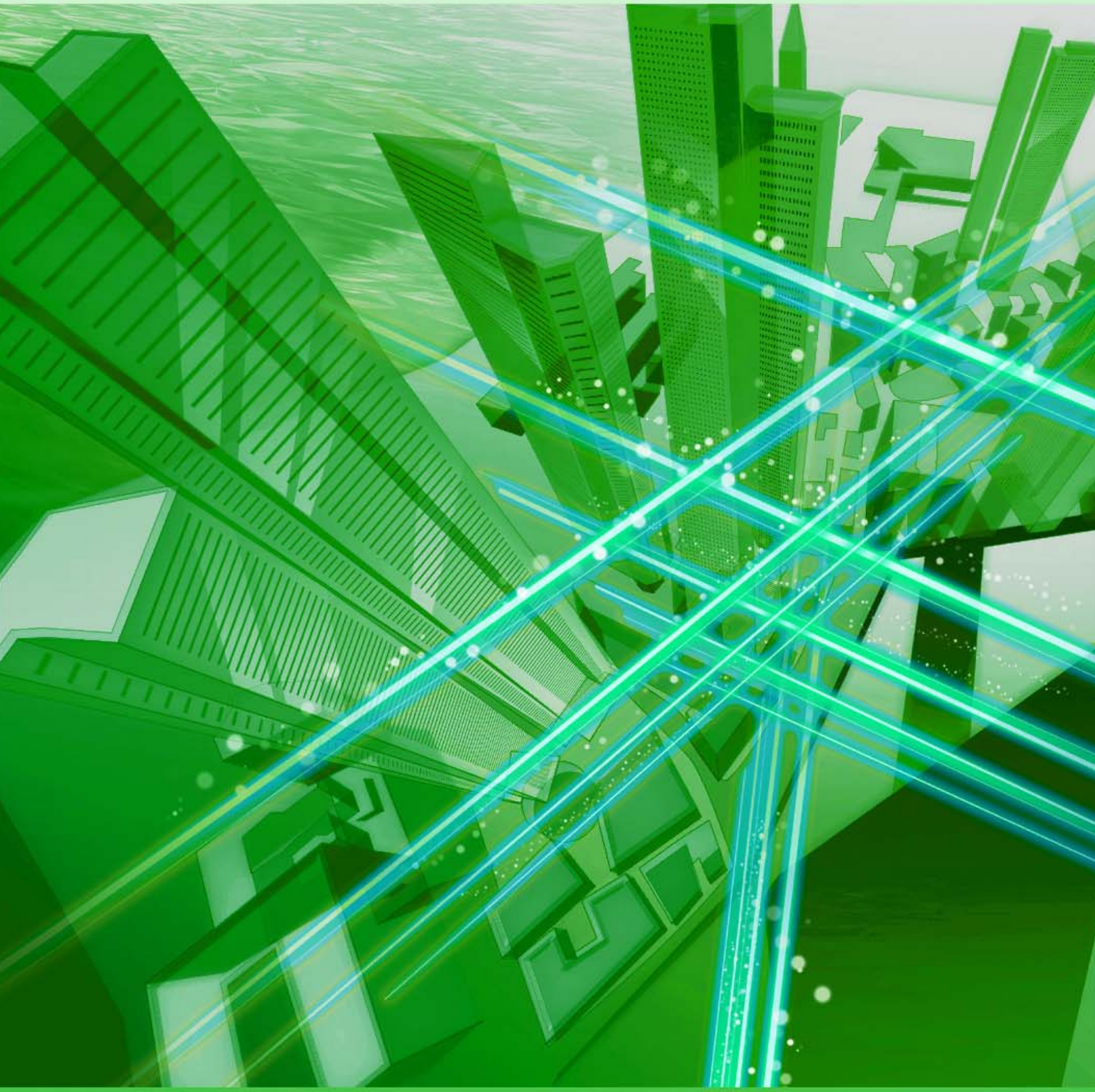
NTT Technical Review

2
2023



February 2023 Vol. 21 No. 2

NTT Technical Review

February 2023 Vol. 21 No. 2

Extending Service Areas to Sea, Sky, and Digital Space with the Same Enthusiasm as When I Joined the Company

Toru Maruoka
President and Chief Executive Officer, NTT Communications

Abstract

As a member of the new DOCOMO Group, NTT Communications provides clients with one-stop-shop services and solutions by combining the Group's resources and offerings under the enterprise-business brand "docomo business." We interviewed Toru Maruoka, president and chief executive officer of NTT Communications, who is promoting digital transformation in society and industry, about the direction and strategies of NTT Communications.

Keywords: digital transformation, co-creation, customer experience

Go Together Project: Create new value and culture by respecting each other

—The new DOCOMO Group began full operations in 2022. How is the new organization going?

In January 2022, NTT Communications and NTT COMWARE became subsidiaries of NTT DOCOMO, forming the new DOCOMO Group. In July 2022, the new DOCOMO Group integrated the management policies and business functions of the three companies, and has been striving to increase revenues in the enterprise and smart-life (finance and payment services, etc.) businesses and accelerate structural reform in the telecommunications business. As a member of the new DOCOMO Group, NTT Communications is responsible for the Group's enterprise business. We play a role in promoting the digital transformation (DX) of society and industry by providing one-stop-shop services to all clients ranging from large to small and medium enterprises.

We have been very productive since becoming a member of the new DOCOMO Group. We have been preparing for the "Go Together Project" since before the full-scale launch of the Group in July, and now that the new organization has been fully formed, we are working hard to understand each other's culture and business. This project is based on "respect" for the other party, which is the basis for developing global business, and we are aiming to create new value and culture together.

In fact, synergy between each company has been created, and although we face certain issues, each workplace is stimulating each other with its own originality and ingenuity. I believe the fact that we are physically working in the same office is a major factor. Having people who used to work at different locations right in front of you will make communication

smoother and collaboration easier.

—Is your business off to a good start?

The Go Together Project has helped to integrate corporate cultures and methods of the three companies. As a result, the content of our proposals to clients changed, and the speed of creating proposals increased, which generated orders and enabled us to start our new business smoothly. Under our new enterprise-business brand "docomo business," we have begun to see results from our efforts to create innovations that promote structural reforms in society and industry through cutting-edge solutions, such as the 5th-generation mobile communication system (5G) and Internet of Things (IoT), as well as fixed-mobile-convergence (FMC) services that we can now offer by combining the resources of each company.

In the new DOCOMO Group, the businesses of NTT Communications and NTT DOCOMO are complementary. NTT Communications specializes in enterprise business for large corporations and corporations in metropolitan areas, and we have been providing information and communication technology (ICT) solutions, such as datacenters, clouds, and security, in addition to telecommunications services. As a top mobile communication brand in Japan, NTT DOCOMO has established a foothold in enterprise business throughout the country by using its ability to reach small and medium-sized corporations. By combining their areas of expertise in enterprise business, we have expanded our sales coverage to include small and medium-sized corporations as well as large corporations nationwide. Toward future growth areas, we will integrate its existing solutions with mobile solutions such as IoT/FMC, applications, and the vast amount of market data held by NTT DOCOMO to provide "integrated solutions" in a one-stop-shop manner.

We hope people experience the future society at OPEN HUB Park

—Beneficial synergies have been created, right?

The new DOCOMO Group intends to reach out to small and medium-sized corporations in particular. In accord with our "Start Dash Program," we are currently visiting these clients to listen carefully to their requirements. We have approximately 1.6-million clients, and those requirements vary widely. Since circumstances differ according to region, the top management of each regional base plays a central role in these efforts while combining the skills of NTT Communications and NTT DOCOMO, each of which has its own strengths.

Toward the next generation of ICT solutions, the new DOCOMO Group has established NTT QONOQ, which is engaged in the extended reality (XR) business, and has started work on the technological

development and social implementation of Web3, which is the next-generation Internet that uses blockchain and other technologies. By incorporating these new areas into our integrated solutions, we aim to transform our business structure by increasing the percentage of sales in these areas from the current 35% to 50% or more in two years (2025). The enterprise business of the new DOCOMO Group is targeting operating revenues of two-trillion yen in FY2025. It will be very challenging, but it is not impossible, so I want to strive to achieve the target.

—NTT Communications has opened OPEN HUB Park in Otemachi Place, where its head office is located.

OPEN HUB Park is a place for co-creation that aims to create a Smart World—a sustainable future society in which social issues are solved through DX. As a symbol of the transformation of NTT Communications, one of the floors used as office space was transformed into a new workplace for co-creation. At OPEN HUB Park, our clients and partners, our 400 employees who are experts in their respective fields, and catalysts who are experts from outside the company collaborate to create new businesses and implement them in society by combining their technologies and knowledge. To date, approximately 1000 corporations and 2500 people have visited and used OPEN HUB Park.

Visitors can experience things that will stimulate their imagination. For example, state-of-the-art ICT infrastructures such as 5G, software-defined wide area network/local area network, and the All-Photonics Network, a key service of the NTT's Innovative Optical and Wireless Network (IOWN), are installed, and experiments on robot control using them are conducted on a daily basis. In this setting, engineers from various backgrounds can collaborate through XR. By bringing their own technologies and assets to OPEN HUB Park and fusing them with the latest ICT solutions from the DOCOMO Group, clients and partners can not only create business ideas but also conduct various experiments to implement those ideas in society.

—Expectations for IOWN are also growing, right?

I sense that our clients' expectations for IOWN are very high. The roadmap for implementing IOWN services was presented at NTT R&D Forum 2022. Our role in this initiative is to implement the next-generation ICT infrastructure for services such as Remote World and Digital Twin Computing by using technologies developed at NTT's laboratories. We are working daily to build a society that the IOWN concept envisions, namely, the "smart society," "low-carbon society," and "well-being society."

IOWN can dramatically reduce and curb power consumption while accommodating the increasing amount of traffic in communication networks. The NTT Group has released a new environmental and energy vision called "NTT Green Innovation toward 2040," which aims to achieve carbon neutrality by FY2040 by using IOWN and other technologies. In datacenter sectors, the Group aims to achieve carbon neutrality by 2030 by accelerating the conversion to renewable energy and introducing low-power-consumption technologies.

Our clients' awareness of the need to "go green" has increased significantly, and we are working with NTT Anode Energy to make various proposals to our clients. For example, we have seen positive feedback from our clients for (i) off-site power purchase agreements with parties such as convenience stores and other companies, under which we install new renewable-energy power plants and supply the power

generated to those parties, and (ii) "docomo Denki Green," a retail electricity service that uses renewable energy and enables customers to earn more d POINTs, a customer loyalty program, for each electricity bill than those with "docomo Denki Basic." At some of our datacenters, we offer multiple green energy solutions so that customers can choose a renewable energy source according to their needs.

Fulfilling our social responsibility by harnessing the collective strengths of the DOCOMO Group

—What is important when communicating with clients?

As IoT becomes ever more pervasive, becoming a member of the DOCOMO Group has increased the number of our projects in the IoT field, and I have come to recognize the greater social responsibility of telecommunications carriers than ever before. In the event of a failure, the DOCOMO Group must demonstrate its collective strengths and resolve it quickly. At NTT Communications, we will thoroughly pursue the customer experience (CX) that is unique to our enterprise business and continue to improve the value we offer at customer contact points across the company. In other words, I believe it is important to comprehensively enhance CX from the entrance to the exit of the customer journey—from the time a service is proposed and introduced to the operation and problem-solving phases.

The key to enhancing CX is the employee experience (EX) of every employee. With that in mind, we have been promoting work-style transformation such as flexible and hybrid work. Our remote-work ratio is constantly 70 to 80%, and we have put tools and rules in place to enable employees to work regardless of time and location. As we are seeing some sort of normality return after the COVID-19 pandemic and social activities become more prevalent, I also understand the importance of face-to-face communication for team building and co-creation with clients. Rather than simply setting a goal of the remote work ratio, we ask each department to pursue a balance that enables employees to achieve their best performance and maintain their well-being. I believe that we can contribute to society by applying the knowledge gained through this process to improve EX.

—Lastly, could you give some words of encouragement to everyone in charge of research and development (R&D) as well as other employees?

I joined NTT 40 years ago. At that time, Nippon Telegraph and Telephone Public Corporation was working on the information network system (INS), with which the familiar service of telephony is changed from the traditional analog basis to a digital basis, and all types of information, voice as well as data and images, are transmitted. INS also envisioned a paradigm shift in society as the subject of communication expands from person-to-person to person-to-machine and machine-to-machine. The excitement and enthusiasm I had back then, just prior to the privatization of the Corporation, has not wavered.

We take on challenges of extending our service

areas from land to sea, sky, and digital space by leveraging the capabilities of the NTT Group, which includes the technology of NTT laboratories. In addition to providing FMC services on land, we successfully achieved 1-Mbit/s undersea transmission over a 300 m and developed a wireless underwater drone that can be controlled remotely at the end of 2022. Since 2021, NTT laboratories and Regional Fish Institute, Ltd. have been conducting demonstration tests of carbon-dioxide conversion technology that applies genome editing to algae and fish/shellfish to reduce the amount of carbon dioxide dissolved in the ocean. Regarding the sky, space infrastructure development, high-altitude platform stations, and drones are other themes we are focusing on. We have high expectations for the expansion of services accompanying the deregulation of drones. Through these efforts, we are enthusiastic about developing communication services across land, sea, and sky to achieve the "extreme coverage extension*"—a goal of 6G/IOWN.

NTT's R&D capabilities are among the best in the world. The products and services that emerge from those efforts are of high interest to our clients. Since I oversaw the voice business in my previous job, I have a particular attachment to voice-recognition technology. I have helped in the advancement of contact centers for our company and our clients by combining ForeSight Voice Mining and artificial-intelligence chatbots, which use voice-recognition technology. A recent example is NTT sonority's MWE001 earphones, which were commercialized using Personalized Sound Zone technology for creating a sound space that enables you to hear only the sounds you want to hear. The timing of this product was right to launch worldwide as remote activities were increasing. I believe that this type of R&D will contribute to improving all NTT's business, and I want to see more of such R&D.

The success of our business depends on all our employees, and the growth of our employees is the growth of our business. While practicing a new way of working that combines face-to-face and remote work in the era of living with COVID, I hope that each of you will grow through your own career development. Our aim is to create a virtuous cycle in which you and the company grow together. I want all employees to think about how they can gain the trust of clients and satisfy them. Let's use our cutting-edge technology to create an exciting world.

Interviewee profile

■ Career highlights

Toru Maruoka joined NTT in 1982. In his career at NTT Communications, he became senior vice president in 2012 and senior executive vice president in 2018. He has been in his current position since June 2020.

* Extreme coverage extension: Extending the area in which base stations can communicate with mobile terminals to all areas, such as the sky, sea, and space, not covered by current mobile communication systems.

I Want to Think from a Broader Perspective to Achieve My Ultimate Goal

Jun-ichi Kani
Senior Distinguished Researcher,
NTT Access Network Service Systems Laboratories

Abstract

In Japan, against the backdrop of the spread of high-definition video-streaming services and network applications such as cloud storage and work applications, the provision of high-speed communication services is gaining pace, and the research and development of optical access networks to support these services is under high expectations. Jun-ichi Kani, a senior distinguished researcher at NTT Access Network Service Systems Laboratories is playing a leading role in researching and developing new optical access networks for the beyond fifth-generation mobile communication system (5G)/6G era. We interviewed him about the progress of his research activities and his approach to research.

Keywords: optical access network, digital coherent access, All-Photonics Network

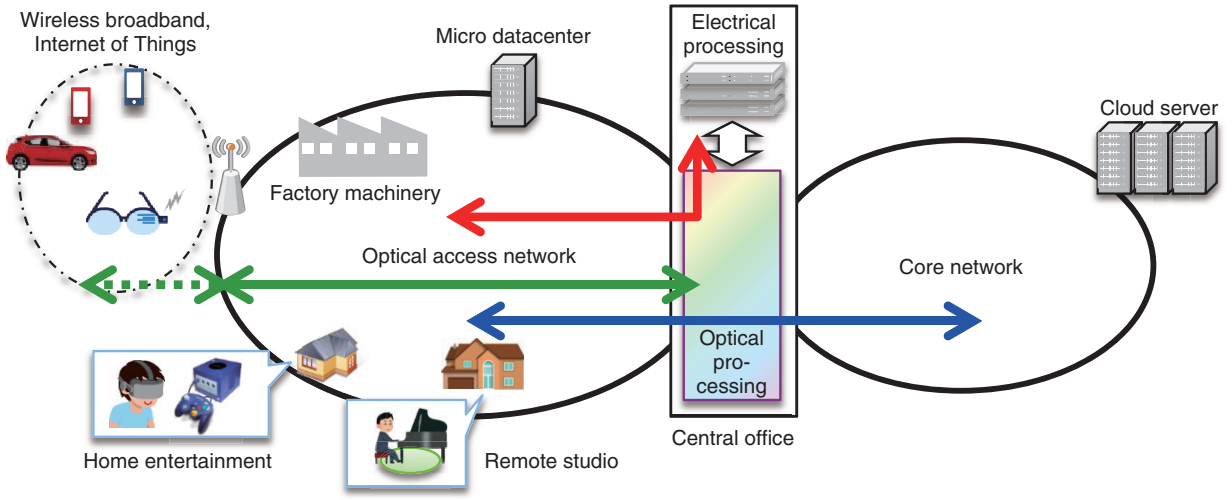
Pursuing a new optical access network that accelerates the evolution of information and communication services

—It has been two years since our last interview. Could you first give us an overview of the research you are currently conducting?

I am continuously pursuing the development of new optical access networks that will accelerate the evolution of information and communication services. In addition to researching, along with my team members, elemental technologies and architectures that will dramatically improve system performance and flexibility of optical access networks, I am also involved in global collaborative activities to implement and popularize new optical access networks.

A current optical access network transfers traffic to a core network at a central office. An analogy of this is a bus passenger transferring to a train at a train station. This transfer involves converting an optical signal into an electrical signal, processing the electrical signal for transfer, and converting the electrical signal back into an optical signal after the transfer. We aim to integrate the access and core networks to create a network that can transmit optical signals to designated locations without signal conversion (**Fig. 1**).

Optical-access-network technology has supported the development of a broadband service called fiber to the home (FTTH), which provides optical services to every home. Today, high-speed mobile Internet is



- Separation of optical and electrical processing makes it possible for optical signals to access designated locations without signal conversion. (Just like being able to travel anywhere by car instead of having to transfer from bus to train.)
- As much of the electrical processing is handled by commodity servers possible. (Just like it is now possible to do various things using personal computers and smartphones by simply adding or changing software; in contrast, dedicated devices, such as word processors, calculators, and portable music players, were conventionally used.)

Fig. 1. Future optical access network.

becoming more widespread, and equipment in central offices and antennas for 5G (5th-generation mobile communication systems) and next-generation wireless local area networks are all connected by fiber optic networks.

Under the assumption that everything from factory machinery and various sensors to transportation systems and electric-power systems will be connected via a network, the requirements for bandwidth and latency will become more complicated. Therefore, I believe that optical access networks will evolve from the foundation of FTTH to a common access platform for supporting diverse services and systems. Accordingly, we are researching and developing optical access networks with an eye on evolving them into that future common access platform.

—I hear that you have achieved high-profile research results. Would you tell us about them?

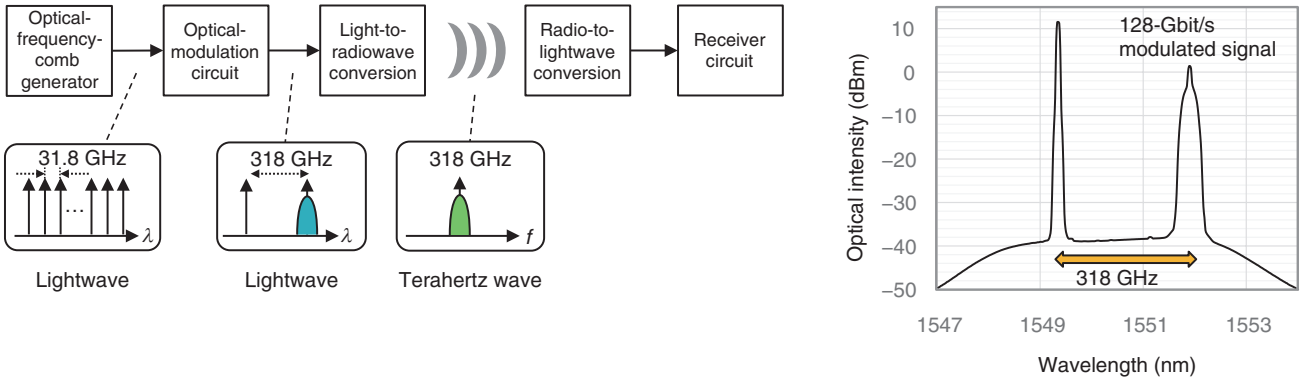
I'll explain two research results on elemental technology of optical access networks: (i) significant improvement in transmission performance and (ii) improvement in flexibility of network systems through softwarization of transmission functions.

Optical access systems called passive optical networks (PONs) are currently being deployed in Japan and other countries to roll out FTTH services. Current PON systems transmit binary intensity-modulated signals and receive only the optical intensity, and access networks with a transmission rate of 1 to 10 Gbit/s, splitting ratio of 1:32, and transmission distance of about 20 km are in widespread use.

To drastically improve the transmission performance of current PON systems, we have been conducting pioneering research on a method called *digital coherent access*. As we reported in Optics Express in 2021 [1], we experimentally verified the real-time feasibility of this method on a PON system with both uplink and downlink transmission rates of 10 Gbit/s and achieved a transmission distance of 40 km and power budget of more than 50 dB, which is a significant milestone.

The published results represent a twofold improvement in transmission distance and a 20-dB (100 times) improvement in power budget for the current 10G-PON. In the U.S., CableLabs, which sets cable television-related standards, has begun standardizing digital coherent access, and we are proud to have contributed to this technological trend.

Regarding improving the flexibility of network systems through softwarization of transmission functions, we have been striving to reduce latency, which had been a challenge, and achieved a processing



(a) Configuration used in the experiment

(b) Output spectrum of optical-modulation circuit

Fig. 2. Terahertz-wave communication technology using optical frequency comb.

speed of less than 1 ms for a 10G-PON by using software on a commodity server without the use of dedicated large-scale integrated circuits (LSIs). Our paper reporting this result has been published by IEEE Network [2].

We also accomplished signal processing using software on a commodity server without using dedicated LSIs in digital-coherent reception, which is essential for long-distance transmission, and demonstrated a transmission speed of 10 Gbit/s. Our paper reporting these accomplishments was presented at the European Conference on Optical Communication (ECOC) 2021 [3].

Publications in top optics-related journals and continuous achievement of world-class research results

—You have attracted attention for your research activities, which are highly regarded both academically and socially.

I received the ITU Association of Japan Accomplishment Award in 2021 for contributing to the development of high-speed and sophisticated optical access networks by leading standardization activities of optical access systems as an associate rapporteur at the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) Study Group 15. My contributions to accelerating the formulation of recommendations on optical access systems at ITU-T by facilitating technical discussions and promoting the formulation of technology roadmaps at the Full Service Access Network (FSAN) initiative was also recognized.

I am also researching ultrahigh-speed wireless communication using terahertz waves, a new domain of radio waves, in collaboration with Professor Tadao Nagatsuma of Osaka University, who is a leading expert in terahertz communication. By using a multi-wavelength light source called an *optical frequency comb*, it is possible to generate precise terahertz waves with a system that is compatible with fiber optic networks. We experimentally demonstrated a 128-Gbit/s transmission, which is the world's fastest data rate for terahertz-wave communication when using an optical-frequency-comb-based transmitter and intradyne receiver (**Fig. 2**). This result was reported at the Opto-Electronics and Communications Conference (OECC) in 2022 [4].

Regarding research on architecture, my team discussed and devised a new configuration of the optical-processing functions at a central office and called it Photonic Gateway, as it is considered an entry point for the future All-Photonics Network (APN), and implemented it as a combination of components. The results were reported at the Optical Fiber Communication Conference and Exposition (OFC) in 2021 and 2022.

These achievements will contribute to actualizing Japan's vision of the future called Society 5.0 in which cyberspace and physical space are highly integrated to balance economic development and solving social issues. Artificial intelligence and virtual reality are attracting attention for achieving this vision; however, it is crucial for information to be transmitted stably and smoothly by optical communication on the infrastructure that supports these technologies.

The optical communication that I pursue is behind the scenes in the sense that it is a technology that supports the foundation of information and communication services; even so, it is an important technology that accelerates the evolution of information and communication services and is useful to society. I hope to continue to play a leading role in developing advanced optical access technology.

—You are also focusing on IOWN, right?

In 2019, NTT announced the Innovative Optical and Wireless Network (IOWN) as a future vision of an innovative optical-based network and information-processing infrastructure. Although still limited to specific applications and areas, we will start providing IOWN services at the beginning of 2023, as we gradually improve its performance and expand its usage.

IOWN consists of three key components: (i) the APN, which introduces photonics-based technology to everything from networks to terminals, (ii) Digital Twin Computing, which enables highly accurate predictions by combining the real and digital worlds, and (iii) Cognitive Foundation, which connects and controls information and communication technology (ICT) resources in multiple domains and multiple layers. I am focusing on the access architecture and transmission technology needed to build the APN.

I am also participating in the IOWN Global Forum (IGF), which aims to promote global implementation of IOWN, to discuss the architecture of the APN. To achieve step-by-step deployment of the APN, it will be important to deliver short-term solutions as well, so I am shifting gears slightly from research. I am pleased that the research I have been pursuing for many years can contribute to making IOWN a reality. I want to continue to take on the challenge of creating new technology and architecture for networks to build a new ICT environment. IGF has provided me with more opportunities to have discussions with various experts in Japan and abroad, and I am grateful for the stimuli I have received from these discussions. Since the foundation of IGF as a U.S. corporation in 2020, meetings have been held online due to the COVID-19 pandemic, but in 2022, an in-person meeting was held for the first time since the pandemic began.

I have been a researcher for 20 years. Just predicting the evolution of technology is interesting

—What do you value in your research activities?

I value having discussions with people in various fields. As I mentioned earlier, I have been involved in international-standardization activities for a long time and have been a researcher for more than 20 years. In 2021, I was honored to serve as general chair of OFC, at which it has been my goal to present a paper ever since I was a young researcher. As I have been witnessing and excited about the evolution of the optical communication industry, it was very stimulating to be involved in the management and planning of OFC, which covers the entire industry. I will continue to cooperate with many researchers and engineers in global forums such as academic societies and standardization committees and will take on challenges toward the year 2030.

Discussions in these forums help me understand the differences in perspectives on certain issues. I am reminded that if I am to pursue global standards in my field, namely, communication networks, I need to think from a broader perspective to achieve my ultimate goal of making the results of my research useful to as many people as possible.

To achieve this goal, I'd like to look at the evolution of technology from a long-term perspective, as I mentioned in my previous interview. This is because if you set short-term goals of two, three, or five years, your research will inevitably become too limited in scope. As we discussed last time in regard to Amara's law, the impact of a new technology is overestimated in the short term and underestimated in the long term. While we have hope for various technologies in the short term as technology trends, we tend to avoid making bold predictions concerning the long term. However, in reality, over the span of the last 10 or 20 years, many things have changed more drastically than we had expected.

—What are your thoughts when you are competing as a world-class researcher? What would you like to say to future generations of researchers?

I find it interesting simply to predict the evolution of technology. The hit or miss of the prediction is also exciting. For example, during your research activities, just when you think that no more progress can be made in a certain field, a new theme will pop up, and

you will be betrayed by your thoughts—in a good way. I believe that being a researcher is an interesting job that enables you to pursue your field of expertise unceasingly.

Therefore, I don't feel a sense of "defeat" when other researchers publish their results ahead of us. There were a few times when other researchers published similar ideas of mine and I thought I should have taken a little more time to pursue them. Even so, I am happy that the technology I am involved in is progressing with other researcher's help, so I will strive to do better next time. Rather than focusing on themes that are already apparent, I want to focus on capturing potential needs that could lead to long-term changes in Amara's law.

What I am realizing at my age is that one can continue doing what they like and that "continuity is the father of success." I think one will be good at what they like after keeping on doing it; no one starts off being excellent.

As a senior distinguished researcher, I am also responsible for supporting the younger generation of researchers in taking on new challenges. I want to support them as a way of repaying the debt of gratitude for all the support I received during my research career.

As an active researcher, I want to keep the spirit of challenge in mind. Momofuku Ando, the founder of Nissin Foods, invented instant noodles at the age of 51, and he continued developing new products into his 90s. I am now in my 50s, and I too want to keep doing the best I can. I want to continue to approach my research from a fresh perspective, the same as that of the younger generation, while keeping in mind the balance between intellectual curiosity and usefulness to the world.

References

[1] T. Kanai, M. Fujiwara, R. Igarashi, N. Iiyama, R. Koma, J. Kani, and T. Yoshida, "Symmetric 10 Gbit/s 40-km Reach DSP-based TDM-PON with a Power Budget over 50 dB," Optics Express, Vol. 29, No. 11, pp. 17499–17509, 2021.

[2] T. Suzuki, S. Kim, J. Kani, and T. Yoshida, "Low-latency PON PHY Implementation on GPUs for Fully Software-defined Access Networks," IEEE Network, Vol. 36, No. 2, pp. 108–114, 2022.

[3] S. Kim, T. Suzuki, J. Kani, and T. Yoshida, "Demonstration of Real-time Coherent 10-Gb/s QPSK Reception Implemented on a Commodity Server," ECOC 2021, Sept. 2021.

[4] R. Igarashi, K. Toichi, T. Saijo, R. Koma, K. Hara, J. Kani, T. Yoshida, and T. Nagatsuma, "First Demonstration of 128-Gbit/s 300-GHz-band THz Transmission Using OFC-based Transmitter and Intradyne Receiver," OECC 2022, July 2022.

■ **Interviewee profile**

Jun-ichi Kani received a B.E., M.E., and Ph.D. in applied physics from Waseda University, Tokyo, in 1994, 1996, and 2005. He joined NTT Optical Network Systems Laboratories in 1996, where he researched optical multiplexing and transmission technologies. He has been with NTT Access Network Service Systems Laboratories since 2003, where he is engaged in research and development of optical communications systems for metropolitan and access network applications and currently heads the Access Systems Technology Group. He has been participating in ITU-T and the FSAN initiative since 2003.

Research of Cryptographic Protocols for Secure Communications in the Quantum Computer Era

Takashi Yamakawa
Distinguished Researcher, NTT Social Informatics Laboratories

Abstract

The development of quantum computers has been progressing rapidly in recent years based on principles fundamentally different from those of conventional computers. It is known that they can be used to break many of the encryption schemes that are now in actual use. To counter this threat, there is a need for "post-quantum cryptography" that cannot be broken even by quantum computers. In this interview, we asked NTT Distinguished Researcher Takashi Yamakawa to tell about his research in solving such social issues using cryptography.

Keywords: post-quantum cryptography, zero-knowledge proof, secure computation

Providing secure communications in preparation for the coming era of quantum computers

—Dr. Yamakawa, please explain to us the meaning of post-quantum cryptography.

Post-quantum cryptography means "cryptography that is secure against the threats of high-performance quantum computers." The research and development (R&D) of quantum computers has been progressing rapidly in recent years, and the possibility exists that quantum computers will become widely used in the near future. Security in current cryptographic schemes is based on the difficulty of prime factorization, but quantum computers feature the ability of factoring prime numbers to an extent not possible by classical computers. Consequently, if quantum computers should become commonly used in society, it is predicted that existing cryptographic schemes will be broken in several minutes leading to social disorder. It is therefore essential that all ciphers now in use be replaced with post-quantum cryptography before general-purpose quantum computers come into use to ensure secure information communications in the future. In fact, the National Institute of Standards and Technology (NIST) in the United States embarked on a standardization project for post-quantum cryptography in 2017, and because the demand for information security systems that can withstand quantum computing is increasing, I also began research in post-quantum cryptography.

My first undertaking after entering NTT was the research of quantum-secure public-key cryptography. In public-key cryptography, the example of the padlock is often used in reply to the question, "What is cryptography in the first place?" A padlock can be

Classical cryptography vs. post-quantum cryptography

	Classical cryptography	Post-quantum cryptography
Attack by classical computer	✔	✔
Attack by quantum computer	?	✔

Fig. 1. Relationship between classical cryptography and post-quantum cryptography.

used by anyone to lock (encrypt) a box (data), but to open the box, a key (decryption) is needed. So when sending someone a box (data), secure communications can be achieved by preparing a padlock, placing data in the locked (encrypted) box, and sending the box. This cryptographic system is called public-key cryptography. Specifically, in my research, I proposed a general technique for transforming a cryptographic system having weak security, or chosen-plaintext-attack security, into one having strong security, or chosen-ciphertext attack security. This technique was later adopted in a key-exchange, public-key-cryptography system called NTRU, which became a finalist as a candidate algorithm in the post-quantum cryptography standardization competition organized by NIST.

—At present, what are you specifically researching in post-quantum cryptography?

In the field of post-quantum cryptography, I'm now researching "zero-knowledge proof" and "secure computation." First, zero-knowledge proof, in brief, is a cryptographic protocol (a communication protocol using cryptography) for "proving that a certain statement is true without providing any additional knowledge other than the truth of that statement." This would correspond, for example, to saying, "I would like to prove that the correct answer to this puzzle exists." Of course, simply disclosing the answer would prove that "the answer exists," but this would reveal "knowledge" in the form of that answer. In short, technology that makes it possible to prove that an answer to a puzzle exists without conveying "knowledge" about that fact is called zero-knowledge proof.

Basically speaking, conventional cryptography only considers attackers using classical computers with respect to the security of zero-knowledge proofs, but whether they are secure if an attacker is using a quantum computer is unclear, so this is why I am researching post-quantum zero-knowledge proofs (**Fig. 1**). In this research, I have so far obtained negative results and positive results. As a negative result, I proved that a quantum-secure zero-knowledge-proof method that satisfies the same advantageous properties as classically secure methods "does not exist." This finding reflects a fundamental difference between classically secure zero-knowledge proofs and quantum-secure zero-knowledge proofs, a surprising result. As a positive result, I proved that making an appropriate transformation of a classically secure method as I mentioned above would directly result in a quantum-secure method as long as the definition of a zero-knowledge proof were to be relaxed within a range that presents no problems in actual use. This research could be applied, for example, to an anonymous authentication protocol as in proving that "I carry proper identification without having to reveal my identity."

Next, secure computation is a cryptographic protocol for calculating, for example, statistical quantities from multiple sets of data each possessed by a different party without disclosing that data among those parties. As in the case of zero-knowledge proofs, conventional research in secure computation basically considered only classical attacks, but whether it was quantum-secure was still unclear, which is why I took up this research. In terms of specific research, I have configured a quantum-secure method satisfying the same advantageous properties as the classically secure method and a method having a slightly relaxed version of security.

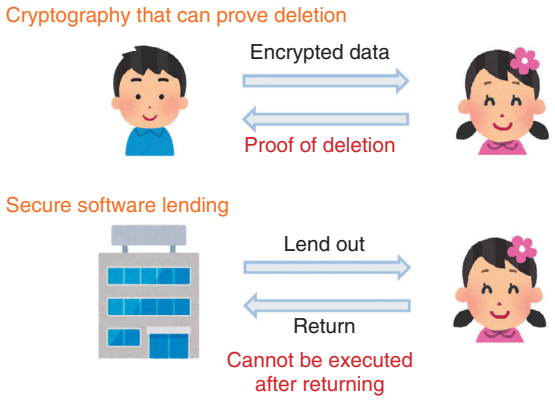


Fig. 2. Solving social problems through research of new cryptographic functionality using quantum computers.

—What other research are you conducting as a fusion of quantum computing and cryptography?

I am also engaged in the research of new cryptographic functionality using quantum computers. Classical cryptographic protocols suffer from an unavoidable problem in that they are all expressed in terms of digital data. For example, once data gets into someone's hand, it can be copied any number of times, and in addition, there is no technology for verifying that certain data has been deleted from the standpoint of another person. Realistically speaking, however, there is a much demand in society in the area of communications for preventing certain data from being copied and for guaranteeing that certain data has indeed been deleted. With this in mind, I am researching cryptographic protocols using quantum computers with the aim of achieving such functionality by cryptographic techniques (**Fig. 2**).

To be more specific, I am looking to achieve cryptographic functionality by making good use of the "no-cloning theorem" in quantum mechanics that states that it is impossible to copy a given quantum state. This is substantially different from classical digital data that can be copied any number of times, so I have researched a cryptographic method that can prove that certain ciphertext has been deleted using that theorem. I am also studying a cryptographic protocol for lending out software in a secure manner. This means, in short, a function that enables software to be executed during the period that it is being lent out but prevents it from being executed after being returned. This type of protocol had already been proposed, but in my research, I successfully achieved a function having a level of security that is even more reliable.

This new cryptographic functionality using quantum computers constitutes new technology, and it is still at a stage in which basic theory has room to mature. In fact, we are now in a proof-of-concept stage, but given that there is a real need in society for programs that cannot be copied and for proofs of data deletion, I think that many useful applications of these technologies will be appearing in the real world sometime in the future.

I am also researching the verification of quantum computers using cryptography. Although great strides are now being made in the development of quantum computers, it will take some time before they come into common use, so until then, general users who want to use a quantum computer will have to do so via the cloud from a classical computer. At that time, it will be necessary to verify the validity of those quantum computations to guarantee that the cloud is returning valid computational results. To give you a better idea of this research, let's let a quantum computer solve a puzzle for which the correct answer emerges only when the calculations are done correctly. Since this puzzle is generated on the user's side, the user already knows the answer, so if the quantum computer issues the correct answer, this tells the user that those quantum calculations are correct. Conversely, if the answer is incorrect, the user knows that the quantum computer did not perform the calculations correctly. To achieve this in reality, it will be necessary to skillfully embed cryptographic tools in quantum computations.

Additionally, it will be necessary, even in the quantum-computer R&D stage prior to such a function, to verify whether a quantum computer that is truly

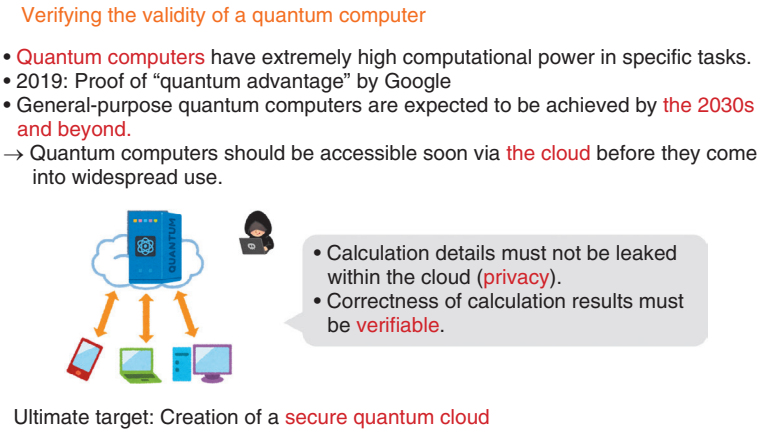


Fig. 3. Verifying the validity of a quantum computer using cryptography.

operating correctly has been created. In this regard, I have proposed a method for verifying the validity of quantum computations at very high speeds (**Fig. 3**), so we are making progress in this research. Furthermore, in protocol for verifying the validity of the statement "I have a quantum computer," I have proposed an entirely new method that uses only a function that behaves randomly called a hash function as a cryptographic tool. This method is fundamentally different from conventional methods.

Solving an abundance of problems and contributing to future research and human development

—What are some difficult challenges in your current research?

Classical cryptography is backed by basic results accumulated over many years, but quantum cryptography that I am researching is a field of research that has just begun. It is still in an entirely undeveloped state, and as a result, there are many unsolved problems dealing with very basic aspects of the theory. To give you an example, it is known that many cryptographic functions in classical cryptography have the property expressed as "calculations are easy to do but determining the original input from the results of those calculations is difficult," which is equivalent to a one-way function. It is still not known, however, whether the same holds in quantum cryptography. Recently, in 2019, a leading information and technology company published a paper claiming that quantum computers can solve problems faster than classical computers (quantum advantage). However, the method it describes is not "verifiable" in terms of cryptography and the assertion that quantum computers truly do exceed classical computers is not convincing from the standpoint of a third party. Even if speaking in generalities, the lack of a basic theory here can impede the configuration of more complex and high-performance ciphers. For this reason, we should research a method that can validate quantum advantage in terms of cryptography and work to solve fundamental problems.

—Please tell us about your research goals and vision going forward.

In my research, I believe it to be highly important to solve problems thought to be highly difficult to the point of greatly surprising researchers around the world. When attempting to solve truly difficult problems, many such attempts will end in failure. On the

other hand, by setting high goals, it is not uncommon to obtain a variety of interesting research results as a by-product, so I feel that it is vitally important to take on research with high goals in mind. My goal in research from here on is not so much to aim for applications in the near future but rather to contribute to future R&D through research of basic theory. Specifically, I would like to produce results that are still having an impact several tens of years or even hundreds of years from now by solving basic unsolved problems in quantum cryptography. I believe that these research results will deepen humankind's understanding of "computation" and lead to a more prosperous and enriched society making extensive use of quantum computers.

—Dr. Yamakawa, please leave us with a message for other researchers and students.

In the world of cryptography, the name "NTT" is known throughout the world, and at international conferences and other events, just mentioning NTT is enough to convey its credentials, which has the advantage of substituting as a business card. In addition, NTT brings together invited professors and superb postdoctoral researchers and research interns, which enables researchers to form international relationships and connections. Whatever field you are working in, this can be a great boost to advancing your own research. Abe Research Laboratory that I belong to within NTT Social Informatics Laboratories specializes in basic research in cryptography, and I am grateful that it recognizes the importance of basic theoretical research and allows us to continue this research. I believe it to be one of the most excellent research institutions in the world, of which there are few. In addition, I feel it is exactly such basic research that becomes the source of NTT's future competitiveness, and with this in mind, I will continue in my day-to-day research efforts.

Finally, I would like to thank all of my fellow researchers for their ongoing support of my research and their helpful discussions. I believe that new ideas are born through daily discussions with a variety of people. I look forward to advancing my research together with anyone having an interest in my research topics.

■ Interviewee profile

Takashi Yamakawa studied cryptography at the Graduate School of Frontier Sciences, The University of Tokyo and received his Ph.D. in 2017. He entered NTT in the same year. He has been a distinguished researcher at NTT Social Informatics Laboratories since 2022 conducting research in the combined field of quantum computing and cryptography. He was a visiting scholar at Princeton University from 2020 to 2021 performing joint research with Mark Zhandry, a leading scientist in this field. His papers have been accepted for presentation at Eurocrypt and CRYPTO sponsored by the International Association for Cryptologic Research (IACR), FOCS sponsored by IEEE, and other conferences.

R&D of Innovative Technologies in Space, Environment, and Energy

Yuji Maeda

Abstract

It has been two years and seven months since NTT Space Environment and Energy Laboratories was established with the aim of creating innovative technologies for regenerating the global environment and achieving a sustainable and inclusive society. During this time, we have proposed many unconventional research themes heretofore nonexistent at NTT laboratories and have been active in establishing specific themes, setting up systems, and bringing people together. At long last, NTT Space Environment and Energy Laboratories is taking shape. This article takes a new look at Earth from the viewpoint of space and describes the current state of various challenges to be met to change the future of the global environment.

Keywords: space, environment, energy

1. Introduction

NTT Space Environment and Energy Laboratories was established in July 2020 with the aim of taking a new look at Earth and the social environment that we live in from the high vantage point of space and through a wide variety of fields in contrast to the conventional framework of environment and energy. We thus seek to contribute to the regeneration of the global environment and development of innovative technologies.

The NTT Space Environment and Energy Laboratories vision can be summed up as follows.

"NTT Space Environment and Energy Laboratories aims to create next-generation energy technologies and resilient environmental adaptation technologies to help achieve zero environmental impact with a view to regenerating the global environment and creating a sustainable and inclusive society."

The specific image of a society that we wish to create through this vision is called a "resilient society." The idea behind this type of society is not only to make the impact on the global environment of the society that we live in more or less zero but to also enable our society to accommodate the changes in the global environment. To this end, a resilient society aims to achieve zero power outages through the local production and local consumption of green energy and use of a distributed, autonomous, and cooperative energy network. In addition to achieving zero damage by natural disasters through high-accuracy forecasting, it seeks to extract energy from typhoons (disaster green energy).

For these three years since our founding, we have been busy setting up research systems, building up our research team, and forming tie-ups with many research institutions. In particular, we have launched a website called Beyond Our Planet [1] as owned media for boosting recruitment of outside personnel and have been updating the content of this site regularly with the hope of raising the visibility of NTT Space Environment and Energy Laboratories. We have increased our staff 1.5 times since our founding and have begun more than 40 collaborative tie-ups with startup companies, outside institutions, and universities. We are thus taking up the challenge of unconventional research themes in new fields that have so far been nonexistent in NTT laboratories.

As a specific example of a resilient society we are aiming for, we launched the Resilient Society Research Group in collaboration with the National Research Institute for Earth Science and Disaster

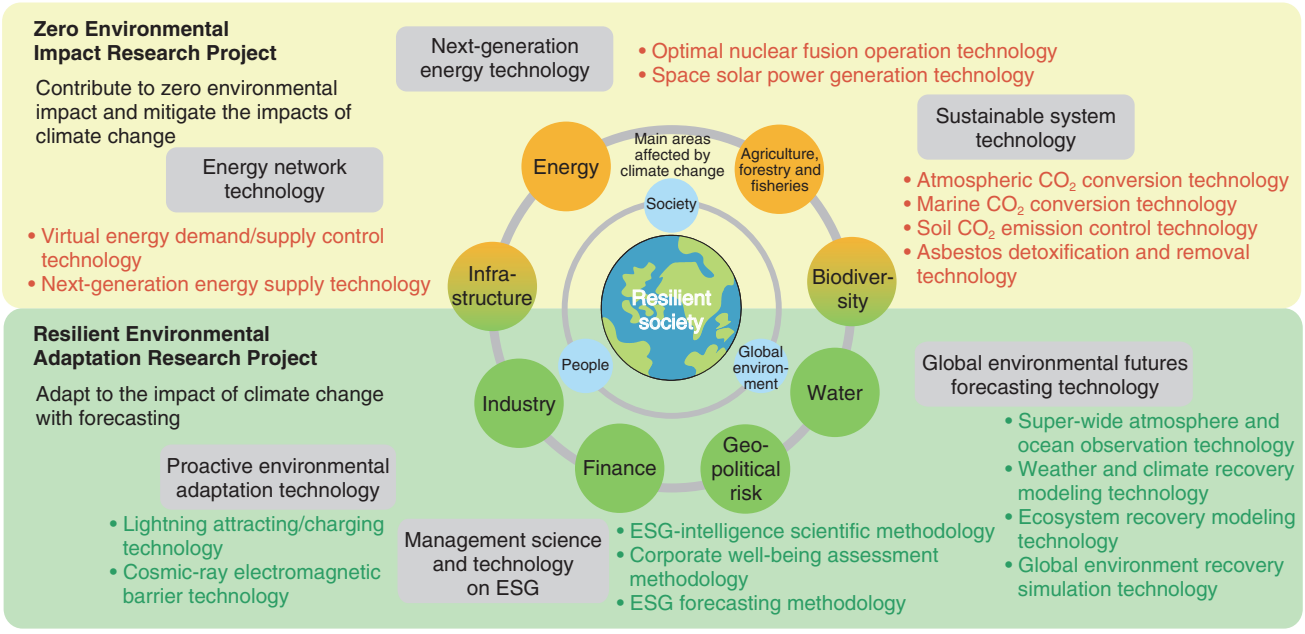


Fig. 1. Total view of research themes.

Resilience (NIED) and compiled the results of studies over a year and several months in a book titled "Realization of Resilient Society" published in April 2022 [2]. To survive a catastrophe such as an earthquake directly under the Nankai Trough or the Tokyo metropolitan area, this book investigates a resilient society that should be achieved and establishes policies for creating such a society by using new technologies based on NIED's science and technology for disaster risk reduction and NTT's Innovative Optical and Wireless Network (IOWN). It then summarizes the above in the form of joint recommendations. Since a resilient society cannot be achieved solely on the basis of technology, the book also examines new social systems and social visions that are deemed necessary together with technical innovation. Specifically, the book examines several social visions that should be adopted including a "distributed, autonomous, and cooperative society" that would eliminate the large-city, centralized type of society that excessively pursues efficiency, "Anthropocene economic society" to achieve economic growth while solving environmental problems, and "carbon-neutral and sustainable society" to coexist with the natural environment. As to how to make things better through a catastrophe, the book makes specific recommendations on "building back better."

The research themes we are now undertaking are shown in **Fig. 1**. These are divided into two main projects at NTT Space Environment and Energy Laboratories, i.e., Zero Environmental Impact Research Project at the top of the figure and Resilient Environmental Adaptation Research Project at the bottom. Each is further divided into three research groups that cooperate with one another in moving research forward. As shown at the center of the figure, our aim is to apply the results of our research to eight areas impacted by climate change and create a resilient society by reducing the impact of climate change while maintaining a balance amongst the global environment, society, and individuals. The following provides an overview of each project.

2. Zero Environmental Impact Research Project

In this project, our research aims to contribute to zero environmental impact as part of the NTT Group's Environment and Energy Vision. We are particularly researching energy network technology to supply renewable energy with good efficiency, next-generation energy technology for creating thoroughly green energy, and sustainable system technology for converting carbon dioxide (CO_2).

Energy network technology will make maximum use of renewable energy. For example, virtual energy demand/supply control technology will absorb the

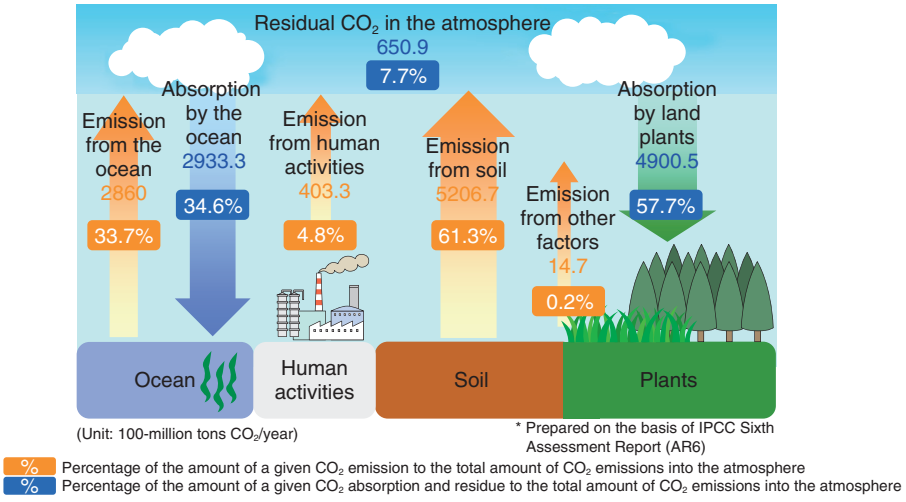


Fig. 2. The overall picture of global CO_2 flux.

output fluctuations in renewable energy by integrating control of the information processing workload of information and communication technology equipment in NTT's datacenters with control of storage batteries and electric vehicles. In addition, next-generation energy supply technology will make safe and reliable use of direct current (DC) power supplies possible and achieve the local production and local consumption of renewable energy and a super-resilient power supply. We have begun technology trials in collaboration with NTT operating companies and have obtained a variety of results such as technical specifications for the safe outdoor use of DC power supplies.

Next-generation energy technology includes optimal nuclear fusion operation technology to achieve stable and high-output operation of fusion reactors and space solar power generation technology to wirelessly transmit energy obtained in outer space to the ground in a large-capacity and efficient manner. Nuclear fusion power is a safe energy source that reproduces on Earth a phenomenon that occurs on the sun. Research in this field is now underway in countries worldwide aiming for commercialization in the 2050s. We are working with the National Institutes for Quantum Science and Technology in Japan and the ITER International Fusion Energy Organization on research related to the stable control of plasma in fusion reactors using IOWN. Next-generation energy technology also includes space solar power generation, which is an ambitious undertaking to use lasers or microwaves to wirelessly transmit energy obtained from sunlight by using geostationary satellites at an altitude of 36,000 km to the ground on a continuous 24/365 basis. To begin with, we are researching long-distance wireless power transmission on the ground and studying applying technology to supply power to drones, transmit power wirelessly to areas hit by a power outage, and use power in outer space, on the surface of the moon, etc.

The CO_2 flux throughout Earth is shown in **Fig. 2**. The numerical values in the figure are the results of calculations based on the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) published in August 2021. It may be surprising to some people that the amount of CO_2 emitted by human activities, which is associated mostly with energy use, is no more than 4.8% throughout Earth. Soil actually emits the most CO_2 at 61.3%, and even the ocean emits 33.7%. As for the amount of CO_2 absorbed, land plants absorb 57.7% while the ocean absorbs 34.6%. In short, while it is certainly important to decrease the amount of CO_2 emitted by human activities and to essentially make it zero, it is just as important when considering balance and circulation throughout Earth to consider and deal with the absorption/emission of CO_2 from the soil and ocean simultaneously with human activities. On land, where emissions are greater than the amount absorbed, decreasing emissions from the soil and increasing absorption by plants to achieve a better balance is a matter of urgency. It is likewise necessary to enhance its absorbing power of the ocean and decrease its emission of CO_2. In summary, there is a

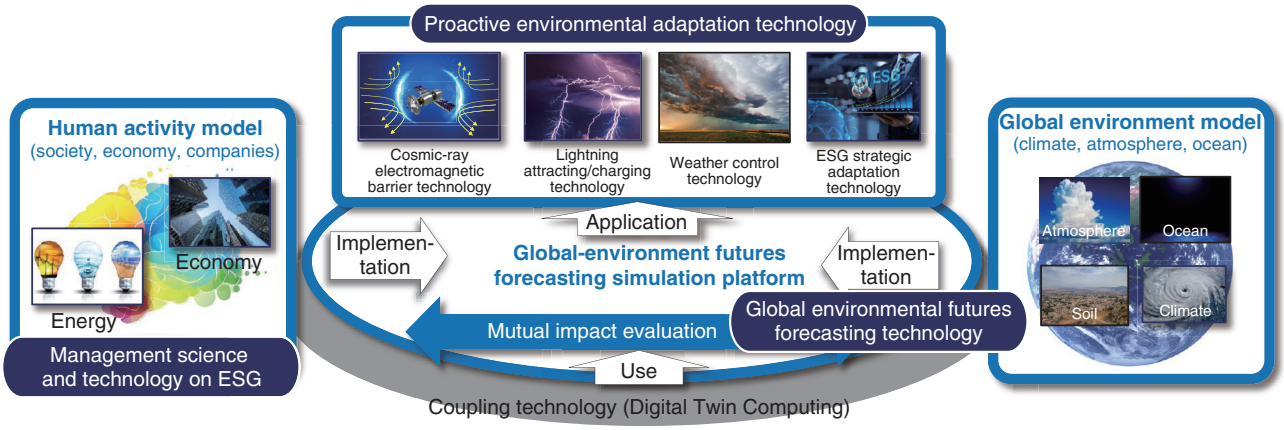


Fig. 3. Resilient Environmental Adaptation Research Project.

need to halt or reduce deforestation, soil contamination, and marine destruction/pollution while reducing CO_2 emission caused by human activities.

Sustainable system technology thus involves the research of CO_2 conversion technology for reducing CO_2 in the atmosphere, water, and soil. Specifically, we are researching the application of genome editing to plants and algae to increase CO_2 absorption and reduce CO_2 in the atmosphere in relation to the food chain and food circulation while increasing long-term fixation of carbon in the ground, in living organisms, and organic matter. We are also actively forming tie-ups with startup companies such as Regional Fish Institute, Ltd. and Euglena Co., Ltd. and expanding such activities. We are also researching the use of laser light to detoxify asbestos in construction materials.

3. Resilient Environmental Adaptation Research Project

The Resilient Environmental Adaptation Research Project has been undertaking two key research themes: management science and technology on environmental, social, and governance (ESG) and proactive environmental adaptation technology for making ultrahigh-accuracy forecasts of the global environment and society and avoiding/reducing risk. As part of this project, the Global Environmental Futures Forecasting Technology Group was established in October 2021 to boost research and development on forecasting the global environment and society on the basis of the analysis of measurement data obtained from outer space and the overall global environment (**Fig. 3**). Management science and technology on ESG seeks to construct a forecast model of human society and the economy and global environmental futures forecasting technology seeks to construct a forecast model of the climate, weather, and oceans. Coupling these two models to achieve high-accuracy forecasts on the global environment will contribute to the creation of a resilient society that can proactively and preemptively adapt to changes in the global environment.

In management science and technology on ESG, we are researching ways of forecasting in terms of human society and environmental impact. Our aim is to formulate ESG-related management strategies so that the NTT Group can resiliently adapt to even unpredictable risks to society and the economy. Since this is a new academic field, we have been conducting a variety of surveys and analyses, automating the sorting and collection/analysis of information sources, and holding discussions with outside institutions. Going forward, we plan to launch seminars and workshops at academic societies and test future predictions in actual business.

With global environmental futures forecasting technology, we aim to clarify the path to regenerating the global environment and achieve a resilient society that can adapt to changes in the environment. We will make wide-area observations of the atmosphere and oceans to create high-accuracy weather and climate models that are based on physical processes on Earth and ecosystem models that are based on biological and chemical processes on Earth. We will then use these models to forecast global regenerative processes. In this regard, there are currently few real-time observations of ocean water vapor or undersea

characteristics that act as energy sources of extreme weather such as typhoons and linear rainbands, so this is an unexplored area. We are therefore researching this area in collaboration with Okinawa Institute of Science and Technology Graduate University, Japan Agency for Marine-Earth Science and Technology, and Typhoon Science and Technology Research Center in the Institute of Advanced Sciences, Yokohama National University to measure and analyze these characteristics using satellite Internet of Things [3] and create advanced weather and climate models.

Finally, with proactive environmental adaptation technology, we are researching means of proactively adapting to lightning and cosmic rays that can now be predicted to some extent. We are researching technology for preventing damage by lightning strikes to critical facilities by using drones to attract and guide lightning to a desired location and technology for storing and using the electrical energy of lightning. After completing testing of lightning-resistant drones using artificial lightning, we conducted tests using natural lightning up to March 2022 in Uchinada Town, Ishikawa Prefecture, the area in Japan with the most lightning in winter. We will continue this testing this winter to firmly establish this technology.

The National Institute of Information and Communications Technology reports on the impact of cosmic rays, which are caused by solar activity, in the form of space weather forecasts. Cosmic rays can cause software errors and erroneous operation in semiconductors mounted on communications equipment, and technology for evaluating these errors has been advancing for some time. To further this development, we are evaluating the impact of cosmic rays on space equipment and the human body and researching cosmic-ray electromagnetic barrier technology for reducing the impact of powerful electromagnetic fields. Looking to the future, we plan to develop proactive cosmic-ray protection technology for use in outer space at locations such as space datacenters and the surface of the moon that are impacted directly by cosmic rays.

4. Conclusion

The research introduced in this article is still in its infancy, but the Feature Articles in this issue will take up several themes in which real results are starting to appear [4–7]. Readers can look forward to continued growth at NTT Space Environment and Energy Laboratories as we take up the challenge of creating innovative technologies in the fields of environment and energy from the viewpoint of space.

References

[1] Beyond Our Planet (in Japanese), https://www.rd.ntt/se/media/

[2] Resilient Society Research Group and Y. Takashima, "Realization of Resilient Society," Nikkei BP Consulting, Tokyo, Japan, 2022 (in Japanese).

[3] Press release issued by NTT on May 29, 2020 (in Japanese). https://group.ntt/jp/newsrelease/2020/05/29/200529a.html

[4] Y. Toriumi, Y. Fujiwara, H. Minami, N. Nakamura, and T. Tanaka, "Next-generation Energy Technology Contributing to Zero Environmental Impact," NTT Technical Review, Vol. 21, No. 2, pp. 22–27, Feb. 2023.
https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202302fa2.html

[5] K. Sakoda, M. Ito, S. Imamura, and K. Takaya, "CO_2 Conversion and Emission-control Technologies toward Carbon Neutrality," NTT Technical Review, Vol. 21, No. 2, pp. 28–32, Feb. 2023.
https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202302fa3.html

[6] A. Koyama, X. Zhang, M. Hisada, and M. Hara, "Technology for Forecasting the Global Environment and Human Society," NTT Technical Review, Vol. 21, No. 2, pp. 33–38, Feb. 2023.
https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202302fa4.html

[7] T. Ikeda, M. Maruyama, H. Iwashita, T. Masuda, A. Nagao, F. Ishiyama, Y. Hiroshima, and R. Kiuchi, "Proactive Environmental Adaptation Technology to Ensure Safe and Secure Living Conditions Even under Extreme Natural Phenomena," NTT Technical Review, Vol. 21, No. 2, pp. 39–44, Feb. 2023.
https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202302fa5.html

Yuji Maeda
Vice President, Head of NTT Space Environment and Energy Laboratories.

He received a Ph.D. in systems information science from Future University Hakodate, Hokkaido, in 2013. He joined NTT Telecommunication Networks Laboratories in 1991. He has been engaged in managing projects related to general emergency management such as those concerning natural disaster response and cybersecurity. He received the Scholarship Encouragement Award from the Institute of Electronics, Information and Communication Engineers (IEICE) in 1998. He is a senior member of IEICE and member of the Institute of Electrical and Electronics Engineers (IEEE).

Next-generation Energy Technology Contributing to Zero Environmental Impact

Yohei Toriumi, Yutaka Fujiwara, Hiroya Minami, Naomichi Nakamura, and Toru Tanaka

Abstract

With the aim of building a sustainable society, NTT Space Environment and Energy Laboratories is engaged in research toward the creation of clean and environmentally sound energy and the smart use of energy. In this article, we introduce technologies related to fusion power and space solar power, which are overwhelmingly clean and inexhaustible energy sources, virtual energy demand/supply control technology that makes the most effective use of renewable energy, and next-generation energy supply technology based on highly reliable and highly efficient direct-current power supply systems.

Keywords: innovative clean energy, renewable energy, zero environmental impact

1. Optimal operation technologies for fusion reactors

To enable fusion reactors for fusion power generation, it is necessary to maintain the stability of the burning plasma for a long time. Therefore, we aim to develop an optimal operation technology for fusion reactors to achieve high-speed control for plasma stabilization by using the Innovative Optical and Wireless Network (IOWN) and artificial intelligence/machine learning (AI/ML). For this approach, we need knowledge on fusion physics, so collaboration with partners promoting fusion research is essential. Therefore, we have concluded a comprehensive cooperation agreement with the ITER International Fusion Energy Organization (ITER Organization) [1] and a cooperation agreement with National Institutes for Quantum Science and Technology (QST) [2] to promote research and development.

In past fusion research experiments conducted worldwide, the plasma maintenance time was several tens of seconds, and the out-versus-in power amplification ratio of the fusion reaction (fusion power/total input heating power) was Q = 1.25. The ITER project, the largest fusion research project in history, was launched to further improve these characteristics. The target value of the plasma maintenance time is about 3600 s, and the out-versus-in power amplification ratio of the fusion reaction is Q = 10. Plasma control is executed by confinement magnetic field control, plasma heating control, and fuel-supply control. However, real-time control is difficult. Plasma behavior is very complicated because there are many particle species. Each has a different kinetic velocity, and different physical phenomena on a spatio-temporal scale coexist. They also all interact with each other. It takes time from measurement to analysis since the plasma fluctuates over an ultrashort period on the order of 10^{-8} s when we measure and analyze a specific event change and control to correct the plasma behavior. The response time of the control equipment is also much slower than the analysis, so the control cannot be conducted in time.

Hence, we aim to stabilize fusion plasma and increase the fusion power in two steps. First step is predicting fusion-plasma behavior in the near future with a high-speed calculation based on the time evolution data and current measurement data of fusion

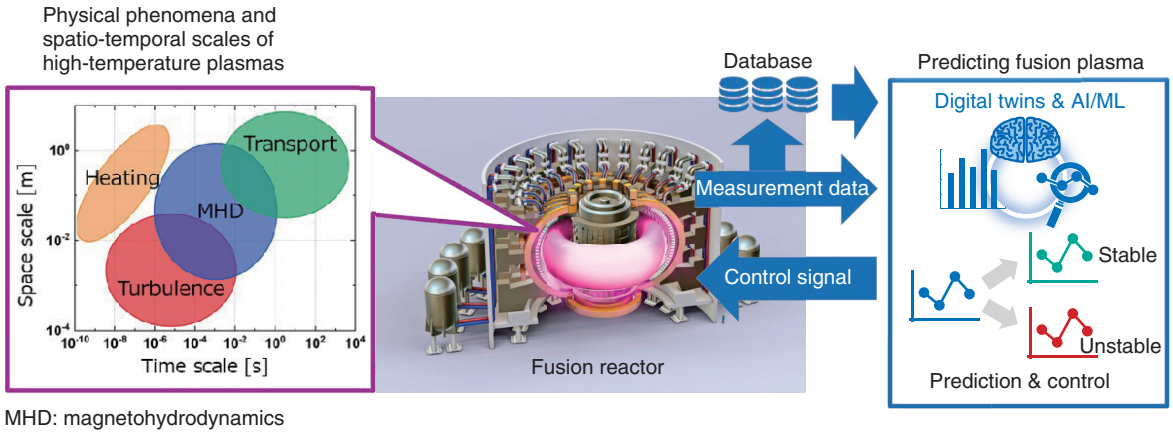


Fig. 1. Optimal fusion reactor operation by predicting fusion plasma.

plasma. The second step is proactively controlling the fusion plasma. In past operation, fusion plasma was controlled by determining the position and shape of the plasma. However, we can also control plasma instability more quickly by obtaining information on the inside of the plasma in real time. Therefore, we are developing an algorithm based on AI/ML for modeling plasma behavior. We will achieve the optimum operation of fusion reactors by combining this algorithm with a high-speed, high-capacity, and low-latency control network compared with the current control network (**Fig. 1**).

2. Space solar power system

Space solar power system technology is a technology in which energy obtained from sunlight by using a geostationary satellite 36,000 km above Earth is delivered to Earth by means of laser beam and microwaves day and night and converted into electric power and other energy for use on Earth. We focus on the laser beam, which has a smaller beam spread angle than microwaves and is easier to transmit over long distances, and are advancing research on this technology in three areas.

The first is a technology to convert sunlight gathered in space into a laser beam. Because of limits on the weight and volume of satellites, it is necessary to convert sunlight into a laser beam in the smallest possible configuration. Therefore, we are engaged in research on solar-pumped laser technology that can convert sunlight directly into a laser beam without using electric power. Thus far, we have grown Nd/Cr:YAG[*1] crystals for the laser medium, which can absorb light in the wavelength band of sunlight and produce an infrared laser beam of 1064 nm, and confirmed laser oscillation in the laboratory. We plan to optimize the composition of the crystal to achieve high efficiency and high power output, improve its durability and longevity, and develop a device that can concentrate sunlight and capture it efficiently in the laser.

The second is a technology for laser beams to be able to reach far distances accurately. The characteristics of laser beams is that they are highly linear and easily transmitted over long distances, but when transmitted over distances as far as 36,000 km, the normal laser beams spread over a range of several 10 m due to diffraction. It is also assumed that when passing through the atmosphere, the aim of the laser beam is disturbed by several meters because it is affected by atmospheric fluctuations called atmospheric disturbances. Therefore, we are studying transmission methods suitable for long-distance transmission of laser beams. Special beams, such as the Bessel beam[*2] and Laguerre-Gaussian beam[*3], which are said to be resistant to diffraction and disturbance, can be formed by phase modulation. We have verified their effects on diffraction and disturbance through simulations and ground-based transmission

*1 Nd/Cr:YAG: A crystal for a laser medium in which the absorption of light in the wavelength band of sunlight is enhanced by the addition of neodymium (Nd) and chromium (Cr) to a garnet-structured crystal composed of yttrium and aluminum complex oxide ($Y_3Al_5O_{12}$).

*2 Bessel beam: A type of non-diffracted beam in which the beam does not spread due to a diffraction phenomenon.

*3 Laguerre-Gaussian beam: A beam with circular deflection and a spirally changing phase.

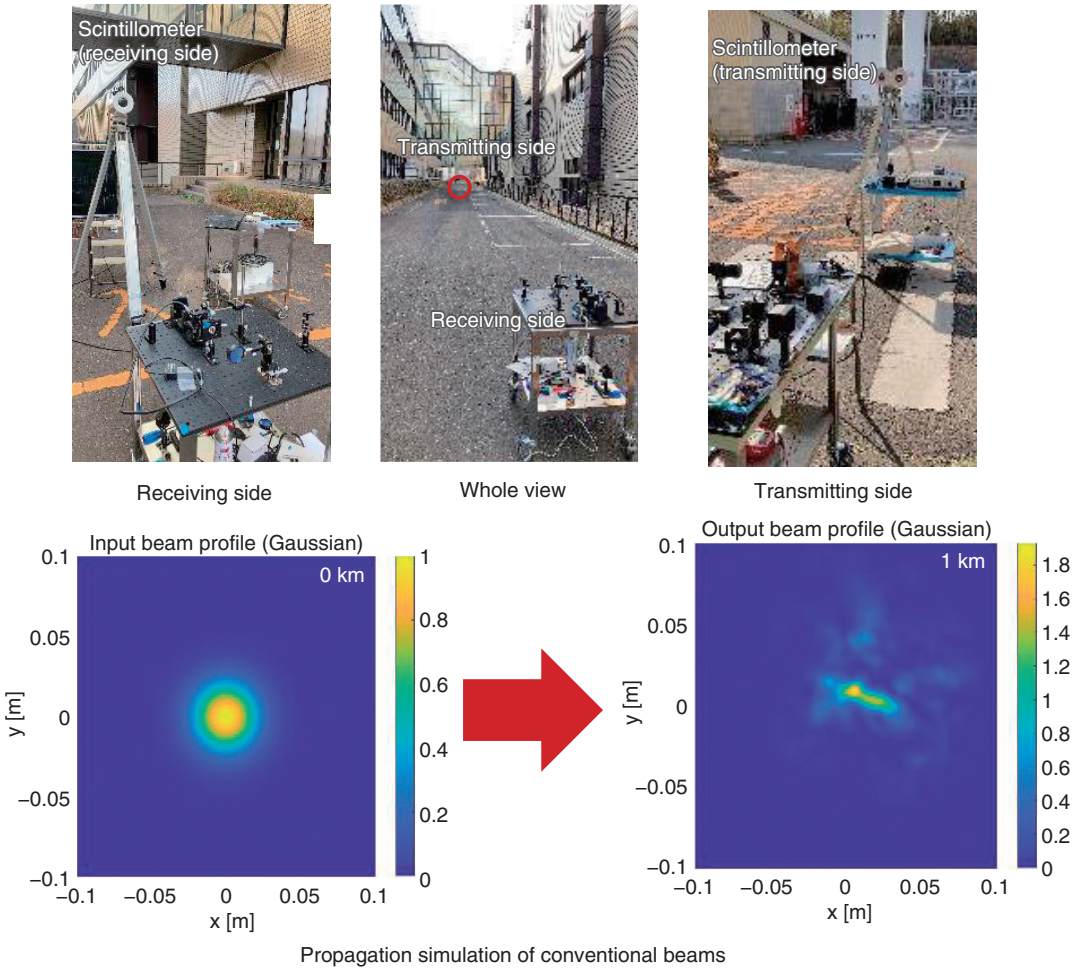


Fig. 2. Laser beam outdoor propagation experiment and propagation simulation.

experiments and are studying beams that are more resistant to disturbance and reach long distances (**Fig. 2**).

The third is photoelectric conversion technology that can withstand high-intensity laser light arriving from space and convert this light into power with high efficiency. We aim to convert laser light into electric power with a conversion efficiency that far exceeds that of conventional solar cells by developing a photoelectric conversion device tuned specifically for the wavelength of laser light. However, the theoretical limit of the conversion efficiency of compound semiconductors, which is expected to be the most feasible, is about 50%, so about half the conversion is heat. Thus, we are also studying other ways to use laser energy such as generating hydrogen and ammonia through thermochemical reactions.

3. Virtual energy demand/supply control technology

Virtual energy demand/supply control is a technology for using renewable energy more efficiently without waste by adjusting the power consumption of information and communication technology (ICT) equipment, such as servers and routers, installed in NTT's datacenters located across the country (**Fig. 3**). While expectations are rising for the large-scale implementation of renewable energy to stand against climate change, since the amount of power generated by most renewable energy sources fluctuates depending on weather conditions, it becomes more difficult to maintain a balance between supply and demand in individual regions as more renewable energy sources are introduced. Therefore, we are conducting research and development on a technology to balance power

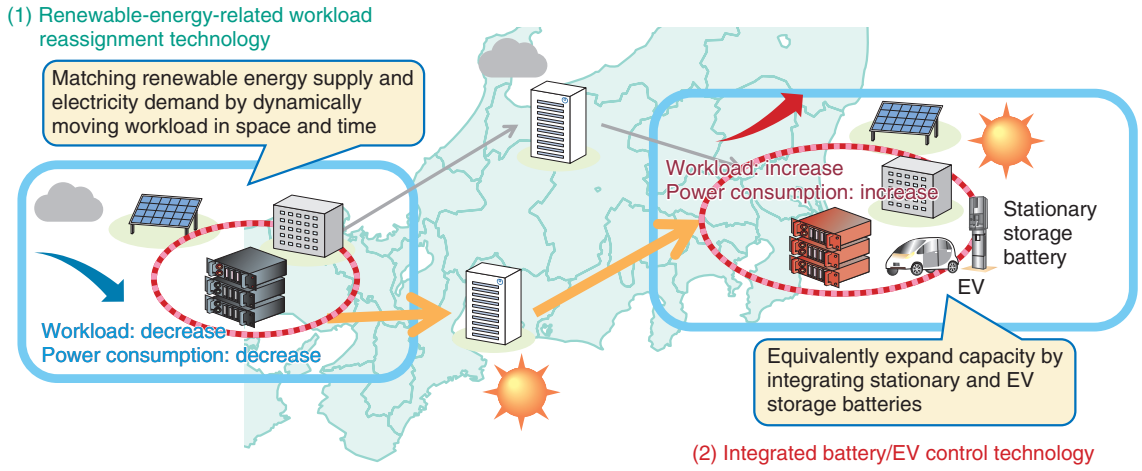


Fig. 3. Virtual energy demand/supply control technologies.

supply and demand by reassigning the information processing of ICT equipment in NTT's datacenters across regions in accordance with the gap between demand and the amount of renewable energy generation in each region (renewable-energy-related workload reassignment technology). We are also developing a technology to enhance the supply-demand adjustment capability in NTT's datacenters by providing integrated control of stationary and on-vehicle storage batteries (integrated battery/electric vehicle (EV) control technology).

Within NTT's datacenters, ICT equipment executes information and communications processing to provide a variety of services. The work processed with such equipment is generally referred to as "workload." Datacenter workloads consume power so great that datacenters are likely to benefit the most from workload reassignment. Therefore, we are focusing on developing elemental technologies for servers in datacenters. This technology consists of three phases: forecasting, optimization, and control. In the forecasting phase, we are trying to break down the power consumption of servers by workload and forecast each workload separately. In the optimization phase, we set the target power-consumption value for each timeframe and each region to reduce energy-supply-demand gaps then create a workload reassignment pattern as a control plan for achieving the target values while preventing service quality from deteriorating. This has made it possible to simultaneously handle both spatiotemporally movable workloads, such as scientific and technical computing, and spatially movable (temporally unmovable) workloads, such as virtual desktops. In the control phase, workload reassignment and communication-traffic routing are executed using virtualization technology on the basis of an optimized control plan.

We believe that the expected decentralization of datacenters will further enhance the benefits of this technology.

4. Next-generation energy supply technology

Next-generation energy supply technology makes local production for local consumption of renewable energy and resilient energy supply possible by using safe and highly reliable direct-current (DC) power supply systems. The power supply systems of NTT's telecommunication buildings supply ICT equipment with an electric power of 48 or 380 DCV and can directly supply power from storage batteries during power outages. By developing this technology established by NTT, we aim to distribute power combining DC power and renewable energy in the area around NTT's telecommunication buildings and to provide safe power supply without power outages even during disasters. Since the storage battery is directly connected to the power supply line, stable power supply is possible even if electromagnetic pulses of HEMP (high-altitude electromagnetic pulse) or cosmic rays come down to the ground. Therefore, this power supply technology is expected to be less affected by cosmic rays from solar flares caused by solar activity, which is expected to increase in 2025.

Forming a DC microgrid enables power interchange among a number of consumer buildings with

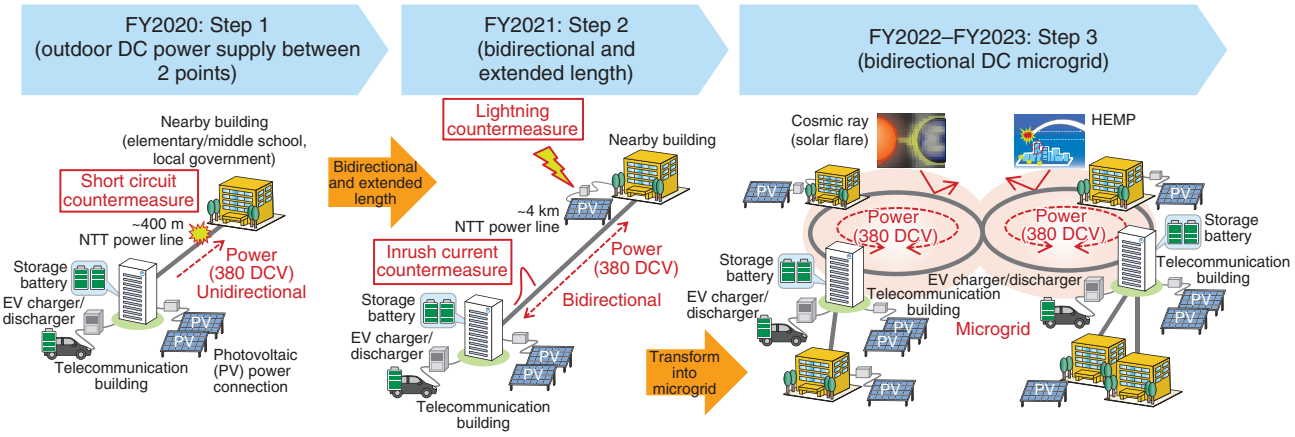


Fig. 4. Steps toward building a DC microgrid.

distributed energy resources as well as power-outage risk reduction. To implement this system, we are proceeding using 380 DCV with a three-step study, as shown in **Fig. 4**. In FY2020, as step 1, we implemented technology that enables a one-to-one connection between an NTT telecommunication building and elementary and junior high schools that serve as evacuation shelters. The power supply distance is 400 m or less. For short-circuit accidents that occur when the plus and minus of a power supply line are connected, we implemented electrical safety technology by assembling a conventional fuse and overcurrent protection function (gate block) inside the DC-power-supply device.

In FY2021, as step 2, we promoted the development of technology to extend the power supply distance (4 km) from an NTT telecommunication building to a consumer building and technology to bidirectionally supply power. As the power supply distance increases, the impedance component (inductance component against the resistance component) of the power supply line increases. Therefore, when the power is turned on, the voltage drop, which is caused by an inrush current, increases. This shows the high possibility that the DC-power-supply device will stop. Therefore, we clarified the relationship between the power supply distance and value of the voltage drop due to the capacitance of the capacitor and derived the conditions necessary to avoid equipment outages.

Regarding the bidirectional power supply technology, when a number of photovoltaic power (PV) systems and bidirectional EV chargers are installed in consumer buildings, the risk of lightning surges entering the NTT telecommunication building via power supply lines increases because the ground potential increases when a lightning strikes these systems. Therefore, by focusing on potential equalization, which is the basis of lightning countermeasures, and clarifying the conditions for connecting various ground electrodes safely and effectively, the rise in ground potential can be prevented without adding new countermeasure systems. Then, the risk of lightning surges entering telecommunication buildings decreases.

Using these technologies, in collaboration with NTT Anode Energy, we are conducting demonstrations of power backup for evacuation shelters during disasters, with the aim of developing a smart energy system for Chiba City. As step 3, we will proceed with research on DC microgrids and work on DC-power-supply resistance to solar flares that are expected to increase in 2025.

5. Future developments

Toward the creation of innovative energy, for optimal operation of fusion reactors, we will collaborate with the ITER Organization and QST to advance technology demonstrations that will lead to the success of experimental fusion reactors and actualization of fusion power generation, and in the field of space solar power system technology, we will advance the early deployment of technologies such as energy transmission on the ground while developing technologies in space. For the effective use of renewable energy, which will be introduced in large quantities in the future, we aim to achieve local production for

local consumption of energy by promoting demand/supply control in multiple buildings using virtual energy demand/supply control technology and enable new power accommodation and resilient power supply with DC microgrids using next-generation energy supply technology. We will aim for zero environmental impact by establishing these technologies.

References

[1] Press release issued by NTT, "Conclusion of a Cooperation Agreement with ITER - First Private Japanese Company to Have a Long Term Non-commercial Cooperation Agreement with the ITER Organization -," May 15, 2020. https://group.ntt/en/newsrelease/2020/05/15/200515c.html

[2] Press release issued by NTT on Nov. 6, 2020 (in Japanese). https://group.ntt/jp/newsrelease/2020/11/06/201106a.html

Yohei Toriumi
Senior Research Engineer, Next-Generation Energy Technology Group, NTT Space Environment and Energy Laboratories.
He received a B.E. and M.E. in electrical and electronics engineering from Tokyo Institute of Technology in 2003 and 2005. He joined NTT in 2005, and his research interests include energy systems and laser applications.

Yutaka Fujiwara
Senior Researcher, Next-Generation Energy Technology Group, NTT Space Environment and Energy Laboratories.
He received a B.S. in mechanical and aerospace engineering from Utah State University, USA, in 2009. He also received an M.E. and Ph.D. in engineering mechanics and energy from the University of Tsukuba, Ibaraki, in 2014 and 2017. He worked at National Institute for Fusion Science as an assistant professor in 2017 and joined NTT in 2021.

Hiroya Minami
Senior Research Engineer, Energy Network Technology Group, Zero Environmental Impact Research Project, NTT Space Environment and Energy Laboratories.
He received a B.E. and M.E. from Seikei University, Tokyo, in 1994 and 1996. He joined NTT in 1996 and has been engaged in research on traffic technologies of communications systems, ubiquitous systems, and service delivery platforms. He received the Young Engineer's Award from the Institute of Electronics, Information and Communication Engineers (IEICE) in 2003. He is a member of IEICE.

Naomichi Nakamura
Senior Research Engineer, Energy Network Technology Group, Zero Environmental Impact Research Project, NTT Space Environment and Energy Laboratories.
He received a B.E. in physics from Nihon University, Tokyo, in 2004 and M.E. in nanoscience and nanoengineering from Waseda University, Tokyo, in 2006. He joined NTT laboratories in 2006 and studied electromagnetic compatibility technology for telecommunication. He has been researching and developing methods of lightning protection and grounding for telecommunication systems.

Toru Tanaka
Senior Research Engineer, Supervisor, Zero Environment Impact Research Project, NTT Space Environment and Energy Laboratories.
He received a B.E. and M.E. in quantum science and energy engineering from Tohoku University, Miyagi, in 1996 and 1998. He joined NTT Integrated Information and Energy Systems Laboratories in 1998. He developed high-voltage DC power supply systems for telecommunication buildings and datacenters. From 2009 to 2012, he was a manager at NTT FACILITIES, where he developed power supply systems and smart community. He received the 2003 and 2009 Shibusawa Award of The Japan Electric Association (JEA). He is a certified Professional Engineer, Japan (P.E.Jp) in electrical & electronics engineering. He is a member of IEICE.

CO_2 Conversion and Emission-control Technologies toward Carbon Neutrality

Kazuma Sakoda, Manami Ito, Sousuke Imamura, and Kazuhiro Takaya

Abstract

This review outlines two technologies contributing to carbon neutrality: (1) efficiently converting atmospheric and oceanic carbon dioxide (CO_2) into organic matter by improving the carbon-fixation capacity of plants and algae, and (2) reducing CO_2 emissions from soil by controlling the organic-matter decomposition induced by microorganisms.

Keywords: carbon neutrality, genome-editing technology, biogeochemical cycle

1. Three strategies to reduce atmospheric CO_2 level

The absorption and emission of carbon dioxide (CO_2) occur through biological activities, and their balance significantly impacts the atmospheric CO_2 level on Earth (**Fig. 1**). Compared with the total amount of CO_2 emissions to the atmosphere, the amount of CO_2 absorption by land plants for photosynthesis*1 and by the ocean is 57.7 and 34.6%, respectively [1], whereas the amount of CO_2 emissions from soil accounts for 61.3%. NTT Space Environment and Energy Laboratories is developing three technologies to (1) reduce atmospheric CO_2 with a focus on plants, (2) reduce oceanic CO_2 with a focus on the food chain between algae and fish/shellfish, and (3) control CO_2 emissions from soil with a focus on organic-matter decomposition induced by microorganisms.

2. Conversion technology for atmospheric and oceanic CO_2

Plants and algae absorb CO_2 from the surrounding environment into their bodies and synthesize organic matter from CO_2 by using light energy (i.e., carbon fixation) for their growth. The enhancement of the CO_2 fixation capacity in these organisms has the potential to accelerate their growth and CO_2 absorption, ultimately contributing to a reduced level of atmospheric and oceanic CO_2. This section introduces research on reducing atmospheric and oceanic CO_2 levels by enhancing the carbon-fixation capacity in plants and algae.

2.1 Conversion technology for atmospheric CO_2 focusing on plant photosynthesis

Plants in nature are exposed to not only favorable conditions but unfavorable ones such as high temperatures, drought, and water lodging. To enhance the carbon-fixation capacity of plants, it would be effective to increase the CO_2 assimilation amount per unit time, lengthen the period of carbon fixation, and stabilize carbon fixation under unfavorable conditions. One promising pathway toward these goals is to reveal the genes involved in each biological process then modify the gene functions by genetic engineering. Here, we consider a case aimed at increasing the CO_2 assimilation rate as an example. The whole

*1 Photosynthesis: A biochemical reaction in plants and algae that synthesizes organic compounds from CO_2 using light energy.

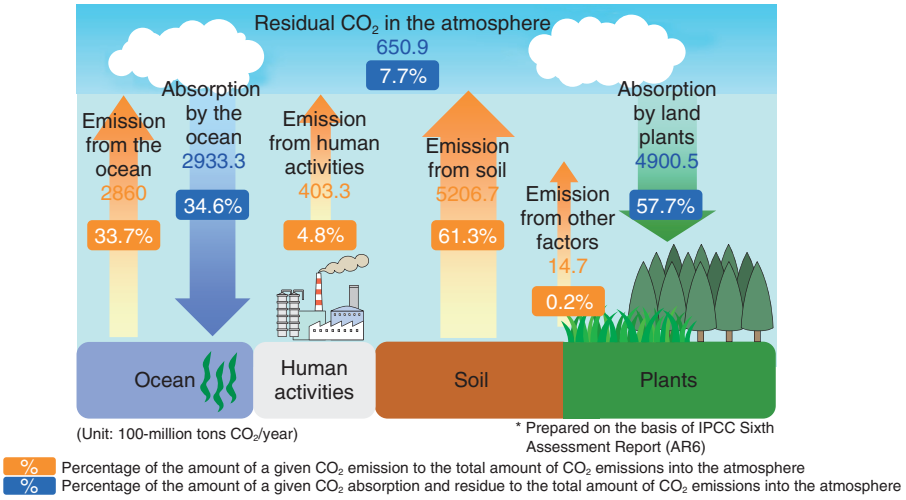


Fig. 1. The overall picture of global CO_2 flux.

process of CO_2 assimilation by plants can be mainly divided into two processes: the CO_2 diffusion process from the atmosphere to the chloroplast stroma and the CO_2 fixation process consisting of various biochemical reactions at the chloroplasts. Previous studies have revealed the genes functioning in the regulation of both processes. Modification of those genes by genetic engineering was reported to increase the CO_2 assimilation rate. On the other hand, most studies have been conducted under fully controlled conditions in a laboratory environment, while only a few have demonstrated reproducibility in the field. The genes that have been validated are only a small part of a vast number of genes in plants, indicating that most genes are untapped for enhancing carbon-fixation capacity.

To enhance the carbon-fixation capacity of plants, we are planning to (1) select target genes, (2) improve genetic engineering tools, and (3) develop genetically modified plants with target genes and assess their carbon-fixation capacity. First, we have selected target genes with the potential to enhance carbon-fixation capacity considering previous studies and our own experiments. We focus on genome-editing technology[*2] as a genetic engineering tool, for modifying the target genes in plants without genetic recombination. We aim to improve the accuracy and efficiency of applying this technology to plants, while establishing a novel technique for genome editing. We are also developing a plant-cultivation system that can evaluate both environmental conditions and plant phenotypes such as growth and CO_2 assimilation rate in the same time sequences, making it possible to quantify the impact of genome editing on the carbon-fixation capacity in plants. In the future, we will expand the experimental conditions to field environments and apply the obtained knowledge to woody and crop plants. This could lead to the development of plants with a great ability for carbon fixation and food production.

2.2 Conversion technology for oceanic CO_2 focusing on food chains

To enhance the carbon-fixation capacity in algae, we are planning to select target genes, develop genome-edited algae, and evaluate their carbon-fixation capacity. Algae have a short growth cycle, which makes them unable to keep organic matter produced by photosynthesis in their body for long periods. It would be, thus, important for the carbon fixed by algae to accumulate in other living organisms with a long growth cycle for reducing oceanic CO_2 levels. To achieve this, we are focusing on the food chain between algae and fish/shellfish in the ocean [2]. The carbon fixed by algae is delivered and deposited into the bodies of fish and shellfish through the food chain. We are planning to apply genome-editing technology to algae to increase the carbon-fixation capacity and growth rate, and to fish and shellfish to increase the growth rate and deposited carbon amount in shells and cartilage (**Fig. 2**) in collaboration with

*2 Genome-editing technology: Technology to modify targeted base sequences on the genome of an organism.

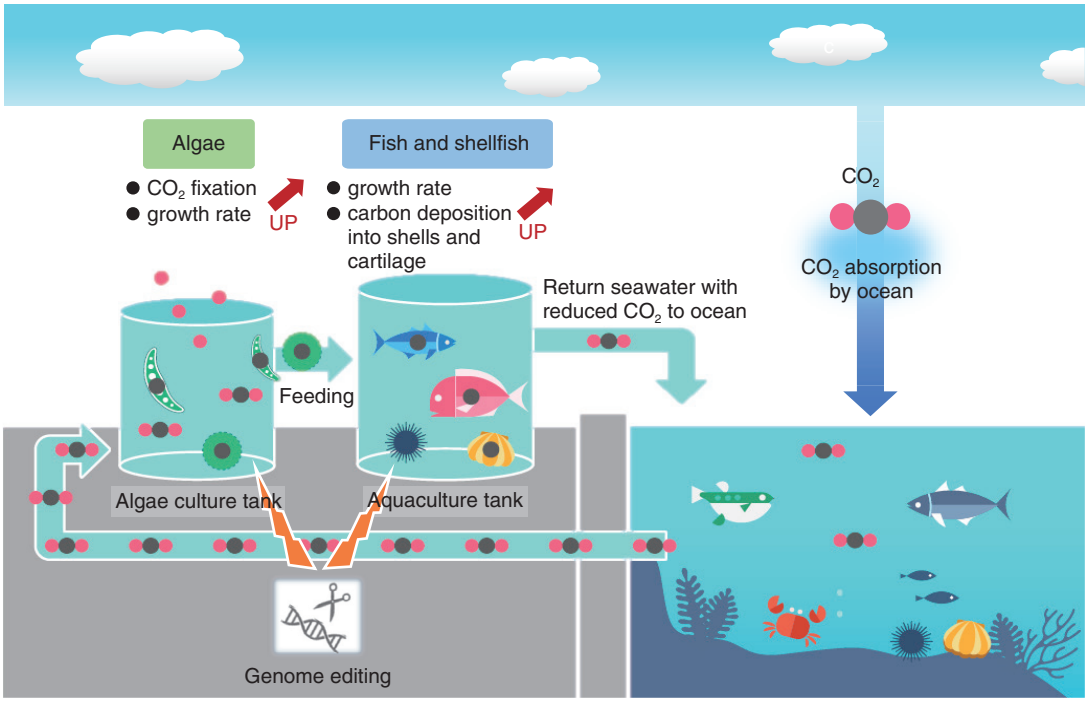


Fig. 2. Demonstrative model of oceanic CO_2 reduction by applying genome-editing technology to algae and fish/shellfish.

Regional Fish Institute, Ltd. This has the potential to increase and prolong carbon fixation using the synergistic effect between algae and fish/shellfish. We have been examining the optimal combination of algae and fish/shellfish and favorable feeding conditions by using a land-based aquaculture system. This system allows us to conduct experiments using genome-edited organisms without the risk of them leaking into the marine ecosystem. In the future, we will apply genome-editing technology to a single optimal combination of algae and fish/shellfish then test whether it is effective for reducing oceanic CO_2 levels.

3. Control technology of CO_2 emissions from soil

Various types of organic matter, such as animal waste, dead leaves, and plant roots, accumulate in soil. This organic matter is decomposed into inorganic matter by living organisms, and the inorganic matter is taken up by plants for synthesis into organic matter. Through this biogeochemical cycle, CO_2 is generated mainly during organic-matter decomposition induced by microorganisms in soil (**Fig. 3**). Therefore, controlling organic-matter decomposition can lead to technology for reducing CO_2 emissions from soil. This section introduces research on reducing CO_2 emissions from soil by controlling organic-matter decomposition.

To reduce CO_2 emissions from soil by controlling organic-matter decomposition, the following question needs to be answered; "how much organic matter is decomposed and by which factors, causing CO_2 to be emitted from soil?" Soil is characterized by three aspects, biological characteristics (the type and number of organisms), chemical characteristics (the type and amount of chemicals), and physical characteristics (hardness and breathability), and these affect the organic-matter decomposition while interacting with each other. When plants grow in soil, they show high photosynthetic activity under rich nutrient conditions and secrete organic matter from their roots into the soil. Soil characteristics and plant growth also affect organic-matter decomposition through their interactions. In addition, soil characteristics and plant growth are affected by environmental conditions such as temperature and water content. Overall, it would be essential to clarify the relationship between CO_2 emissions and soil characteristics, plant growth, and environmental conditions to develop technology to reduce CO_2 emissions from soil.

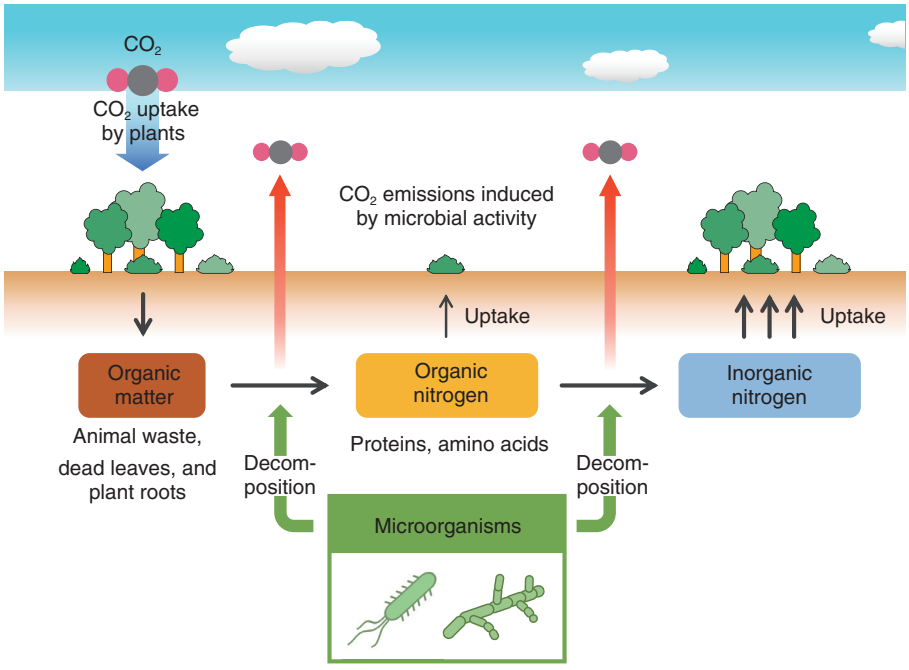


Fig. 3. CO_2 emissions from soil through organic-matter decomposition.

To develop such technology, we are planning to (1) obtain and analyze a large-scale dataset including soil characteristics, plant growth and photosynthetic activity, environmental conditions, and soil CO_2 emissions then (2) develop a mathematical model simulating the soil CO_2 emission process. We are currently developing a system that enables high-throughput collection of the dataset by using information and communication technology and Internet of Things (IoT) for plant cultivation and various measurements. The soil CO_2 emission process has a complex network structure in which various factors interact with each other. Analyzing the obtained dataset by using artificial intelligence technology, we will attempt to obtain a picture of the network and elucidate the mechanism underlying soil CO_2 emissions. This would enable mathematical modeling of the CO_2 emission process through organic-matter decomposition and clarify the conditions required for reducing soil CO_2 emissions under given environments. These achievements might contribute to the development of technologies for agricultural production and forest management with reduced environmental impact.

It is important to develop technology that both reduces soil CO_2 emissions and maintains plant growth suitable for agricultural and forest ecosystems. While CO_2 is generated through the decomposition of organic matter into inorganic matter in soil, plants uptake inorganic matter such as inorganic nitrogen[*3], a major nitrogen source, for their growth. A reduced amount or decomposition of organic matter in soil could reduce CO_2 emissions but inhibit plant growth. One pathway to balancing soil CO_2 emission and plant growth is to control the microorganism activity so that CO_2 generation through organic-matter decomposition declines. However, this is very challenging because there are a huge number and variety of microorganisms in soil, and the ecology of most microorganisms remains unknown. Another pathway is to develop plants showing a high availability of organic nitrogen[*4]. Several plants species have been reported to uptake organic nitrogen for their growth, and there is an interspecific variation in them, but the underlying mechanisms are largely unknown. We are currently searching for the genes involved in the uptake of organic nitrogen by plants. In the future, we will develop plants that show vigorous growth even under low inorganic-nitrogen levels

*3 Inorganic nitrogen: A general term for nitrogen compounds containing no carbon, such as ammonium nitrogen, nitrite nitrogen, and nitrate nitrogen.

*4 Organic nitrogen: A general term for nitrogen compounds containing carbon, such as proteins, peptides, and amino acids.

by applying genome editing to identified genes. This has the potential to achieve crop production with a low supply level of chemical fertilizer including inorganic nitrogen, which is important in terms of saving resources and preventing environmental pollution.

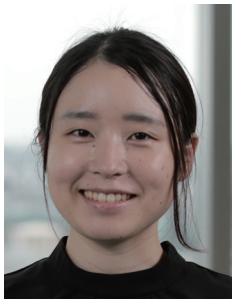
4. Future perspectives

In this article, we outlined the technologies we are developing for CO_2 conversion and emission control. For CO_2 conversion technology to be practical, it needs to be provided as a packaged technology considering the use or storage of the produced organic matter. We are developing packaged technology for CO_2 conversion and utilization in algae focusing on the food chain in the ocean, and a similar attempt will be carried out for plants. Controlling the organic-matter decomposition in soil is key for CO_2-emission control technology but must be compatible with the activities of living organisms in ecosystems. Under this context, we are planning to construct a simulation model to assess the impact of controlling organic-matter decomposition on the entire ecosystem. We will promote the practical use of these technologies to achieve carbon neutrality while preserving the environment, food production, and biodiversity.

References

[1] The Intergovernmental Panel on Climate Change (IPCC), "Sixth Assessment Report," https://www.ipcc.ch/assessment-report/ar6/
[2] Website of NTT R&D, "Research on Reducing CO_2 in the Ocean through the Application of Genome Editing Technology to the Carbon Cycle of Algae, Fish, and Shellfish," https://www.rd.ntt/e/research/JN202203_17553.html

Kazuma Sakoda
Researcher, Sustainable System Group, Zero Environmental Impact Research Project, NTT Space Environment and Energy Laboratories.
He received a Ph.D. in agricultural science from Kyoto University in 2019. He worked as a JSPS (Japan Society for the Promotion of Science) Research Fellow at Kyoto University from 2019 to 2020 and the University of Tokyo from 2020 to 2022. He was in the Department of Plant Biology and Institute for Genomic Biology, University of Illinois in 2016 and the Division of Plant Science, Research School of Biology, the Australian National University in 2019 as a visiting scholar. He joined NTT Space Environment and Energy Laboratories in 2022 and is currently studying technology for reducing atmospheric CO_2 levels by enhancing the capacity of plant photosynthesis. He is a member of the Crop Science Society of Japan and the Japanese Society of Plant Physiologists.



Manami Ito
Researcher, Sustainable System Group, Zero Environmental Impact Research Project, NTT Space Environment and Energy Laboratories.
She received a B.E. and M.E. in control engineering from the Tokyo Institute of Technology in 2015 and 2017 and is now a Ph.D. student. She joined NTT Secure Platform Laboratories in 2017 and studied IoT security and TEE (Trusted Execution Environment). In 2020, she requested a transfer to her current group to study greenhouse gas reduction through a biological approach. She is a member of the Japanese Society of Microbial Ecology.

Sousuke Imamura
Distinguished Researcher, Sustainable System Group, Zero Environmental Impact Research Project, NTT Space Environment and Energy Laboratories.
He received a Ph.D. from the Tokyo University of Agriculture and Technology in 2005 and was a JSPS Research Fellow at the University of Tokyo from 2005 to 2009. He joined Chuo University as an assistant professor in 2009. In 2012, he was appointed as an associate professor at the Tokyo Institute of Technology. In 2019, he was at the Institute for Plant Biochemistry, Heinrich-Heine-University Düsseldorf as a visiting professor. In March 2021, he joined NTT Space Environment and Energy Laboratories as a distinguished researcher. His research interests include the regeneration of the global environment using photosynthetic organisms, especially algae, with molecular biology approaches.
He received prestigious awards from the Society of Genome Microbiology, Japan, in 2010 and the Nagase Science and Technology Foundation in 2017. He is a member of the Japan Society for Bioscience, Biotechnology, and Agrochemistry, the Japanese Society of Plant Physiologists, the Society of Genome Microbiology, Japan, and the Japanese Society of Photosynthesis Research.

Kazuhiro Takaya
Senior Research Engineer, Supervisor, Sustainable System Group, Zero Environmental Impact Research Project, NTT Space Environment and Energy Laboratories.
He received a B.E. and M.E. in electrical and electronic engineering from Okayama University in 1993 and 1995 and Ph.D. in electrical engineering from Kyoto University in 2019. He has been engaged in research on CO_2 conversion technologies using electrochemistry and biology.

Technology for Forecasting the Global Environment and Human Society

Akira Koyama, Xiaoxi Zhang, Masaki Hisada, and Minako Hara

Abstract

NTT Space Environment and Energy Laboratories aims to contribute to achieving sustainable corporate growth and a resilient society by proactively adapting to changes in the social and natural environment on the basis of highly accurate forecasts of the global environment and human society. In this article, we introduce two technologies. One is global environmental futures forecasting technology for clarifying Earth's regeneration process by linking global-scale observations and modeling of the physical, biological, and chemical processes of Earth and simulating these processes. The other is management science and technology on environmental, social, and governance (ESG) for supporting the formulation of corporate ESG management strategies by predicting the future of human society and environmental impact.

Keywords: global environment, ESG management, future prediction

1. Introduction

The Sustainable Development Goals adopted by the United Nations in 2015 encourage private sector actors to solve social problems as businesses, and attention is being paid to corporate responses to social problems such as poverty, greenhouse gas emission reduction to mitigate climate change, and adaptation measures to reduce the impact of climate change. To achieve sustainable growth under these conditions, financial indicators as well as non-financial indicators need to be considered. We are also witnessing the emergence of previously unforeseeable events such as disasters caused by extreme weather, global pandemics, and armed conflicts. With this background, the NTT Group has set an ambitious environmental and energy vision to achieve both economic growth and zero environmental impact. To contribute to this vision, this article introduces the global environmental futures forecasting technology and management science and technology on environmental, social, and governance (ESG) that enable proactive and flexible responses to the rapidly changing global environment and global situation on the basis of highly accurate forecasts of the global environment and human society.

2. Global environmental futures forecasting technology

Global environmental futures forecasting technology reveals the potential regenerative processes of the global environment and enables the global environment to be forecast through observations, modeling, and simulating physical phenomena such as climate, weather, and physical processes in the ocean, as well as biological and chemical phenomena such as ecosystem circulation and carbon cycles over large areas. The ocean, which covers about 70% of Earth's surface, is a largely unexplored area that has not been directly observed in real time, despite its great effect on extreme weather such as typhoons and liner

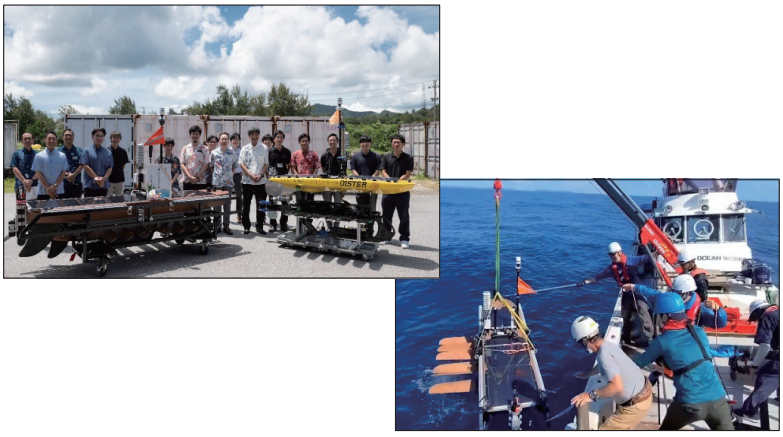


Fig. 1. Atmospheric and ocean autonomous observation system (Seiuchi-san) and dropping it into the sea.

rainbands. We are working on observing and modeling physical phenomena such as weather using satellite Internet of Things (IoT) technology [1]. This article introduces an experiment involving atmospheric and oceanic observations conducted with the Okinawa Institute of Science and Technology Graduate University (OIST) to improve the accuracy of extreme weather forecasting and a modeling study of marine ecosystems incorporating biological and chemical processes.

2.1 Efforts to forecast extreme weather

Extreme weather events, such as typhoons and linear rainbands, have been occurring frequently. To improve accuracy in extreme weather forecasting, it is important to observe the interaction between the atmosphere and ocean as well as improve the accuracy of numerical forecasting models. Ocean temperature and humidity as well as ocean surface and underwater temperature need to be directly observed to improve forecasting accuracy, but the number of sensors is insufficient, making observations along the path of typhoons very difficult. The area directly under a typhoon is very difficult to observe because of the harsh environment in which storms and high waves occur. To conduct real-time ocean observations directly under typhoons, we developed the atmospheric and ocean autonomous observation system "Seiuchi-san" that can autonomously record observations for long periods without human intervention. In July 2022, we commenced observations offshore of Okinawa in collaboration with OIST (**Fig. 1**). We observed the area near the center of Typhoon Hinnamnor in August 2022. For future work, we will analyze the experimental data to improve accuracy of typhoon forecasts and research real-time continuous observation techniques in the ocean near Japan to improve the accuracy of extreme weather forecasts. We will attempt to broaden the scope of observations in the ocean near Japan as well as in distant oceans where typhoons occur through joint research with the Japan Agency for Marine-Earth Science and Technology.

2.2 Efforts to model marine ecosystems

Marine ecosystems are constantly transforming due to the effect of air temperature, water temperature, and changes in sunlight intensity, which is exacerbated by climate change. The results of human activities, such as agricultural runoff carrying various nutrients and chemicals, flow into the ocean through rivers. It is also difficult to observe ecosystems and quantify changes when we do not fully understand the role of individual organisms in nutrient cycling. Therefore, we aim to observe and model marine ecosystems, including plankton and other microorganisms, fish, and mammals, using new observation technologies that use satellite IoT technology, and to forecast marine ecosystems using simulations of environment changes. We are currently studying ecosystem-cycle forecasting technology that models ocean-ecosystem circulation processes and predicts the effects of climate change and human activities, fish-ecosystem monitoring technology that restores the ecosystem balance by constructing indicators of fish well-being, and microorganism-diversity-modeling technology that models the diversity of millions of microbial species and forecasts changes due to climate change (**Fig. 2**).

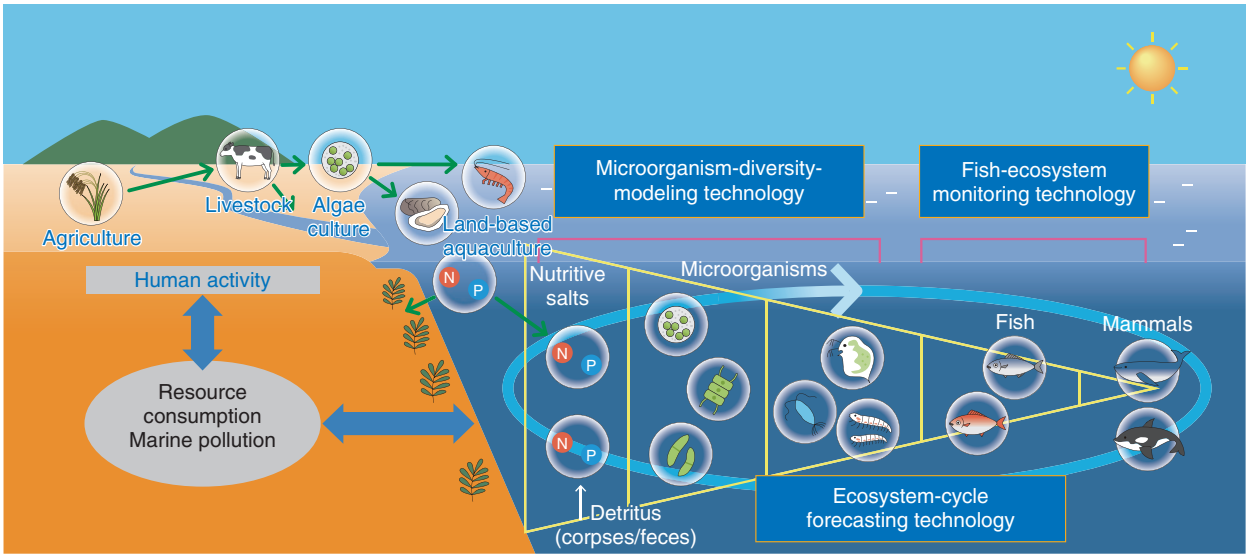
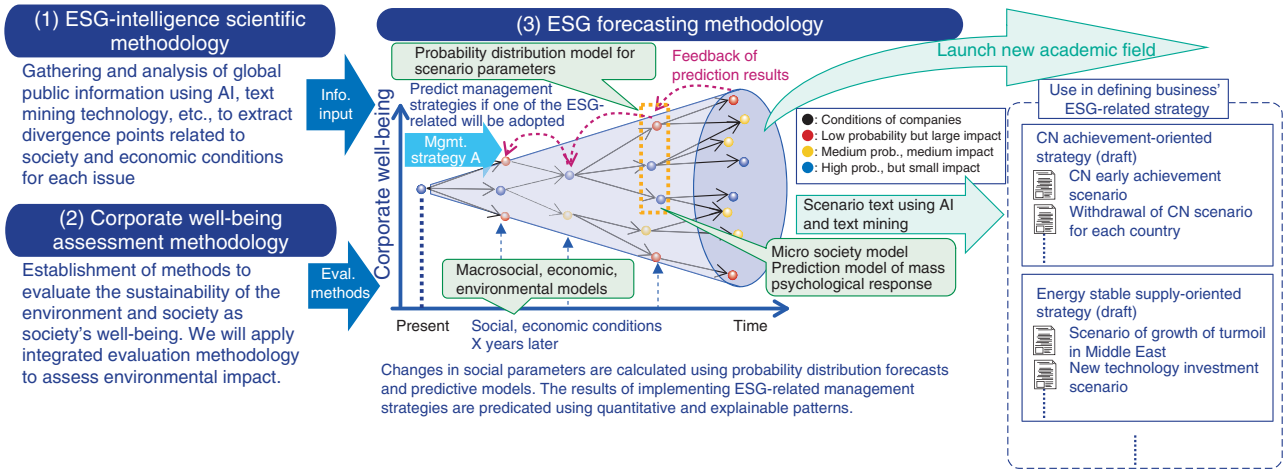


Fig. 2. Marine ecosystem model.



CN: carbon neutral

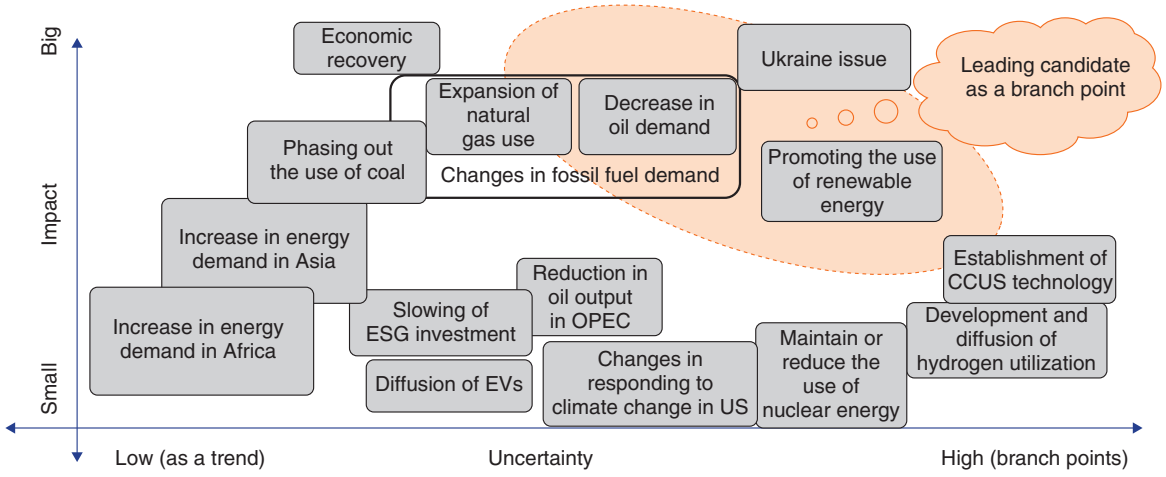
Fig. 3. Overview of management science and technology on ESG.

3. Management science and technology on ESG

Management science and technology on ESG is used for establishing scientific-prediction methodology on human society and global environmental impact to scientifically support the formulation of corporate management strategies related to non-financial values such as ESG. We are currently investigating an ESG-intelligence scientific methodology, corporate well-being assessment methodology, and ESG forecasting methodology (**Fig. 3**).

3.1 ESG-intelligence scientific methodology

We collect global information on politics, economy, society, technology, and environment using artificial intelligence (AI) including text mining technology, etc., and scientifically analyze them as information that contributes to the formulation of management strategies regarding ESG. For example, we are collecting and analyzing information necessary to



CCUS: carbon capture, utilization, and storage
EV: electric vehicle
OPEC: Organization of Petroleum Exporting Countries

Fig. 4. Attribution analysis using conventional method.

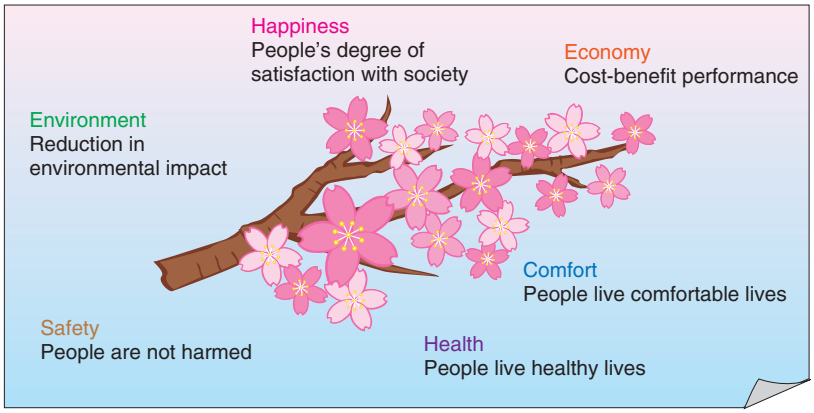


Fig. 5. Overview of the GSF Index.

formulate business strategies related to carbon neutrality and energy, in light of the latest efforts to decarbonize around the world and the energy crisis caused by the conflict in Ukraine. To create multiple possible future scenarios, important influencing factors are extracted on the basis of the collected information and set up as branch points in the creation of future scenarios. **Figure 4** shows an example of manual analysis with the conventional method. For the same information sources as in the conventional method, by applying AI text mining technology to the aforementioned series of analysis processes, we are attempting automatic information collection and analysis so that the bias of manual information analysis can be eliminated and branch points can be extracted objectively.

3.2 Corporate well-being assessment methodology

To evaluate the contribution of information and communication technology (ICT) to achieve a sustainable society, NTT developed the Gross Social Feel-good Index (GSF Index) [2] for quantitatively evaluating the positive and negative effects of ICT services and solutions in terms of their impact on the global environment, society, and economy (**Fig. 5**). The corporate well-being assessment methodology is

an extension of the GSF Index to establish a method for quantitatively evaluating the sustainability of the global environment and human society in terms of societal and corporate well-being. This methodology is an attempt to evaluate the contribution of corporations toward a well-being society that people desire, particularly for multiple stakeholders and considering non-financial impact. In FY2021, in a joint research project with Kyoto University, we conducted a quantitative evaluation of employee satisfaction in companies by identifying priority issues on the basis of findings from a questionnaire survey.

3.3 ESG forecasting methodology

The ESG forecasting methodology is used to establish a set of scientific-prediction models to quantitatively predict the results of implementing a single ESG-related management strategy in multiple possible futures using the branch points obtained using the ESG-intelligence scientific methodology. The set of scientific-prediction models consists of a macroeconomic model that predicts economic, social, and environmental changes at the macro level by using input-output analysis [3] and a micro-social model that predicts changes in individual behavior related to environmental impact. By combining these models, the risks and effects of implementing corporate ESG-related management strategies can be predicted that cannot be predicted manually on the basis of changes in social conditions output from the models. The results of the quantitative forecasts are output as scenarios, and the forecast results are evaluated using the corporate well-being assessment methodology. We aim to develop scientific technology that will be useful in the formulation of ESG-related management strategies that can lead to a better future for companies and society as a whole.

4. Future work

This article introduced global environmental futures forecasting technology and management science and technology on ESG. Regarding global environmental futures forecasting technology, we aim to develop technologies for simulating the regeneration process of the global environment by modeling the physical, biological, and chemical processes of the global environment using the results of ultra-wide-area observations. For management science and technology on ESG, we aim to develop technology for forecasting human society and environmental impact. These two technologies will be linked using Digital Twin Computing [4] technology and implemented on a simulation platform for forecasting the global environment, which will enable the mutual influences of the global environment and human activities to be taken into account. On the basis of forecasting, we aim to proactively adapt to changes in the social and natural environment.

References

[1] J. Kato, “Proactive Environment Adaptation Technology for Living Safely and Securely,” NTT Technical Review, Vol. 19, No. 6, pp. 37–41, June 2021.
https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202106fa5.html

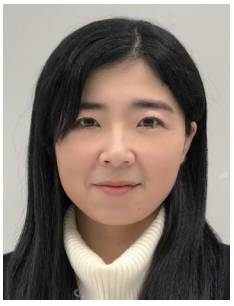
[2] M. Tsuda, M. Hara, Y. Nemoto, and J. Nakamura, “Gross Social Feel-good Index—Social Impact Assessment for ICT Services,” NTT Technical Review, Vol. 5, No. 3, pp. 43–47, Mar. 2007.
https://ntt-review.jp/archive/ntttechnical.php?contents=ntr200703043.pdf

[3] Ministry of Internal Affairs and Communications, “Outline of the Input-Output Tables for Japan,” https://www.soumu.go.jp/english/dgpp_ss/data/io/outline.htm

[4] T. Nakamura, “Digital Twin Computing Initiative,” NTT Technical Review, Vol. 18, No. 9, pp. 13–18, Sept. 2020.
https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202009fa1.html

Akira Koyama
Senior Research Engineer, Global Environment Futures Forecasting Technology Group, NTT Space Environment and Energy Laboratories.

He joined NTT EAST in 2000 and worked as a system engineer. He transferred to NTT Secure Platform Laboratories in 2014 to work on risk management system development. In 2020, he moved to NTT Space Environment and Energy Laboratories, where he established research on extreme weather and marine ecosystems.



Xiaoxi Zhang
Senior Research Engineer, ESG Management Science Group, Resilient Environmental Adaptation Research Project, NTT Space Environment and Energy Laboratories.

She received a B.S. and M.S. in social engineering from Tokyo Institute of Technology in 2007 and 2009. Since joining NTT in 2009, she has been engaged in research on risk-based management of telecommunication infrastructures and assessment of environmental impact of ICT use. She specializes in environmental and social forecasting simulations. She is a member of the Institute of Electronics, Information and Communication Engineers.

Masaki Hisada
Group Leader, Global Environmental Futures Forecasting Technology Group, Resilient Environmental Adaptation Research Project, NTT Space Environment and Energy Laboratories.

He received a bachelor's degree from International Christian University in 1999 and a master's degree in information science from the Nara Institute of Science and Technology in 2001. Since joining NTT in 2001, he has studied the fields of online education systems, high-availability database management systems, and software development. In 2010, he joined as a director of business development team in NTT Com Asia located at Hong Kong. He then returned to NTT as a manager of the open-source software center, where he led the development of a distributed database management system in the open-source community.

Minako Hara
Group Leader, ESG Management Science Group, Resilient Environmental Adaptation Research Project, NTT Space Environment and Energy Laboratories.

She received an M.E. and Ph.D. in applied chemistry from the University of Tokyo. She joined NTT Energy and Environment Systems Laboratories in 2006 and studied environmental assessment and international standardization activities. She moved to NTT WEST in 2016 and engaged in the formulation of the NTT West Group's environmental management strategy. She transferred to NTT Space Environment and Energy Laboratories in 2020 and later became a group leader. She is a member of the Society of Environmental Science, Japan and the Society for Environmental Economics and Policy Studies.

Proactive Environmental Adaptation Technology to Ensure Safe and Secure Living Conditions Even under Extreme Natural Phenomena

Takashi Ikeda, Masato Maruyama, Hidenori Iwashita, Toshihisa Masuda, Atsushi Nagao, Fumihiko Ishiyama, Yoshiharu Hiroshima, and Ryu Kiuchi

Abstract

NTT Space Environment and Energy Laboratories is developing technologies for humans to proactively adapt to extreme natural phenomena so they can live safely and securely on Earth and in space. We have been developing technologies to protect communication equipment from lightning strikes and cosmic rays. This article introduces lightning control and charging technology and cosmic-ray barrier technology that builds on the technologies we have developed as well as brings about fundamental changes to conventional countermeasures.

Keywords: lightning, drone, cosmic ray

1. Introduction

NTT is driving innovative research and development to create a *smart world*, a society in which everyone can lead a prosperous life. In such a society, the failure of a single device can have a flow-on effect and significantly affect systems that people depend on. Therefore, it has become more important than ever to keep infrastructures and critical systems running stably even in the event of disasters and other phenomena. Recent technological innovations have given rise to initiatives involving the use of drones and satellite communications to ensure uninterrupted services and early recovery of communications in the event of disasters.

NTT Space Environment and Energy Laboratories is conducting research and development to enable humans to lead safe and secure lives under various potentially disruptive natural phenomena with a focus on lightning and cosmic rays.

2. Lightning control and charging technology

Lightning strikes are one of the natural phenomena that inflict extensive damage on key infrastructure. The mechanisms of lightning strikes and technologies to prevent lightning damage have been studied for hundreds of years. Despite the fact that various lightning-strike countermeasures have been incorporated into critical infrastructures, lightning damage has still not been completely eliminated. The cost of this damage is estimated to exceed 100 billion yen annually in Japan alone. Preventing damage from lightning strikes is a major challenge in creating a smart world. To address this issue, we have made major upgrades to the technologies we have designed to protect communication facilities from lightning. We are studying technology to use drones to capture lightning bolts, guiding them to locations where there are no people or infrastructure facilities, and inducing strikes to occur there. We are also developing

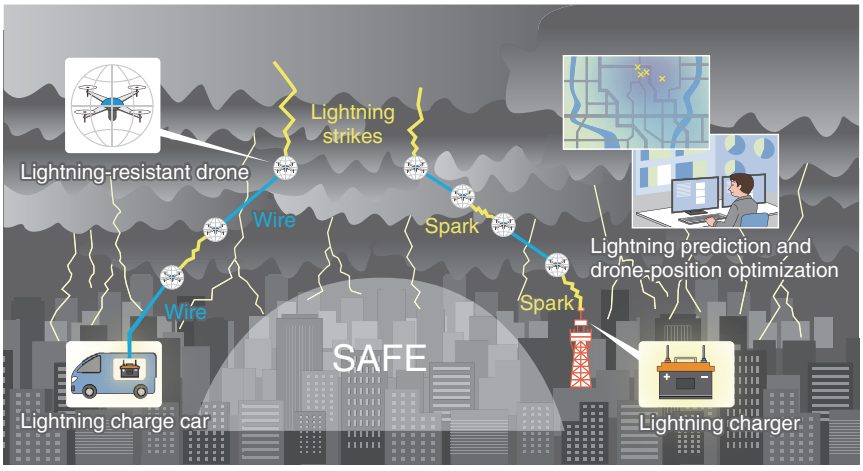


Fig. 1. A system of lightning control and charging using drones.

technology to store and use the energy of induced lightning strikes (**Fig. 1**).

The key device to a system consisting of the above technologies is a lightning-resistant drone, a robust drone that does not fail even when struck by lightning (**Fig. 2**). The drone is encased in a metal shield called a Faraday cage, which protects the drone from lightning currents and the magnetic fields generated by them. Our experiments using an artificial lightning generator have confirmed that the drone can withstand a lightning strike of 120 kA, which is five times greater than average lightning currents. In addition to being resistant to lightning, a Faraday cage must be light enough so that the drone can fly stably even in strong winds. We have conducted various simulations and experiments to develop a Faraday cage that largely satisfies the requirements for protection balanced with lightness.

To demonstrate that this lightning-resistant drone can withstand natural lightning strikes, in December 2021 we began the world's first experiment of intentionally inducing lightning strikes using a drone. The experiment was conducted in collaboration with the Faculty of Engineering, Gifu University off the coast of Uchinada Town, Ishikawa Prefecture, where thunderclouds frequently form in winter (**Fig. 3**). The way to induce lightning strikes is as follows; a drone is flown under thunderclouds. When the electric field generated by the thunderclouds increase, a conductive wire is dropped and stretched from the drone. This must rapidly boost the electric field near the lower end of the wire, resulting in an electric spark between the lower end of the wire and sea surface

Fig. 2. Lightning-resistant drone under development.

(Fig. 3, (1)). This spark makes the wire grounded electrically, which in turn sharply increases the electric field above the drone. This will generate a spark from the top of the drone toward the cloud (Fig. 3, (2)), which is assumed to result in a lightning strike.

Unfortunately, a lightning strike was not induced in the winter FY2021 experiment, but it did confirm that a spark occurred between the lower end of the wire and sea surface, which was part of the lightning-induction process, and that the developed lightning-resistant drone was able to fly stably in strong winds exceeding 20 m/s under thunderclouds (**Fig. 4**). Building on the data obtained in FY2021, we will improve the experimental system and conduct another experiment in the winter of FY2022, aiming at the successful induction of lightning strikes.

In parallel with these studies, we are conducting joint research with Hokkaido University on lightning-strike prediction technology, which is key to

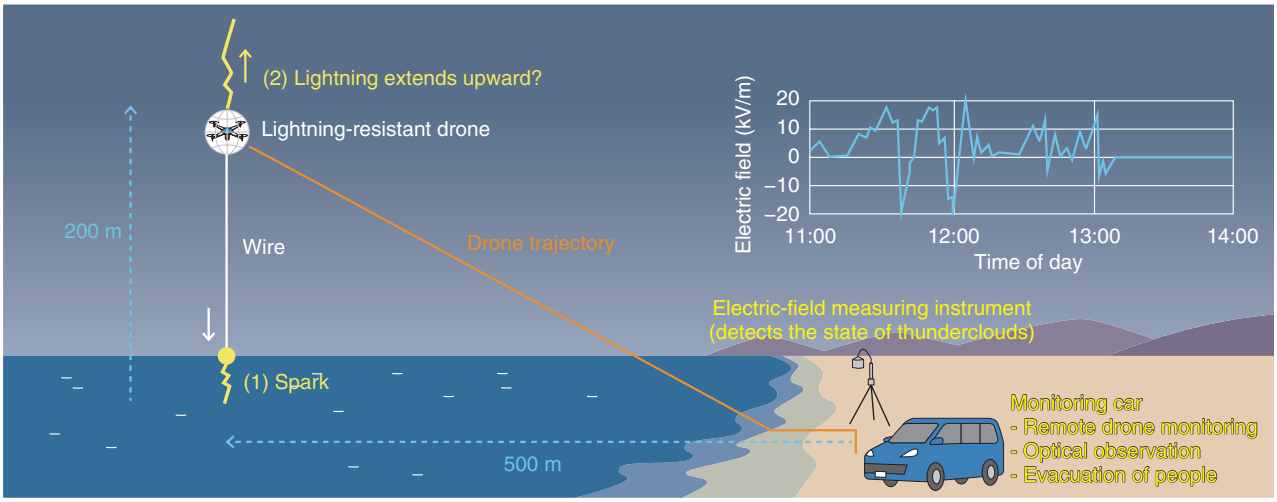


Fig. 3. Experiment of intentionally inducing lightning strikes using a drone.

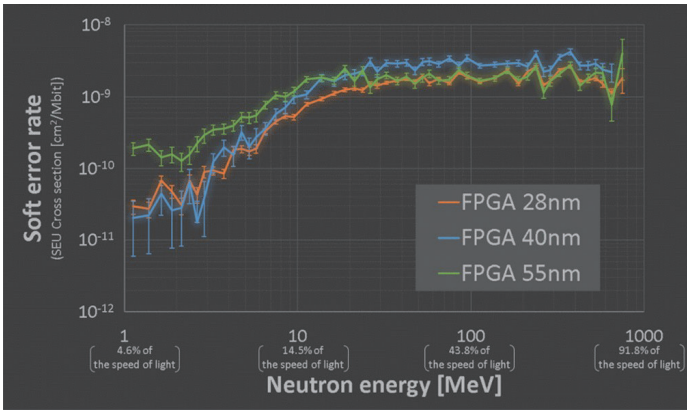
Fig. 4. Drone flying in thunderclouds.

improving the success rate of lightning induction. Applying the university's meteorological lightning model [1], we simulate the weather conditions several days ahead and the associated generation and diffusion of electric charge in clouds. The aim is to develop technology for accurately predicting the areas where lightning strikes occur as well as the number of lightning strikes. We are also studying how to use lightning energy for charging and other purposes. Since lightning bolts generate large currents of up to several hundred kiloamperes that flow in as short a period of time as several milliseconds, it is difficult to charge them to batteries directly. To solve this problem, we are investigating an innovative method for efficiently storing the electrical energy of lightning bolts by converting it into kinetic energy, pressure energy, or other forms of energy. We are making steady progress toward controlling lightning and using it for charging.

3. Cosmic-ray barrier technology

Humans have been exploring space, from launching space infrastructures, such as GPS (Global Positioning System) satellites and communication satellites, to planning space travel. The entry into space is becoming key to the future advancement of mankind. Efforts to develop space technology have matured and are shifting from the traditional efforts led by governments (Old Space) to initiatives led by the private sector (New Space). NTT is aiming at global deployment of services based on the *space datacenter* [2], which will use space to build a solid social infrastructure for a smart world. Although space development has been an attractive area for the advancement of modern society, the utilization of space involves many difficult issues. One is strong cosmic rays, which are unique to the space environment. Our solar system's Sun and other stars in the galaxy emit a constant stream of cosmic rays. This radiation has adverse effects on the human body and electronic devices. In addition, the intensity of solar activity, which waxes and wanes in an 11-year cycle, poses grave threats to the health of our modern electronics-intensive social infrastructure. NTT has established the world's first method [3] of measuring the soft-error rate at different levels of cosmic-ray-generated neutron energy, which affects electronic devices on the ground (**Fig. 5**).

NTT has also been instrumental in achieving the



FPGA: field-programmable gate array

Fig. 5. World's first measurement of soft-error rates at different levels of cosmic-ray-generated neutron energy.

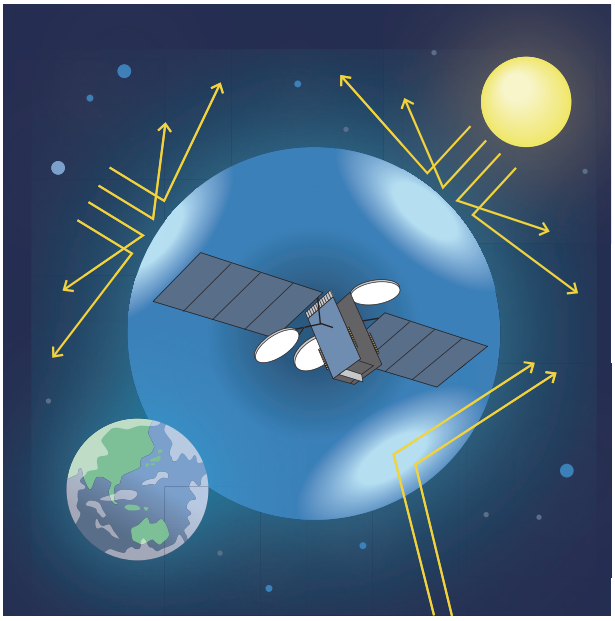


Fig. 6. Cosmic-ray barrier.

international standardization of countermeasures [4] and commercialization of testing services [5]. By applying these achievements to space, we are developing a *cosmic-ray barrier* that will support the use of space by humans and facilitate the construction of a robust social infrastructure (**Fig. 6**).

Cosmic rays consist of charged particles with protons as the main constituent. The trajectory of a charged particle is affected by the magnetic field. On Earth, its geomagnetic field acts as a barrier to cosmic rays. By applying this principle and surrounding satellites, space stations, and lunar bases with such a barrier, it is possible to reduce the risk posed by cosmic radiation. We are currently verifying the effect of such a measure by calculating the degree to which a generated magnetic field changes the trajectory of cosmic radiation using a combination of electromagnetic field analysis and particle transport simulations (**Fig. 7**).

Since cosmic rays have various types of kinetic

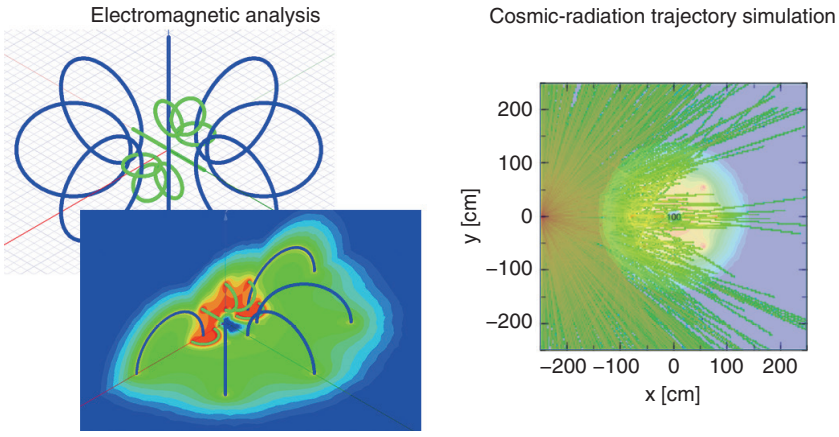


Fig. 7. Electromagnetic analysis of a cosmic-ray barrier and cosmic-radiation trajectory simulation.

energy, it is important to understand the effect of the kinetic energy on the trajectories of charged particles and extent of the impact of cosmic rays. We have succeeded in the hitherto difficult measurement of the impact of the neutron energy generated by cosmic rays on semiconductors. We believe that measuring the impact of the energy of other types of cosmic rays, such as protons and heavy particles, will enable us to evaluate the impact of cosmic radiation more precisely. We are also carrying out repeated experiments using an accelerator that can artificially generate cosmic rays and simulations to develop an effective cosmic-ray barrier.

These research efforts will enable us to construct a highly reliable space datacenter and enable people to stay in space for an extended period, making the dream of manned planetary exploration and the construction of a lunar base a reality. In addition, the data on the impact of cosmic-ray neutrons on semiconductors can be used in designing neutron shielding materials and taking material-level countermeasures, making it possible to protect social infrastructures on the ground and electronic devices in accelerator facilities used for medical treatment and research.

4. Conclusion

This article introduced lightning control and charging technology and cosmic-ray barrier technology. The former aims to eliminate the damage caused by lightning strikes, which are occurring constantly around the world, and ultimately to eliminate lightning strikes by absorbing the energy of thunderclouds. The latter aims to eliminate the impact of cosmic radiation and actualize a future world in which humans can live and work freely and safely in space.

Going forward, we will study proactive responses to natural phenomena other than lightning and cosmic rays.

References

[1] Y. Sato, S. Hayashi, and A. Hashimoto, “Difference in the Lightning Frequency between the July 2018 Heavy Rainfall Event over Central Japan and the 2017 Northern Kyushu Heavy Rainfall Event in Japan,” Atmospheric Science Letters, Vol. 23, No. 1, e1067, 2022.

[2] Press release issued by NTT and SKY Perfect JSAT, “NTT and SKY Perfect JSAT Agree to Establish Space Compass Corporation - Novel Space Integrated Computing Network Enterprise to Aid Realization of a Sustainable Society -,” Apr. 26, 2022. https://group.ntt/en/newsrelease/2022/04/26/220426a.html

[3] Press release issued by NTT, Nagoya University, and Hokkaido University, “Neutron Energy Dependence of Semiconductor Soft Errors Was Successfully Measured for the First Time - Enabling Calculation of the Number of Soft Errors Caused by Neutrons in Various Environments, e.g., in Outer Space or Even on Other Planets,” Nov. 25, 2020. https://group.ntt/en/newsrelease/2020/11/25/201125a.html

[4] Press release issued by NTT, Fujitsu, Hitachi, NEC, Oki Electric, Orange, and The Telecommunication Technology Committee, “International Standards Adopted by ITU-T to Address Soft Errors Affecting Telecommunication Equipment - Enhancing Reliability Based on Recommendations for Design, Testing, and Quality Estimation of Measures Designed to Mitigate Soft Errors Caused by Cosmic Rays,” Nov. 22, 2018. https://group.ntt/en/newsrelease/2018/11/22/181122a.html

[5] NTT-AT, Soft Error Test Service, https://www.ntt-at.com/product/softerror/

Takashi Ikeda
Group Leader, NTT Space Environment and Energy Laboratories.
He received a B.E. and M.E. from the Faculty of Instrumentation Engineering, Keio University, Kanagawa, in 1998 and 2000. He joined NTT in 2000 and is currently engaged in research and development of proactive environmental adaptation technologies.

Masato Maruyama
Senior Research Engineer, NTT Space Environment and Energy Laboratories.
He received a B.E. and M.E. from the University of Electro-Communications, Tokyo, in 2001 and 2003. Since joining NTT in 2003, he has been engaged in research on power supplies and air conditioning for telecommunication equipment to improve reliability and energy efficiency of telecommunication. He is currently conducting research on electromagnetic compatibility technology for communication systems at NTT Space Environment and Energy Laboratories.

Hidenori Iwashita
Senior Research Engineer, NTT Space Environment and Energy Laboratories.
He received a B.S. and M.S. in nuclear engineering from Hokkaido University in 2006 and 2008. He has been researching soft errors since 2012 at NTT Network Service Systems Laboratories and has been engaged in research on a mitigation technique of soft errors in space at NTT Space Environment and Energy Laboratories since 2020.

Toshihisa Masuda
Research Engineer, NTT Space Environment and Energy Laboratories.
He received a B.E. and M.E. from the Department of Electrical and Electronic Engineering, Kyushu Institute of Technology, Fukuoka, in 2007 and 2009. He joined NTT in 2009 and is currently engaged in research and development of proactive environmental adaptation technologies.

Atsushi Nagao
Research Engineer, NTT Space Environment and Energy Laboratories.
He received a B.E. and M.E. from the Department of Communication & Network Engineering, Okayama University, in 2010 and 2012. He joined NTT in 2012 and is currently engaged in research and development of proactive environmental adaptation technologies.

Fumihiko Ishiyama
Research Engineer, NTT Space Environment and Energy Laboratories.
He received a B.S. and M.S. in physics from Tohoku University, Miyagi, in 1988 and 1990, and Ph.D. in computer science from the University of Tsukuba, Ibaraki, in 2020. He has been engaged in research on nonlinear theory of time frequency analysis for proactive environmental adaptation technologies.

Yoshiharu Hiroshima
Senior Staff, NTT Space Environment and Energy Laboratories.
He received a B.E. and M.E. from the Department of Electric and Communication Engineering, Tohoku University, Miyagi, in 1986 and 1988. He joined NTT in 1988 and is currently engaged in research and development of proactive environmental adaptation technologies.

Ryu Kiuchi
Engineer, NTT Space Environment and Energy Laboratories.
He received a B.S. and M.S. in nuclear engineering from Hokkaido University in 2020 and 2022. He joined NTT Space Environment and Energy Laboratories in 2022 and has been researching soft errors.

ITU-T Standardization Activities for Spatial Division Multiplexing Optical Fibers and Maintenance of Outdoor Optical Facilities

Chihiro Kito, Takashi Matsui, and Kazuhide Nakajima

Abstract

International standards related to optical fiber cables and the maintenance of outdoor optical facilities have been developed as ITU-T (International Telecommunication Union - Telecommunication Standardization Sector) Recommendations, the content of which has been discussed in Study Group 15 and revised in accordance with the progress of optical communication systems. We introduce space division multiplexing optical fibers that are expected to become an ultra-high-capacity transmission medium that breaks the communication capacity limit of existing single-mode optical fibers, as well as the standardization trend in the maintenance and operation of outdoor optical facilities, which must be more efficient due to the spread of optical communication services.

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

1. Introduction

The International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) has developed international standard documents (Recommendations) that stipulate the system requirements and functions of communication networks, methods for testing transmission characteristics, and operating methods of network infrastructure, which greatly contribute to ensuring the interoperability and quality of service for telecommunication carriers. In September 2022, a technical report on space division multiplexing (SDM) optical fibers was agreed at Question 5 of ITU-T Study Group (SG) 15 [1] Working Party (WP) 2, which is responsible for establishing new Recommendations and revising existing Recommendations on optical fibers. This technical report is a major step in that it comprehensively describes the maturity and challenges of SDM fiber technology and provides a roadmap for future international standardization activities and practical deployment. Against the backdrop of the demand for proper operation of outdoor optical facilities in line with the spread of optical communication services worldwide, standardization work on maintenance and operation methods of outdoor optical facilities is also being conducted in Question 7 of the SG15 WP2.

The following chapters outline the content of the SDM fiber technical report and trends in the Recommendations for the maintenance and operation of outdoor optical facilities.

2. Technical report on SDM optical fiber cables

The transmission capacity per fiber has already exceeded 10 Tbit/s in a commercial optical communication system. It is expected that significantly larger transmission capacity, more than 100 Tbit/s, will be needed by the late 2020s. However, the maximum transmission capacity of an existing single-mode optical fiber (SMF) will also become apparent at 100 Tbit/s, making SDM optical fiber cables more

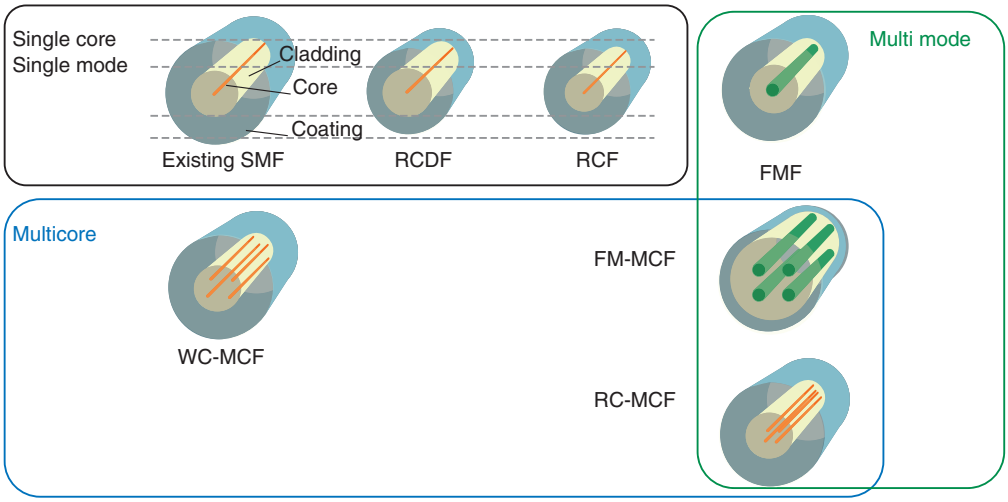


Fig. 1. Classification of SDM optical fibers considered in TR.sdm.

attractive as a new optical transmission medium. Therefore, ITU-T has prepared and published a new technical report, i.e., TR.sdm, during the last SG15 meeting held in September 2022. TR.sdm covers the current technical status of SDM optical fiber cable technology, its applicability to various network areas, and future standardization objectives.

Figure 1 shows the classification of SDM optical fibers considered in TR.sdm. TR.sdm considers novel optical fibers, such as a multicore fiber (MCF) and few-mode fiber (FMF), as well as single-core fibers that have a thinner coating or smaller cladding diameter than existing SMF, namely, a reduced coating diameter fiber (RCDF) or reduced cladding fiber (RCF), respectively. RCDF and RCF are beneficial in maximizing the number of fibers accommodated in existing cables while using the current cabling technology. A weakly coupled multicore fiber (WC-MCF), in which multiple cores are multiplexed so that they operate independently in the same cladding, is expected to expand capacity as much as multiple cores. However, WC-MCF requires a relatively large core pitch to reduce optical signal interference between cores, i.e., crosstalk. A larger core pitch and/or larger number of cores intrinsically requires an enlarged cladding diameter. However, the larger cladding diameter directly degrades the mass-productivity of optical fibers. Thus, a standard 125-μm-cladding-diameter WC-MCF, which has optical properties comparable to those of the conventional SMF, is expected to be useful as a future optical transmission medium. An FMF, which multiplexes multiple types of propagation light (modes) in the same core, can maximize the number of optical signals per unit cross-sectional area. Moreover, a few-mode MCF (FM-MCF) significantly increases the number of spatial channels as the multiple of the number of modes and cores. A randomly coupled MCF (RC-MCF) has a similar cross-sectional structure with a WC-MCF. However, an RC-MCF can propagate the number of modes equivalent to the number of cores by setting the adequate core pitch so that the optical signals are actively mixed between cores. Thus, RC-MCF can achieve higher core multiplicity than WC-MCF. However, these multimode fibers, i.e., FMF, FM-MCF, and RC-MCF, require complex signal processing at the receiver end to demodulate the mixed optical signals. Therefore, the availability of the corresponding transmission technology should be considered carefully for practical deployment. TR.sdm considers that an RCDF or standard cladding diameter WC-MCF would be the first candidate for early SDM transmission systems. RCDF can maximize the number of accommodated fibers in an existing cable and support user multiplexing, which is particularly needed in hyper-scale datacenter interconnections. WC-MCF would be useful for long-haul submarine and terrestrial backbone networks since they set strict limits on cable diameter, number of accommodated fibers, and/or duct size, and these networks intrinsically require continuous upgradability. However, total cost merit should be considered carefully since the deployment of these new SDM optical fibers also requires new installation, connection,

optical amplification technologies, and sub-systems.

3. Standardization activities for maintenance and operation of outdoor facilities

While the annual growth rate of FTTH (fiber-to-the-home) subscribers in the Organization for Economic Co-operation and Development (OECD) countries reached 18.6% over the year to December 2021, the global broadband penetration rate has been increasing due to the increasing number of hours at home and the spread of remote work in the wake of the pandemic [2]. In the near future, the spread of fifth-generation mobile communication systems is expected to lead to a significant worldwide increase in the use of optical broadband for wireless services. Therefore, there is an urgent international need for efficient maintenance and operation of the huge number of outdoor optical facilities expected to support communication services.

In 2020, ITU-T Recommendation L.330 (Telecommunication infrastructure facilities management) was established to define general matters related to management for the proper operation of outdoor facilities. To ensure the safe operation of outdoor facilities over long periods, which cannot avoid aging-based deterioration, it is essential to conduct inspections on appropriate periods, check items, and work flow. ITU-T Recommendation L.330 defines the basic inspection requirements and flow as well as 17 outdoor facilities that should be inspected. It provides an exhaustive list of inspection periods and items to be checked for each type of facility as well as the measurement accuracy of deterioration events required during detailed inspections. The establishment of this Recommendation L.330 will encourage telecom carriers to increase their awareness of inspections as well as accelerate the development of products that meet inspection requirements. Recommendation L.330 has also triggered work to establish maintenance-related ITU-T Recommendations that describe detailed inspection measures, related technologies, and work safety issues that differ for each type of outdoor facility. Specifically, we are in the process of revising the current ITU-T Recommendation L.340 (Maintenance of cable tunnels) to include all underground facilities, such as maintenance holes (MH) and hand holes, for which inspection work is similar to that for cable tunnels. This revision also aims to include examples of using the latest technologies that can improve maintenance efficiency such as no-entry MH inspection technology using camera drones and omnidirectional cameras (see Appendix of the revised Recommendation). Progress is being made toward completion of this Recommendation in 2023.

As with the revision of ITU-T Recommendation L.340, there has been standardization activity to reflect the results of research and development studies on improving the efficiency of the maintenance and operation of outdoor facilities through the application of advanced technologies. One example is ITU-T Recommendation L.316 (Cable identification for the construction and maintenance of optical fiber cable networks by using optical sensing techniques). Established in 2022, ITU-T Recommendation L.316 describes a method for identifying the optical cables to be serviced from among congested optical cables by monitoring the vibrations intentionally applied to the optical cable by the workers at the maintenance site. Optical-fiber vibration-measuring equipment installed in a central office can monitor the intentional vibrations. Related to this Recommendation, in May 2022, NTT EAST began a maintenance scheme using optical-fiber vibration-sensing technology. By using optical fiber-vibration-measuring equipment installed in a central office to detect the vibration created by striking the iron lid of the MH, it is possible to determine whether the failure of an optical cable lies in the MH space without entering the MH, thus reducing the time required to manually search for the failure point. Further improvements in maintenance and operation efficiency are expected as a result of technological advances and the timely creation of international standards.

4. Future prospects

On the basis of the technical report on SDM optical fibers agreed to at ITU-T SG15 in September 2022, concrete discussions will be held toward the international standardization of SDM optical fiber technology. Discussions on standardizations for SDM connectors and optical amplification technology, which are essential for the construction of SDM transmission systems, are also progressing at the International Electrotechnical Commission (IEC), and it is expected that the collaboration between ITU-T and IEC will advance standardization activities toward the implementation of next-generation large-capacity transmission systems. In addition, the series of Recommendations related to the maintenance and operation of outdoor facilities will continue to be established and revised in consideration of the efficiency, homogeneity, and digitization of maintenance and

operation tasks.

References

[1] ITU-T SG15, https://www.itu.int/en/ITU-T/studygroups/2022-2024/15/Pages/default.aspx

[2] OECD, “Fibre overtakes cable as the primary fixed broadband technology in OECD countries,” July 2022. https://www.oecd.org/sti/broadband/broadband-statistics-update.htm

Chihiro Kito
Senior Researcher, NTT Access Network Service Systems Laboratories.
He received an M.E. in electrical engineering from Toyota Technological Institute, Aichi, in 2011 and Ph.D. in electrical engineering from Shimane University in 2017. He joined NTT Access Network Service Systems Laboratories in 2011. His research interests include optical reflectometry and optical fiber measurements. He has been a rapporteur of Question 7 of ITU-T SG15 since 2021. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.

Takashi Matsui
Distinguished Researcher, NTT Access Network Service Systems Laboratories.
He received a B.E., M.E., and Ph.D. in electronic engineering from Hokkaido University in 2001, 2003, and 2008. In 2009, he attained the status of Professional Engineer (P.E.Jp) in electrical and electronic engineering. In 2003, he joined NTT Access Network Service Systems Laboratories. He is engaged in research on technologies for the design and measurement of optical fibers. He is a member of IEICE, and an expert on Study Group 15 for international standards for fiber-optics technology in ITU-T.

Kazuhide Nakajima
Senior Distinguished Researcher, NTT Access Network Service Systems Laboratories.
He received an M.S. and Ph.D. in electrical engineering from Nihon University, Chiba, in 1994 and 2005. In 1994, he joined NTT, where he has been engaged in research on optical fiber design and related measurement techniques. He has been a rapporteur of Question 5 of ITU-T SG15 since 2009. He is a member of the Institute of Electrical and Electronics Engineers (IEEE), Optica, IEICE, and Japan Society of Applied Physics (JSAP). He is the recipient of the Best Paper Award at the OptoElectronics and Communications Conference (OECC) in 1996 and 2019, the Best Paper Award from IEICE in 2011, the Achievement Award from IEICE in 2012, and the Maejima Hisoka Award in 2016.

Remote Field Support by the Technical Assistance and Support Center

Technical Assistance and Support Center, NTT EAST

Abstract

The Technical Assistance and Support Center, NTT EAST has been implementing measures to support on-site investigations—which have conventionally been conducted by visiting the site in person—remotely ("remote field support"). This article presents the benefits, requirements, and example implementation of remote field support. This is the seventy-fourth article in a series on telecommunication technologies.

Keywords: remote field support, packet capture, failure analysis

1. Introduction

The Technical Assistance and Support Center (TASC), NTT EAST provides technical support for rectifying telecommunication failures, the causes of which are difficult to identify. We at the Network Interface Engineering Group in TASC have been consulted by maintenance personnel in charge of telecommunication lines and telecommunication equipment in each region in regard to difficult-to-solve telecommunication failures that have occurred in customer offices and private homes, investigated and analyzed the causes of those failures on site, and offered solutions to resolve them.

The COVID-19 pandemic has provided an opportunity for creating a remote communication environment as well as secure and high-speed remote connection and inexpensive, high-performance video-recording equipment. For example, business chat systems, such as Microsoft Teams and web-conferencing systems, are now widely available.

Against this background, TASC has been implementing measures to support on-site investigations—which have conventionally been conducted by visiting the site in person—remotely (remote field support). This article presents the benefits, requirements, and example implementation of remote field support.

2. Overview of remote field support

2.1 Expected benefits of remote field support

The expected benefits of remote field support are summarized as follows. In many cases, an on-site maintenance person spends a long time analyzing a telecommunication failure before TASC is contacted to investigate its cause, so TASC needs to swiftly respond to the failure. During remote field support, analysis and instructions are provided remotely; consequently, the work of setting up equipment on site does not have to be done by skilled individuals, and the investigation can be scheduled quickly. If the failure was a rare event, in some cases the packet-capture files and log data were overwritten, it would be impossible to obtain the desired data at the time the failure occurred. Since data can be obtained by operating equipment remotely, remote field support is also suitable for long-term measurements.

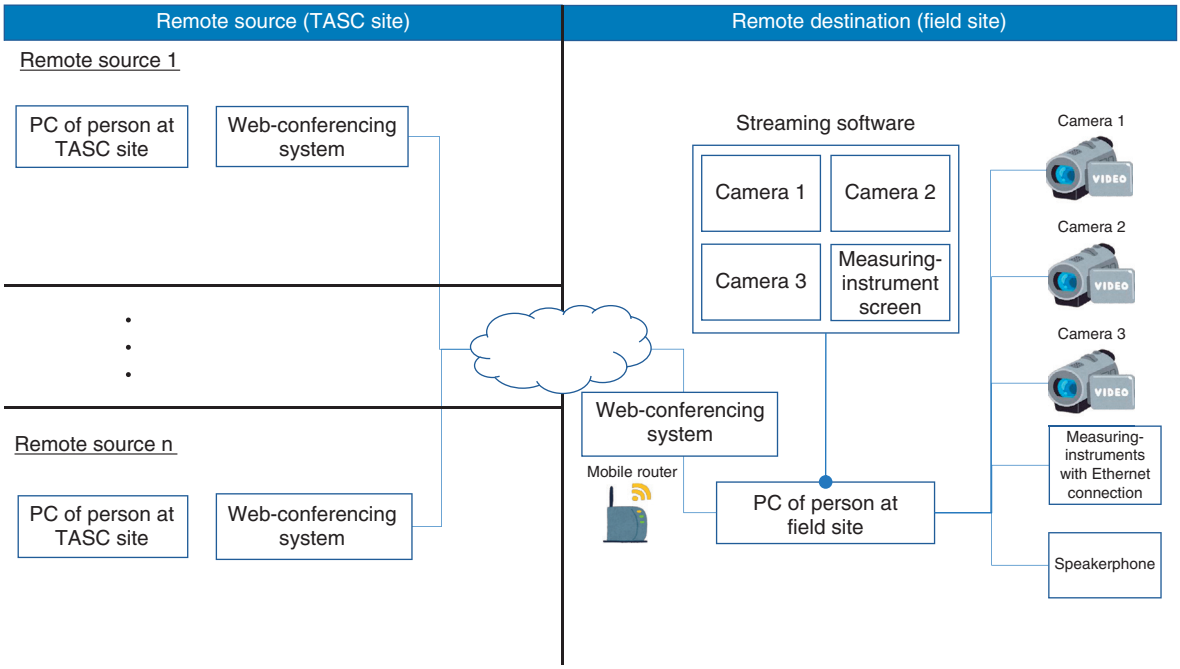


Fig. 1. Example configuration of remote field support.

2.2 Requirements for remote field support

The requirements for conducting remote field support are as follows.

(1) Secure communication

To conduct remote field support, a field site and TASC site are connected via a telecommunication line, and from the standpoint of security, it is desirable to have a closed network connection that does not go through the Internet. Accordingly, a closed virtual private network (VPN) with a mobile router is used to ensure secure communication.

(2) Smooth communication between individuals at a remote source (TASC site) and remote destination (field site)

Communication between individuals at a remote source (TASC site) and remote destination (field site) is critical during remote field support. Accordingly, using a web-conferencing system to constantly connect those two locations allows the investigation of a failure to proceed through close communication in a similar manner to conventional on-site support.

(3) Reduce the burden on individuals at a remote destination

Individuals at a remote destination may feel psychologically burdened because their work is constantly being monitored through a fixed-point camera and microphone. To reduce such burden, it is important to use such equipment with a physical on/off switch. Switching cameras off can also prevent unintended leakage of video.

2.3 Example configuration of remote field support

During remote field support, we send the equipment required for remote communication as well as the measuring instruments to the field site, where a maintenance person sets up and wires streaming equipment and measuring instruments. Audio and video from the field site and the operation screens of the equipment can be shared with the remote-source side via the web-conferencing system, and it is possible to operate equipment remotely and give instructions to the person at the field site. An example configuration of remote field support is shown in **Fig. 1**. The following equipment and communication lines are used during remote field support:

- Web-conferencing system (e.g., Microsoft Teams)
- Streaming software (Open Broadcaster Software (OBS), etc.)
- Video equipment (camera)
- Equipment that supports Ethernet connection
- Speakerphone
- Personal computer (PC) for streaming

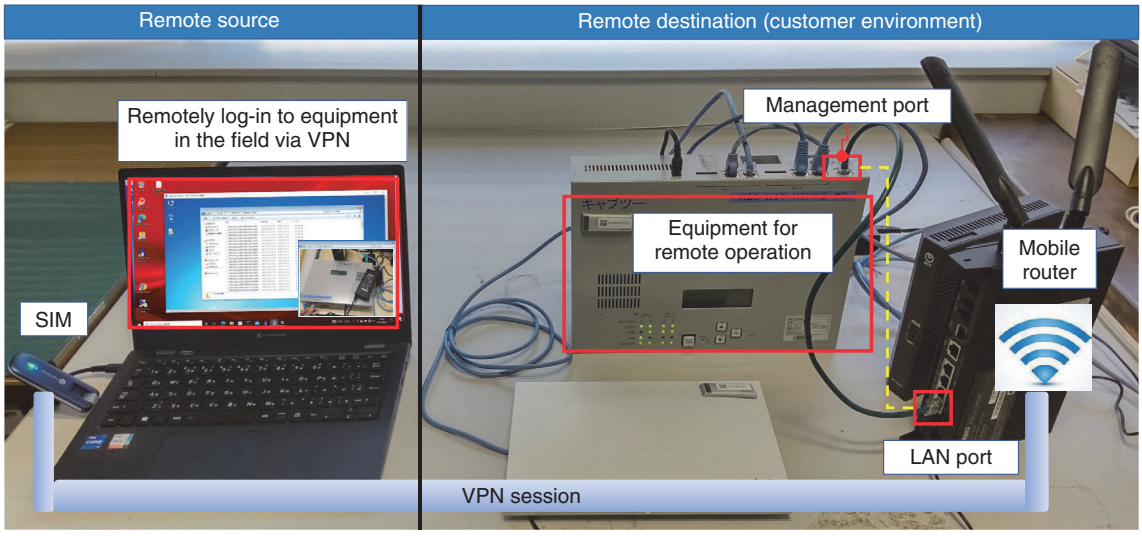


Fig. 2. Configuration of equipment.

- Mobile router and subscriber identity module (SIM)

The PC for streaming is used to transmit the status of the investigation at the field site as well as to communicate with the remote-source side. A mobile router and SIM are used for the connection between the remote source and destination. TASC can set up equipment at the field site remotely, except for starting up the PC and wiring cameras, etc. for streaming, so there is less burden on the person in the field site. If scene and source are set in advance on the streaming software (OBS, etc.), video streaming can be started in a short time after the PC for streaming is connected.

OBS is used to (i) combine videos from the cameras and other instruments installed at the field site with the control screen of a local area network (LAN)-compatible measuring instruments and (ii) share them with the remote-source side. Work status, measuring-instrument screens, and other on-site information can be viewed in a consolidated form in a manner that makes it easier to keep track of the work status. Moreover, measuring instruments that can be controlled and the readings of which can be displayed via an Ethernet connection from a PC are used, so the on-site equipment can be precisely set from the remote-source side.

3. Example implementation of remote field support

3.1 Configuration of equipment

We were consulted in regard to suspected packet loss in a communication line between customer sites that were sending and receiving large amounts of data. To investigate the problem, we accordingly conducted remote field support by capturing packets sent and received between the sites and stopping the packet capture when an error occurred on the customer's application. The equipment configuration that simulates the customer's environment is shown in **Fig. 2**.

The packet-capture tool (*Cap-two* developed by TASC [1]) was connected to the communication line via a mobile VPN, and packet capture was started and stopped remotely by logging into Cap-two from the PC at the remote source. AQstage of NTT Business Solutions was used as the mobile-router SIM, and a closed network was constructed with LTE (Long-Term Evolution) lines. In this remote field support, video streaming using the video system (including the OBS) was not conducted. However, in other cases, a camera was added to the above-described equipment configuration to stream videos. We confirmed that no image delays or audio problems occurred during communication between the remote source and destination.

3.2 Results

By remotely operating equipment installed at a field site, reliable, long-term measurements have become possible, and the time required for remote analysis of a failure was shortened. Compared with conventional on-site support, remote field support—in which equipment is sent to the field site and operated remotely—made it possible to provide technical support quickly and reduce the burden of prior scheduling and travel.

4. Concluding remarks

This report introduced remote field support to solve telecommunication failures, which had conventionally involved a TASC person visiting the site.

By acquiring and analyzing data using a variety of tools, the Network Interface Engineering Group of TASC provides technical support for the early resolution of problems with equipment, terminals, and networks. We will continue to disseminate technologies by providing technical support, developing tools, holding technical seminars, and other means.

Reference

[1] "Exploring New Ways to Use Packet Capture with a Low-cost Capture Tool," NTT Technical Journal, Vol. 29, No. 1, pp. 50–51, Jan. 2017 (in Japanese).

External Awards

Best Paper Award Runner-Up
Winners: Yasunori Ohishi, NTT Communication Science Laboratories; Marc Delcroix, NTT Communication Science Laboratories; Tsubasa Ochiai, NTT Communication Science Laboratories; Shoko Araki, NTT Communication Science Laboratories; Daiki Takeuchi, NTT Communication Science Laboratories; Daisuke Niizumi, NTT Communication Science Laboratories; Akisato Kimura, NTT Communication Science Laboratories; Noboru Harada, NTT Communication Science Laboratories; Kunio Kashino, NTT Communication Science Laboratories
Date: October 12, 2022
Organization: The 30th Association for Computing Machinery International Conference on Multimedia (ACM Multimedia 2022)

For "ConceptBeam: Concept Driven Target Speech Extraction."
Published as: Y. Ohishi, M. Delcroix, T. Ochiai, S. Araki, D. Takeuchi, D. Niizumi, A. Kimura, N. Harada, and K. Kashino, "ConceptBeam: Concept Driven Target Speech Extraction," ACM Multimedia 2022, Lisbon, Portugal, Oct. 2022.

Optics Awards for Excellent Papers
Winner: Masashi Miyata, NTT Device Technology Laboratories
Date: November 14, 2022
Organization: The Optical Society of Japan

For "Full-color-sorting Metalenses for High-sensitivity Image Sensors."
Published as: M. Miyata, N. Nemoto, K. Shikama, F. Kobayashi, and T. Hashimoto, "Full-color-sorting Metalenses for High-sensitivity Image Sensors," Optica, Vol. 8, No. 12, pp. 1596–1604, 2021.

Incentive Award
Winner: Xiaoxi Zhang, NTT Space Environment and Energy Laboratories
Date: November 19, 2022
Organization: Japan Women Engineers Forum

For being a role model for young female engineers by demonstrating leadership in her workplace.

Best Paper Award
Winners: Yohei Tahara, Nihon University; Toshiki Onishi, Nihon University; Asahi Ogushi, Nihon University; Ryo Ishii, NTT Human Informatics Laboratories; Atsushi Fukayama, NTT Human Informatics Laboratories; Takao Nakamura, NTT Human Informatics Laboratories; Akihiro Miyata, Nihon University
Date: November 25, 2022
Organization: Information Processing Society of Japan (IPSJ) Groupware & Network Services Workshop (GNWS)

For "A Study on Detection of Praising Behaviors in Face-to-Face and Remote Dialogues."
Published as: Y. Tahara, T. Onishi, A. Ogushi, R. Ishii, A. Fukayama, T. Nakamura, and A. Miyata, "A Study on Detection of Praising Behaviors in Face-to-Face and Remote Dialogues," Proc. of GNWS 2022, pp. 36–43, Ibaraki, Japan, Nov. 2022.

Best Paper Award
Winners: Takuya Kanai, NTT Access Network Service Systems Laboratories; Shin Kaneko, NTT Access Network Service Systems Laboratories; Jun-ichi Kani, NTT Access Network Service Systems Laboratories; Tomoaki Yoshida, NTT Access Network Service Systems Laboratories
Date: November 30, 2022
Organization: 2022 International Conference on Emerging Technologies for Communications (ICETC 2022)

For "Novel Wavelength-multiplexed AMCC Insertion and Detection Method with Single Receiver for Protocol-independent End-to-end User Connections in APN."
Published as: T. Kanai, S. Kaneko, J. Kani, and T. Yoshida, "Novel Wavelength-multiplexed AMCC Insertion and Detection Method with Single Receiver for Protocol-independent End-to-end User Connections in APN," ICETC 2022, Tokyo, Japan, Nov./Dec. 2022.

IEEE MTT-S Japan Young Engineer Award
Winner: Hiroshi Hamada, NTT Device Technology Laboratories
Date: December 1, 2022
Organization: IEEE Microwave Theory and Techniques Society (MTT-S) Japan Chapter

For "220–325-GHz 25-dB-gain Differential Amplifier with High Common-mode-rejection Circuit in 60-nm InP-HEMT Technology."
Published as: H. Hamada, T. Tsutsumi, A. Pander, H. Matsuzaki, H. Sugiyama, H. Takahashi, and H. Nosaka, "220–325-GHz 25-dB-gain Differential Amplifier with High Common-mode-rejection Circuit in 60-nm InP-HEMT Technology," IEEE Microwave and Wireless Components Letters, Vol. 31, No. 6, pp. 709–712, 2021.

Michiyuki Uenohara Memorial Award
Winner: Hiroshi Hamada, NTT Device Technology Laboratories
Date: December 1, 2022
Organization: IEEE MTT-S Japan Chapter

For "220–325-GHz 25-dB-gain Differential Amplifier with High Common-mode-rejection Circuit in 60-nm InP-HEMT Technology."
Published as: H. Hamada, T. Tsutsumi, A. Pander, H. Matsuzaki, H. Sugiyama, H. Takahashi, and H. Nosaka, "220–325-GHz 25-dB-gain Differential Amplifier with High Common-mode-rejection Circuit in 60-nm InP-HEMT Technology," IEEE Microwave and Wireless Components Letters, Vol. 31, No. 6, pp. 709–712, 2021.

Intelligence, Informatics and Infrastructure Outstanding Potential Paper Award
Winners: Akira Ito, NTT Access Network Service Systems Laboratories; Aiko Furukawa, Kyoto University
Date: December 1, 2022
Organization: Japan Society of Civil Engineering

For "Corrosion Prediction Method for Inner Surface of Telecommunication Conduit with Machine Learning Based on Inspection Results."
Published as: A. Ito and A. Furukawa, "Corrosion Prediction Method for Inner Surface of Telecommunication Conduit with Machine Learning Based on Inspection Results," Artificial Intelligence and Data Science, Vol. 3, No. J2, pp. 517–526, 2022.

Best Poster Award
Winner: Yuki Kubo, NTT Human Informatics Laboratories
Date: December 9, 2022

Organization: 2022 ACM Symposium on Spatial User Interaction (ACM SUI 2022)

For "Ring-type Indirect Pointing Device for Large Displays Using Three-axis Pressure Sensor."
Published as: Y. Kubo, "Ring-type Indirect Pointing Device for Large Displays Using Three-axis Pressure Sensor," Proc. of ACM SUI 2022, Article no. 33, Virtual conference, Dec. 2022.

Best Paper Award

Winners: Takeshi Kakizaki, NTT Network Innovation Laboratories; Masanori Nakamura, NTT Network Innovation Laboratories; Fukutaro Hamaoka, NTT Network Innovation Laboratories; Yoshiaki Kisaka, NTT Network Innovation Laboratories
Date: December 13, 2022
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE) Technical Committee on Optical Communication Systems (OCS)

For "Decoding Complexity Reduction of Forward Error Correction by Channel-polarized Multilevel Coding."
Published as: T. Kakizaki, M. Nakamura, F. Hamaoka, and Y. Kisaka, "Decoding Complexity Reduction of Forward Error Correction by Channel-polarized Multilevel Coding," IEICE Tech. Rep., Vol. 122, No. 70, OCS2022-11, pp. 6–11, 2022.