (Japan)
• Securing the last chain (Last Mile): A customer-centric approach as a proactive security alerts across the supply chain (South Korea)
1.2 Industry-specific initiative
• Keidanren's approach to cybersecurity (Japan)
• Introduction of CRIC CSF (Cyber Risk Intelligence Center - Cross Sectors Forum) and Supply Chain (Japan)
• Supply Chain Cyber Security Consortium (SC3) activities (Japan)
• Introduction of standardization activity on supply chain security in South Korea (South Korea)
Session 2: Small Medium Enterprise
2.1 SDGs
• Measuring Air Pollutants using UAV (Japan)
• Accessibility in the Future Technologies for the Aging Society (Opportunities and Challenges in Asia) (South Korea)
• DNP's Supply Chain Security Initiatives and Issue Recognition (China)
• Securing the last chain (Last Mile): A customer-centric approach as a proactive security alerts across the supply chain (China)
• Brief introduction of Carbon data Reliable Circulation (China)
• How Digitalization Aids Mutual Trust and Cooperation in Small and Medium-sized Enterprises (China)
2.2 Rural communication
• Wireless Flexible mesh Network for Outdoor (Japan)
2.3 Emergence Technology
• Quantum Technology – The new Horizon (Malaysia)
Session 3: APT/ITU-T Workshop on Establishing National Standardization Secretariat (NSS) for BSG Capacity Building
3.1 Keynote speech: Mr. Seizo Onoe
3.2 NSS guideline: Mr. Akihiro Kato
3.3 Panel discussion

rural areas, and quantum computing. Session 3 was designated as an APT/ITU workshop on establishing national standardization secretariats (NSSs) for BSG capacity building. In this session, Mr. Seizo Onoe, Director of ITU's Telecommunication Standardization Bureau (TSB), delivered the keynote speech and Mr. Akihiro Kato, Coordination Advisor, ITU TSB, explained the NSS guidelines. A panel discussion followed, enabling the sharing of various opinions and perspectives.

4. Future direction

ASTAP-37 will be held in 2025, with the exact date and venue yet to be determined. A vice-chair will plan an industry workshop as part of ASTAP-37.

References

[1] APT, https://www.apt.int/APT-Introduction
[2] ASTAP, https://www.apt.int/APTASTAP

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Case Study of Voice Disconnection During Calls on the Hikari Denwa IP Telephone Service due to DHCP Conflicts

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Abstract

This article describes a case study of a failure in which voice calls on the Hikari Denwa IP telephone service were being disconnected due to DHCP (Dynamic Host Configuration Protocol) conflicts. This is the eighty-fourth article in a series on telecommunication technologies.

Keywords: IP telephone, packet analysis, MAC address, DHCP

1. Introduction

Broadband services are now widely used in homes and offices, and Internet protocol (IP) telephone services using optical fiber account for 75% of total fixed-line telephone (landline) services in Japan [1]. The Hikari Denwa service provided by NTT EAST and WEST is a service for IP telephones that uses IP packets to transmit voice (over the optical-fiber broadband service). If a customer has a contract for both Internet connection and Hikari Denwa services, the customer's home network equipment is shared between both services.

The Network Interface Engineering Group of Technical Assistance and Support Center (TASC), NTT EAST, provides technical support, such as on-site analysis of problems related to customer equipment and NTT equipment. This article describes a case study of a failure in which voice calls on the Hikari Denwa service were being disconnected due to Dynamic Host Configuration Protocol (DHCP) conflicts.

2. Details of failure and configuration of customer's equipment

We received a request for trouble shooting from a customer using the Hikari Denwa service that they are unable to hear the other party's voice after a few minutes of the call. They also said that this failure started occurring at a certain point in time, but other than voice calls, no problems with Internet communication occurred at that time.

The configuration of the customer's equipment is shown in **Fig. 1**. A switching hub is connected to downstream of an optical network unit (ONU) of the Hikari Denwa network, and the signal from the ONU is branched into a Hikari Denwa router and Internet-access router (referred to as the commercial router). This Hikari Denwa router has four analog ports, but only two are used to connect to analog telephones. Multiple personal computers (PCs) for Internet communication are connected to the commercial router.

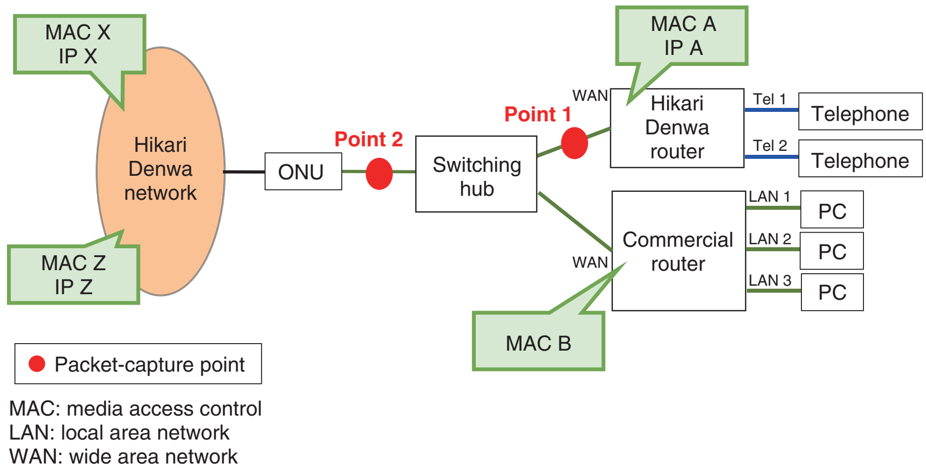

Fig. 1. Configuration of customer's equipment and capture points.

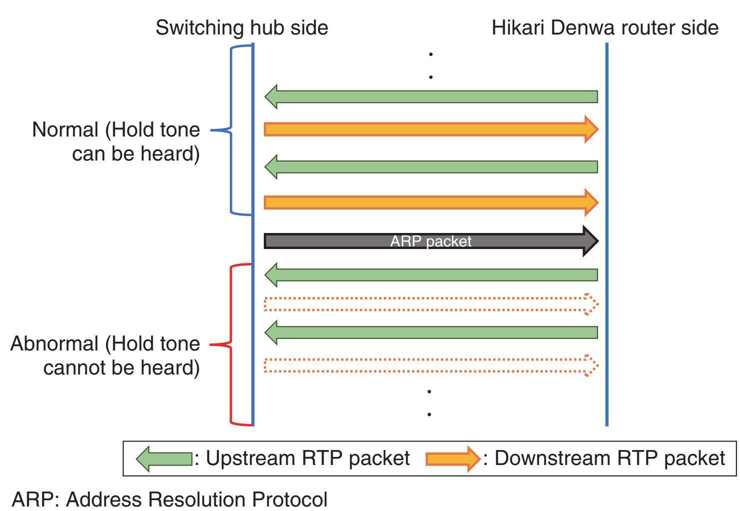

Fig. 2. Flow of Hikari Denwa packets at point 1.

3. Details of investigation

To investigate this failure, we made a test call and sent a hold tone from a test terminal to check the voice status. At that time, we captured Hikari Denwa packets and Internet-communication packets at points 1 and 2 in Fig. 1 and analyzed the status of Real-time Transport Protocol (RTP) packets.

4. Analysis results of RTP packets

4.1 Point 1 (between switching hub and Hikari Denwa router)

As a result of our analysis of the RTP packets at point 1 (**Fig. 2**), we confirmed that both upstream and downstream RTP packets flowed normally at the start of the test call. However, three minutes later, the downstream RTP packets (the hold tone from test terminal) stopped, but the upstream RTP packets (the voice from the customer's telephone) were flowing normally.

A detailed analysis of the IP packets before and

About 3 minutes later

Destination MAC address	Source MAC address	Destination IP address	Source IP address	Protocol	Information	
MAC X	MAC A	IP X	IP A	RTP	G.711 PCM μ-law	①
MAC A	MAC X	IP A	IP X	RTP	G.711 PCM μ-law	
MAC X	MAC A	IP X	IP A	RTP	G.711 PCM μ-law	
MAC A	MAC X	IP A	IP X	RTP	G.711 PCM μ-law	
Broadcast	MAC B	—	—	ARP (request)	**Sender MAC: MAC B** **Sender IP: IP A** Target IP: IPZ *1	②
MAC X	MAC A	IP X	IP A	RTP	G.711 PCM μ-law	③
MAC X	MAC A	IP X	IP A	RTP	G.711 PCM μ-law	
MAC X	MAC A	IP X	IP A	RTP	G.711 PCM μ-law	

*1 Inform MAC B (IP A) of the MAC address of IP Z.

MAC A: MAC address of Hikari Denwa router
MAC B: MAC address of commercial router
MAC X: MAC address of network-side terminal
MAC Z: MAC address of network-side terminal
IP A: IP address of Hikari Denwa router
IP X: IP address of network-side terminal
IP Z: IP address of network-side terminal

Fig. 3. Details of packets at point 1.

after the hold tone stopped flowing (**Fig. 3**) revealed the following steps: (1) upstream and downstream RTP packets flow from the start of the call ("normal" state) and (2) when Address Resolution Protocol (ARP) packets were sent from the commercial router during the call, (3) the downstream RTP packets stopped flowing ("abnormal" state) immediately after the ARP packets began flowing.

An ARP packet is used to map an IP address to a media access control (MAC) address. Normally, an ARP packet specifies its own IP address as the reply destination (sender IP). The ARP packets sent by the commercial router (as confirmed in step (2)) specified the same IP address as the Hikari Denwa router as the sender IP.

4.2 Point 2 (between ONU and switching hub)

As a result of our analysis of the RTP packets at point 2 (**Fig. 4**), we confirmed that both upstream and downstream RTP packets flowed normally at the start of the call and, about three minutes later, ARP packets with the same content as those from the commercial router at point 1 had been observed.

At point 2, unlike point 1, both upstream and downstream RTP packets were flowing normally after the ARP packets were sent. Further analysis of the downstream RTP packets revealed that the destination MAC addresses were different before and after the ARP packets. That is, the destination MAC address of the ARP packets was changed from the Hikari Denwa router to the commercial router.

5. Cause of failure

On the basis of the above results of the investigation, it is concluded that the cause of this failure was the change of the destination MAC address of the downstream RTP packets from the Hikari Denwa router to the commercial router. Therefore, the downstream RTP packets are sent to the commercial router, the RTP packets do not reach the Hikari Denwa router, and the voice becomes disconnected (**Fig. 5**).

The Hikari Denwa router operates as a DHCP client and obtains an IP address from the Hikari Denwa network when it starts up. DHCP is a protocol for automatically assigning IP addresses to devices connected to a network.

At the customer's equipment, the commercial router was connected to the switching hub in parallel with the Hikari Denwa router. The DHCP client function of the commercial router used for the Internet connection should be disabled; however, for some reason, the commercial router was also operating as a DHCP client, so the same IP address as that of the Hikari Denwa router was issued from the Hikari Denwa network, which resulted in sharing the same IP address.

We were able to reproduce the phenomenon of the

About 3 minutes later

Destination MAC address	Source MAC address	Destination IP address	Source IP address	Protocol	Information
MAC X	MAC A	IP X	IP A	RTP	G.711 PCM μ-law
MAC A	MAC X	IP A	IP X	RTP	G.711 PCM μ-law
MAC X	MAC A	IP X	IP A	RTP	G.711 PCM μ-law
MAC A	MAC X	IP A	IP X	RTP	G.711 PCM μ-law
Broadcast	MAC B	—	—	ARP (request)	**Sender MAC: MAC B** **Sender IP: IP A** Target IP: IP Z *2
MAC B	MAC X	—	—	ARP (reply)	Sender MAC: MAC Z Sender IP: IP Z **Target MAC : MAC B** **Target IP: IP A**
MAC X	MAC A	IP X	IP A	RTP	G.711 PCM μ-law
MAC B	MAC X	**IP A**			
MAC X	MAC A	IP X			
MAC B	MAC X	**IP A**			
MAC X	MAC A	IP X			

After ARP resolution is completed, the destination MAC address of the downstream voice packet is MAC B (commercial router), and the destination IP address is IP A (Hikari Denwa router).

*2 Inform MAC B (IP A) of the MAC address of IP Z.

Fig. 4. Details of packets at point 2.

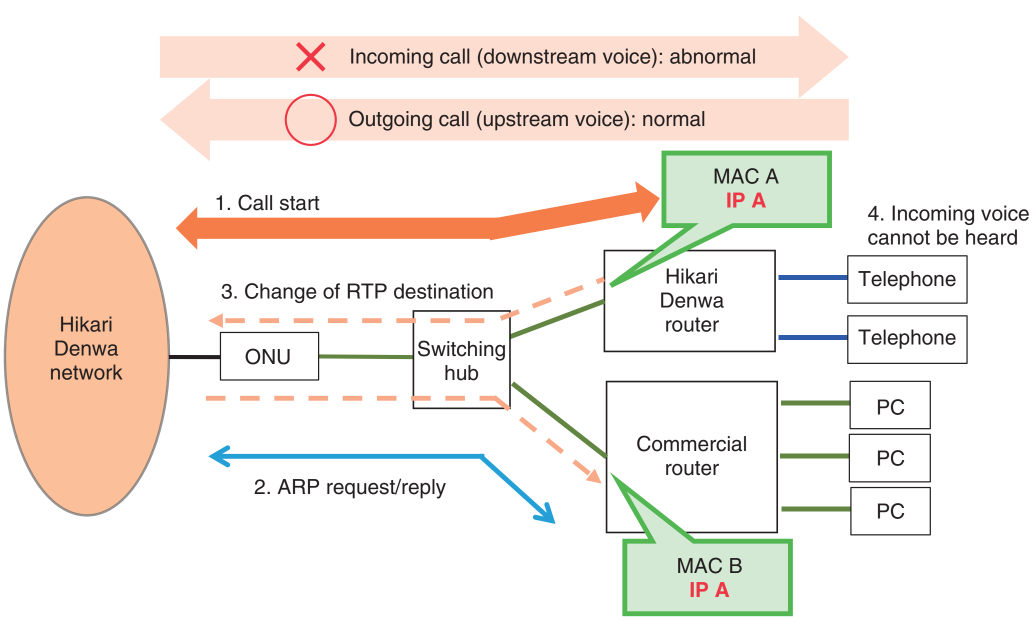

Fig. 5. Mechanism of occurrence of disconnected voice call.

same IP address being assigned to two different routers by connecting the switching hub to a verification line and connecting two Hikari Denwa routers to the downstream of the hub.

In the configuration in which two routers with the same IP address were located in the downstream of a

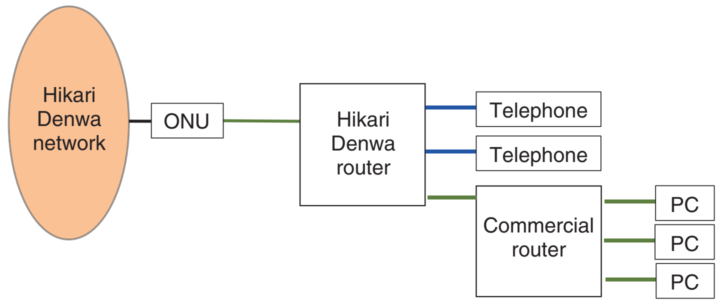

Fig. 6. Recommended configuration for customer's environment.

switching hub, an ARP packet was sent from the commercial router during the call; thus, the destination MAC address of the RTP packet sent from the network side was rewritten as the MAC address of the commercial router.

The switching hub learns the MAC addresses for each port and assigns the destination port to the Hikari Denwa router or commercial router on the basis of the destination MAC address. If the destination MAC address is rewritten, downstream RTP packets are no longer transmitted to the Hikari Denwa router; the result is a status in which the upstream voice can be heard, but the downstream voice cannot be.

6. Summary

The failure occurred for two reasons. (1) A commercial router was installed between the ONU and the Hikari Denwa router. (2) The Hikari Denwa router and commercial router were acting as DHCP clients. On speaking with the customer, this failure occurred after lightning struck a building near the customer's equipment. The DHCP client function of the commercial router was thereby unexpectedly enabled; thus, the same IP address was assigned twice. Considering this finding in regard to the Hikari Denwa service, we do not recommend the configuration in which the switching hub is installed between the Hikari Denwa router and ONU. Instead, we recommend installing the Hikari Denwa router and commercial router in the configuration shown in **Fig. 6**.

7. Concluding remarks

This article described a case study of a failure in which voice calls on the Hikari Denwa service were disconnected.

The Network Interface Engineering Group of TASC acquires and analyzes data using various tools to support the early resolution of problems with equipment, terminals, and networks.

Reference

[1] Ministry of Internal Affairs and Communications, "State of the Number of Subscriptions with Voice Communications Services," White Paper on Information and Communications in Japan, p. 69, 2023. https://www.soumu.go.jp/johotsusintokei/whitepaper/eng/WP2023/pdf/01-chap4_sec2.pdf

External Awards

The Japan Society of Applied Physics Molecular Electronics and Bioelectronics Encouragement Award

Winner: Koji Sakai, NTT Basic Research Laboratories
Date: May 15, 2024
Organization: The Japan Society of Applied Physics Molecular Electronics and Bioelectronics

For "Self-folding Graphene-based Interface for Brain-like Modular 3D Tissue."
Published as: K. Sakai, T. F. Teshima, T. Goto, H. Nakashima, and M. Yamaguchi, "Self-folding Graphene-based Interface for Brain-like Modular 3D Tissue," Adv. Funct. Mater., Vol. 33, 2301836, 2023.

IPSJ Fellow

Winner: Naomi Yamashita, NTT Communication Science Laboratories
Date: June 5, 2024
Organization: Information Processing Society of Japan (IPSJ)

For her pioneering research on system design technology to achieve an inclusive society.

Best Paper Award final 5 nominee

Winners: Tao Morisaki, NTT Communication Science Laboratories; Yusuke Ujitoko, NTT Communication Science Laboratories
Date: June 30, 2024
Organization: Eurohaptics 2024

For "Towards Intensifying Perceived Pressure in Midair Haptics: Comparing Perceived Pressure Intensity and Skin Displacement between LM and AM Stimuli."
Published as: T. Morisaki and Y. Ujitoko, "Towards Intensifying Perceived Pressure in Midair Haptics: Comparing Perceived Pressure Intensity and Skin Displacement between LM and AM Stimuli," Eurohaptics 2024, Lille, France, June/July 2024.

Best Demo Award final 8 nominee

Winners: Tao Morisaki, NTT Communication Science Laboratories; Yasutoshi Makino, The University of Tokyo; Hiroyuki Shinoda, The University of Tokyo
Date: June 30, 2024
Organization: Eurohaptics 2024

For "Midair 3D Texture Display Using Focused Ultrasound Based on Superimposing Pressure Sensation and Vibration Sensation."
Published as: T. Morisaki, Y. Makino, and H. Shinoda, "Midair 3D Texture Display Using Focused Ultrasound Based on Superimposing Pressure Sensation and Vibration Sensation," Eurohaptics 2024, Lille, France, June/July 2024.

IEEJ Electronics, Information and Systems Society Quick Paper Review Promotion Award

Winner: Koji Sakai, NTT Basic Research Laboratories
Date: July 29, 2024
Organization: The Institute of Electrical Engineers of Japan (IEEJ) Electronics, Information and Systems Society

For his contribution to the IEEJ journal through the quick peer review.