NTT Technical Review

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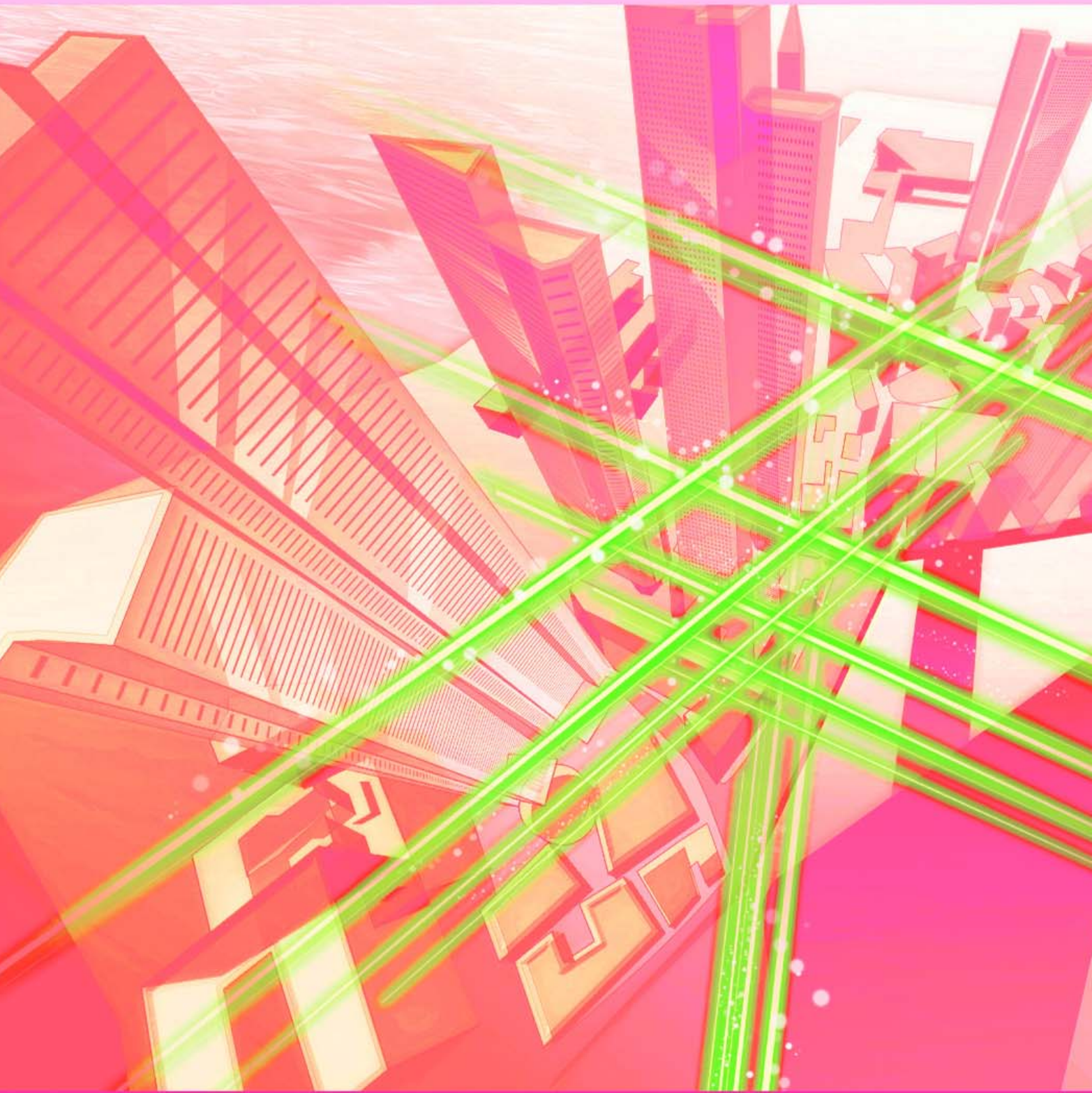

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Global Standardization Activities

- Activity Report of TTC Bridging the Standardization Gap Working Group

Information

- Report on the NTT R&D FORUM 2023 — IOWN ACCELERATION

External Awards/Papers Published in Technical Journals and Conference Proceedings

Don’t Panic, Don’t Get Angry, and Don’t Let It Happen Again

Toshio Kashiwagi
Senior Executive Vice President, Executive Officer (CIO/CDO), NTT COMWARE

Abstract

NTT COMWARE supports the systems that make up NTT’s telecommunications infrastructure and systems related to service operations from the software side. As a member of the NTT DOCOMO Group, it is also developing systems that will serve as the foundation for expanding the Group’s business. We interviewed Toshio Kashiwagi, senior executive vice president and executive officer (chief information officer/chief digital officer) of NTT COMWARE, which is committed to providing new value to society beyond the social infrastructure of telecommunications, about the company’s strengths as a group of software professionals and his attitude as a top executive.

Keywords: software, system development, IOWN APN

The quality and reliability of NTT COMWARE that supports Japan’s social infrastructure

—Could you tell us about the strengths of NTT COMWARE, which supports telecommunications infrastructure as a group of software professionals?

Since its establishment in 1997, NTT COMWARE has supported NTT Group’s telecommunications infrastructure by developing software for network-related systems and designing, developing, maintaining, and operating information-management systems and operational systems for tens of millions of telecommunications service users.

Our great strength is our refined technological capabilities. We have approximately 4100 engineers who support a series of processes—ranging from system planning to development, infrastructure construction, and operation centered on software technology, over 2600 agile-development engineers who design and rapidly create innovative services through continuous improvement in processes, and over 3400 data scientists and engineers. We are committed to providing new value by harnessing these technological capabilities.

To continue to improve our technological capabilities into the future, we emphasize human resources development. We are improving the practical skills involved in agile-development technology and nurturing engineers who have knowledge and skills regarding various data-analysis technologies and the latest digital technologies such as artificial intelligence (AI) and big data.

With this lineup, we are currently undertaking a wide variety of projects, which total about 500 per year. These projects range from large-scale projects worth several tens of billions of yen involving more than 1000 members and spanning several years from planning to service launch to agile development projects using the scrum framework to support our customers’ businesses in an agile manner.

—NTT COMWARE has supported telecommunications infrastructure while promoting the advancement of technology. In consideration of this history and the fact that it is now a member of the NTT DOCOMO Group, what is your current vision?

In 2022, we celebrated the 25th anniversary of the company's founding and, at the same time, together with NTT DOCOMO and NTT Communications, we started anew as a member of the NTT DOCOMO Group. We also launched new NTT COMWARE Group through the absorption of DOCOMO Systems and the acquisition of DOCOMO DATACOM, which became our subsidiary. We took this opportunity to renew the COMWARE Identity and Corporate Message, which state NTT COMWARE's purpose, important values, and aspirations.

To create the COMWARE Identity, we have formulated the COMWARE New Declaration and NTT COMWARE Group Sustainability Policy. The former sets forth the specific business direction that NTT COMWARE will take up to 2027, while the latter defines our stance on sustainability activities that are inseparable from our business.

In a rapidly changing world, it is becoming increasingly important to solve social issues by achieving sustainability, which means making society, the economy, and the environment sustainable into the future. As the values of consumers, business, and society are changing, companies are shifting from digitalization—which focuses on efficiency—to digital transformation (DX)—which focuses on the added value that can be created through digitalization, and the elements required for this shift are also changing. In light of these changes, we need to constantly create new experiences that suit rapidly changing user values and enhance the stability and performance of social infrastructure.

With this requirement in mind, we aim to create a rich communication society, which goes beyond the efficiency that has been prioritized in the past, by promoting DX while pursuing advanced software capabilities, for example, by integrating them with cutting-edge technologies. While maintaining the quality and reliability that we have always valued, we focus on activities from a business perspective so that we can contribute more than ever to the growth and development of our partners.

Transforming ourselves in a new era of innovation

—In 2023, generative AI has gained momentum. As a proponent of data and AI utilization, what is your approach to generative AI and what is the effect of it on sustainability?

I went to the CES electronics trade show in Las Vegas in January 2023, where I heard nobody mention generative AI; however, two months later, I remember being very surprised that it was being talked about in various media. Companies around the world have since then investigated how to use generative AI, and I feel that they are finally ready to use it.

We are also experimenting with how to use generative AI in our development process and operations, and NTT DOCOMO Group is making use of it for each of its businesses. We have also made progress in sharing information on how to publicize the use of generative AI, including use cases, and are beginning to understand ways of using generative AI from a comprehensive viewpoint.

System development is still a "human" job; nevertheless, human system development may not be able to cope with the society of the future, so we must take the lead in identifying and determining to what extent AI can take over from humans. Some of the systems that we currently operate have been in operation since before today's engineers were born. New technologies have emerged, and aging and obsolete hardware has been replaced; however, the basic concept of software running on it has not changed much from when it was originally developed, although some functions have been added and others have been modified. At the time that software was developed, the developers probably did not expect their systems to last longer than their own lifetimes. Even if such systems have the appropriate documentation in place, the number of pages may be enormous, and the thoughts of the developers may only be understood by them and their knowledge cannot be documented. It is challenging to transfer their thoughts and knowledge to the next generation because the developers and engineers who created a certain system have already retired, and the time is coming when we cannot rely on experts. In other words, the aforementioned "sustainability" is no longer possible if we rely on humans. However, since the functions and tasks provided by the systems are implemented through software, the software base will also continue to be used as long as these functions and tasks continue to be needed. To overcome of this situation, it will be important to transfer our assets and knowledge to AI. Perhaps this situation is what the whole world is facing; we are at the dawn of a new era—a turning point.

—The Innovative Optical and Wireless Network (IOWN) is one of the next-generation technologies. Could you tell us about the technological themes that NTT COMWARE is focusing on toward the deployment of IOWN?

We are applying our expertise in the development and construction of operation systems, which has accumulated over many years of supporting telecommunications services, to achieve the optimal construction and operation of networks and develop management systems for IOWN. Among the components of IOWN, namely, the All-Photonics Network (APN), Digital Twin Computing (DTC), and Cognitive Foundation (CF), we are responsible for the operations through CF and its information-processing system. We are currently developing systems related to orchestration, a basic part of CF that

involves monitoring and automatically operating various network components and information and communication technology (ICT) resources in a cross-cutting manner.

In 2023, as one of the use cases of IOWN, XR Ping Pong using the APN was demonstrated for the first time at Interop Tokyo 2023. The APN was used to connect the event site at Makuhari Messe to another site in Abiko (both in Chiba Prefecture), which are about 100 km apart in optical-fiber length to provide the XR Ping Pong experience. Both players wearing virtual-reality headsets can feel as if they were playing the game at the same place thanks to the IOWN APN's low latency achieving 1/200 that of a normal line.

The APN also makes it possible, for example, to control robots and other equipment installed in a datacenter in Osaka from the operation center in Tokyo as if they were being operated locally in Osaka. This capability has the potential to significantly change the work of development sites, developers, and operators.

For 35 years, I have been unable to sleep in peace

—Could you tell us about your background as well as what you value as a top executive?

After joining NTT in 1988, I started my very first job—except for the training period—in software development, which is what I am engaged in now. Even though NTT had been privatized, I believe the long-distance telephone-call charge at that time was about 1000 yen per 10 minutes. A telephone call was very expensive compared to today, so I thought I wanted to contribute to making it cheaper somehow, and to that end, I wanted to reduce costs related to networks and systems. Around that time, as tasks that had been performed by people were being replaced with software, and specialized hardware was replaced with general-purpose hardware, cost reduction accelerated considerably. Consequently, the telephone-call charge was reduced to the current level about 15 years after I joined the company. I'm not sure how much I was able to contribute to reducing telephone-call charges, but I had achieved what I set out to achieve when I first joined the company. Looking back now, I feel that only the foundation for ICT to solve social issues was in place.

Having spent 35 years working at NTT, during which time I have mostly been involved in system development, I now realize the reality that I cannot sleep in peace. From the time I joined the company until now, the number of systems that are in operation has only increased. Moreover, compared to 35 years ago, systems today have become more pervasive in social life, and the importance of stable system operation has increased. If a system malfunctions, the daily lives of many people will be significantly affected; for example, people will not be able to take the train or do their shopping. This trend is unstoppable. Since my job involves such systems, I have no choice but to recognize that I'm in a situation in which I cannot sleep in peace when I consider the social implications of those systems. Most people would want to avoid such a stressful situation; on the contrary, many people have a sense of pride from work that carries such heavy responsibilities.

No matter how meticulously we prepare to avoid system failures during the development process, system failures can occur unexpectedly. Some failures have a probability of occurring about once every several tens of thousands of years; regardless, no matter what the situation, once a failure occurs, we will do our best to quickly resolve it. Since system failures are often caused by software, after receiving reports of such failures, we must calmly and logically analyze the failure in question, investigate the cause of the failure, consider countermeasures, and make final decisions on these matters. Accordingly, we try to take the stance "do not panic or get angry" when we receive reports of a failure. What's more, since the report comes from the employee facing the failure, if their boss gets upset or angry, accurate information will not be reported, and errors in judgment will surely follow. When we have finally solved the failure, since the cause of the failure is identified, we then try to take the stance "don't let it happen again."

I don't remember how I acquired this attitude or how it came about. It may have started when I became a section manager or project manager. Looking back, I recall that my supervisors and others generally took this stance when dealing with failures.

—Our daily life is supported by your "don't let it happen again" stance. Finally, do you have a message for your engineers, researchers, as well as partners and customers?

I've recently been thinking that I have to change the way I work. Ten years ago, from the perspective of systems must continue to be operated normally, I hoped to welcome tomorrow the same as I had today, but now, I need to welcome tomorrow that will differ from today.

While system developers strive to provide the highest quality and reliability possible, they cannot afford to stop the on-site operations of the people who use the systems that they develop. It is important to think carefully about what kind of work a system is being used for on-site and what is the most important work being done there. Therefore, we are changing our way of thinking and working by focusing more than ever on the efficiency and convenience of our customers' operations. It takes time to change attitudes and way of thinking, but we cannot take too long because not only the NTT Group as a whole but also the world is changing. Nevertheless, we would like to change as quickly as possible while avoiding harmful effects in various areas.

I hope that our engineers and researchers will approach their work keeping in mind how the research and development they are currently engaged in will help solve social issues and think about how to adjust to the ever-changing society and how to update their work accordingly. In the past, we had a sense of a technician's skill, such as the mindset "I can be successful on my own," but the sustainability of society as a whole is no longer possible based on that sense. I hope that you will pass on your experiences and knowledge to the next generation and use them as the foundation for creating something new. I have also tried to eliminate work that relies on my own unique abilities, ideas, and knowledge. I was once told by my boss, "Five years from now, a person in the same position as you should not tackle the same problems," and I thought he was right. And our job is to resolve inconsistencies; otherwise, we are just repeating tasks. Our work is always fraught with inconsistencies, but I want us to strive to eliminate them.

I'll conclude with a message to our customers and partners. NTT COMWARE will continue to provide the level of high quality and reliability as before. As a member of the DOCOMO Group, we will strive to contribute to addressing the challenges facing society. We look forward to continuing our partnership with you.

Interviewee profile

■ Career highlights

Toshio Kashiwagi joined NTT in 1988 and became a board member of NTT COMWARE in 2016, executive vice president of the company in 2020, and assumed his current position in June 2021.

Estimating the True Brightness of Each Pixel by Using Noise in a Video Image

Seishi Takamura
Visiting Senior Distinguished Researcher, NTT Computer and Data Science Laboratories

Abstract

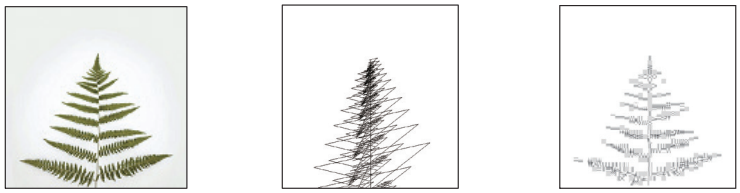
The key to decoding a coded video in such a manner that the decoded video is as clear as possible is to remove noise contained in the original video, which also improves coding efficiency. Many researchers studying imaging have investigated this noise-removal problem; as a result, it is now said that random noise can be reduced to the limit at which only shot noise, a type of noise resulting from the random arrival of photons, remains. Although noise is generally an undesirable phenomenon, research that exploits it to achieve various effects is attracting attention. Seishi Takamura, visiting senior distinguished researcher at NTT Computer and Data Science Laboratories, developed a technology that uses fluctuations (noise) in the brightness of light to estimate brightness beyond the upper limit of digital values. We asked him about this technology and his stance as a researcher: "question everything," "don't be content," "never say no," and "let it lie."

Keywords: image/video coding, noise, 3D-point-cloud image, limit-break sensing

To simultaneously achieve two contradictory goals concerning image/video coding: high reproducibility and improved compression ratio

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

I am mainly researching three technologies. The first is "omni-ambient data-organizing technology" that enables data to be stored and distributed without being discarded and compressed 100 to 1000 times more than possible with general technologies while maintaining higher quality. The second, "real-entity mining technology," removes disturbances such as noise, distortion, out-of-focus, and missing information from captured images, infers the true appearance of the subject, and encodes the images on the basis of that information. I talked about these two technologies in the previous interview (April 2021 issue). The third technology uses fluctuations (noise) in the brightness of light to estimate brightness beyond the upper limit of digital values and accurately estimate the brightness of dark areas. Since April 2022, I have concurrently been a member of a university laboratory researching the omni-ambient data-organizing and real-entity mining technologies with students as



Input image
(fern, natural image)

Our method, 33 bytes
LPIPS=0.7173

JPEG compression, 1580 bytes
LPIPS=0.7209

Fig. 1. Automatic acquisition of rules hidden in natural pattern images and ultra-high compression of those images.

well as at NTT and researching technology for estimating brightness beyond the upper limit of digital values by using fluctuations in the brightness of light at the university.

Let me talk about my ongoing research at the university on a method for automatic acquisition of rules hidden in natural pattern images and ultra-high compression of those images. With this method, if a pattern in nature, such as the pattern on a shell, is converted into a mathematical expression and a manually created algorithm (evolutionary computation engine) is used to automatically generate the pattern (Turing model), or if an algorithm is automatically created and used to automatically generate the pattern (fractal model), a pattern similar to the original pattern can be reproduced (**Fig. 1**). For example, when a fractal model is used to reproduce a photograph of a fern, the learned perceptual image patch similarity (LPIPS), a scale close to human perception, shows an accuracy of 0.7173 (1.0 is a perfect match) achieved in 33 bytes. A JPEG* image of the same LPIPS level would require 1580 bytes, which comparatively indicates that the compression by this method is quite high. I believe that by applying this method, it may be possible to simulate to some extent what is happening inside living organisms.

As I mentioned in the previous interview, by adding one frame of image to the original video and compressing it, it is possible to achieve the same level of video quality with a higher compression rate. I also confirmed that even-higher compression rates can be achieved by using an infrared image for the additional frame.

With Video-based Point Cloud Compression (V-PCC), which is the international standard for three-dimensional (3D)-point-cloud coding, 3D-point-cloud information is decomposed into 2D images for compression, and as shown in **Fig. 2**, the black areas in the 2D images are unnecessary areas

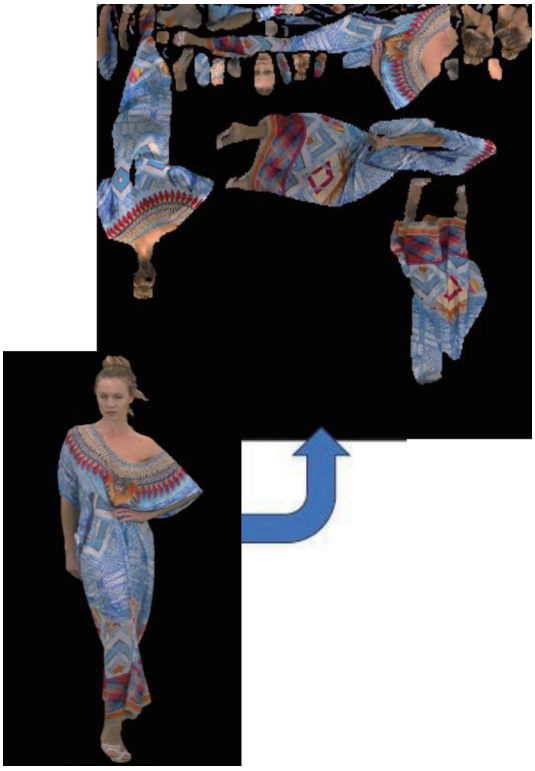


Fig. 2. Converting a 3D-point-cloud image to 2D images.

that are not used for final display, although they are compressed and transmitted. Since the unnecessary areas can be filled in arbitrarily (so-called "padding"), reducing the difference in color, for example, between a padded area and the adjacent area, makes it possible to increase compression efficiency. I am investigating this padding method and aiming to use

* JPEG: Standards for still image coding developed by the Joint Photographic Experts Group, a working group of International Organization for Standardization/International Electrotechnical Commission (ISO/IEC).

it for actual 3D-point-cloud encoding. The effect was confirmed in all four test point clouds that I tested.

—Could you explain the technology for estimating brightness beyond the upper limit of digital values by using fluctuations in the brightness of light?

An image always contains noise, such as shot noise caused by random arrival of photons; random noise, such as thermal noise derived from irregular thermal vibrations of free electrons in a conductor; quantization distortion in the digitization process; and clipping distortion, namely, the top of an output-signal waveform is distorted because the input signal is larger than the standard. Images contain much (about three times) more noise than audio, that is, images have a signal-to-noise ratio (SNR) of around 40 dB, but audio signals have an SNR of around 120 dB (lower SNR indicates greater noise). Video that contains a large amount of noise is coded as it was at the time of capture. Therefore, to obtain a "clear" image, it is necessary to remove the noise, and since removing noise improves the efficiency of encoding, noise removal has been extensively investigated.

Technology that exploits properties of noise has also been investigated and enabled us, for example, to detect falsified areas in images. One effective use of such noise is what we call "limit-break sensing," which makes it possible to infer the "true brightness" of an image beyond the theoretical limit of the image-display system.

Each pixel in an image captured with a camera is digitized as a numerical value (pixel value) that ranges from 0 to 4095 in the case of 12-bit digitization. The highest (brightest) pixel value is 4095, but if the actual brightness of a pixel exceeds 4095, all pixels would be thought displayed at 4095 (saturation value). However, since the image contains random noise, after multiple shots, the pixel value will fall below 4095 at a rate determined by the actual brightness.

In an experiment to verify our limit-break sensing, the row of pixels in the green box on a piece of blank paper in the photo in **Fig. 3** was plotted as a graph with horizontal pixel position on the horizontal axis and pixel values on the vertical axis, and the profile shown in the graph was obtained. When the brightness of the piece of the paper was adjusted to cause partial overexposure (saturated value) and 10,000 images were captured with a separate 12-bit monochrome camera, the average pixel values were plotted and the profile shown in **Fig. 4(a)** was obtained. The

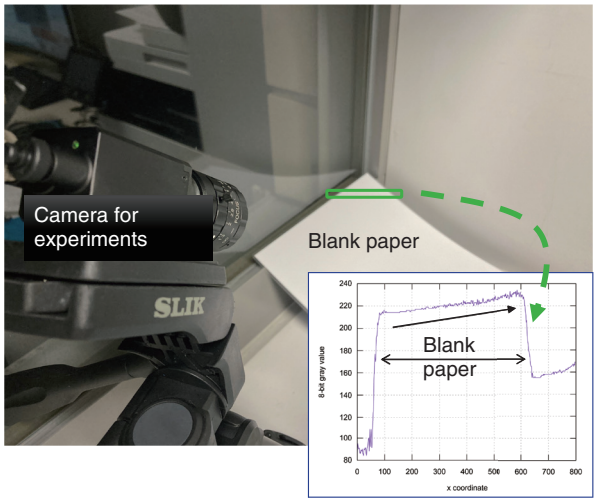


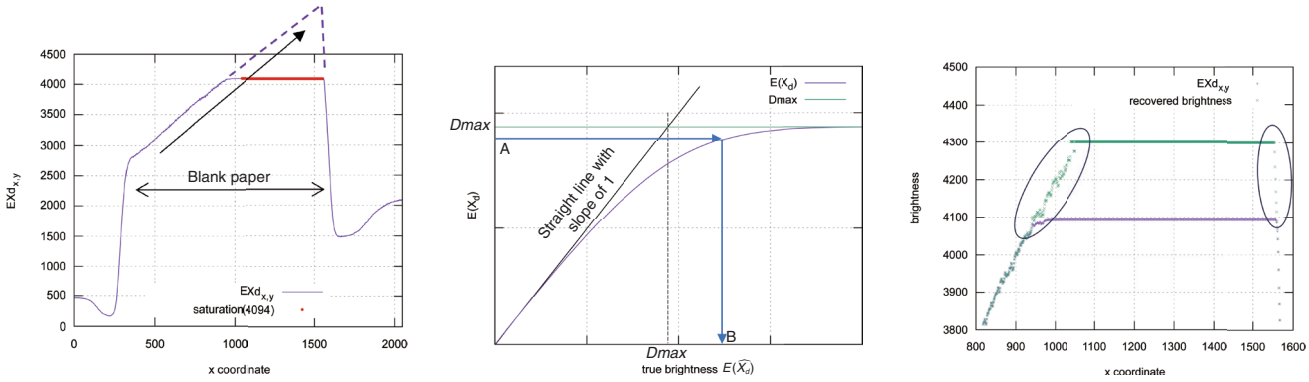
Fig. 3. Experimental scene.

overexposed area is indicated with the red line. By comparing the profile plotted in Fig. 4(a) with that plotted in Fig. 3, it can be estimated that the pixel values of the red-line area would be as shown as the dashed purple line in Fig. 4(a). When the ideal pixel values (true brightness) without clipping or quantization are plotted on the horizontal axis and the expected values of the actual output pixel values with clipping and quantization are plotted on the vertical axis, the relationship shown in **Fig. 4(b)** was obtained as the purple curve. If the average pixels value near the saturation value in Fig. 4(a) are applied to recover the pixel values of true brightness (namely, average pixel value A is converted to B in line with the purple curve in Fig. 4(b)), the values in the green points encircled by the ovals in **Fig. 4(c)**, which exceed the maximum camera output pixel value (4095), are obtained. This indicates that the pixel values of true brightness can be estimated. Note that the fully saturated area (the area in which the pixel value never falls below 4095 in 10,000 shots) cannot be recovered, so the pixel value is determined as 4300.

—You have received many awards for these achievements in a short period, haven't you?

I am grateful that I have received or will receive the following 11 awards and have given six invited lectures since May 2022:

- Standardization Achievement Award from Information Processing Society of Japan (IPSJ)/Information Technology Standards Commission of



(a) (b) (c)

Fig. 4. Average pixel values of captured image and results of recovering pixel values of true brightness.

Japan (May 2022)
- IPSJ Fellow (June 2022)
- FY2022 Excellent Patent Award (1st Class) from NTT Corporation (November 2022)
- Best Paper Award at Picture Coding Symposium of Japan and Image Media Processing Symposium (PCSJ/IMPS) (jointly won by S. Kudo, Y. Bando, S. Takamura, and M. Kitahara) (December 2022)
- Best Poster Award at PCSJ/IMPS (December 2022)
- IE Award from the Institute of Electronics, Information and Communication Engineers (IEICE) Technical Committee on Image Engineering (jointly won by S. Kudo, Y. Bando, S. Takamura, and M. Kitahara) (December 2022)
- Certificate of Appreciation from IEEE Region 10 (December 2022)
- IE Award from the IEICE Technical Committee on Image Engineering (March 2023)
- Fellow from Asia-Pacific Artificial Intelligence Association (AAIA) (July 2023)
- Certificate of Appreciation from Asia-Pacific Signal and Information Processing Association (APSIPA) (November 2023)
- Achievement Award from IEICE (jointly won by S. Matsuo, Y. Bando, and S. Takamura) (June 2024, to be awarded)

Researchers usually receive awards after several years of research, so ten awards within a year and a half of changing my job seems like a lot to me, so my timing must have been good. However, among those awards, the PCSJ/IMPS Best Poster Award in December 2022 and the IE Award in March 2023 were awarded for research I started after April 2022, and I am surprised that they were awarded in the first year of that research. These two cases are good examples of how world-first findings can be obtained without spending a lot of money; for example, the experiment for estimating true brightness that I mentioned used a camera costing no more than 100,000 yen. Because I did not spend much money, I devised experimental methods and conducted experiments with a certain idea of what kind of results I would get, and those experiments turned out exactly as I had presumed. Therefore, I feel a great sense of accomplishment.

Acquiring research opportunities at universities, conducting research in a wide range of fields, and contributing to the increase in the number of IEEE Fellows from Japan

—What kind of research activities will you be focusing on in the future?

I have been researching at a university for a year and a half now, and I have had two things that I could not have experienced at NTT laboratories, namely, obtaining research funds, such as Grants-in-Aid for Scientific Research and other competitive research funds, and giving student guidance, including setting research themes. As well as applying for research funds myself, I also collaborate with researchers outside the university to apply for them. Although it is very difficult to obtain funding, I finally obtained a research fund in 2023. The number of students who I am mentoring has increased from 2 in 2022 to 16 in

2023, and the weight of research guidance on me has increased considerably.

At NTT, I have been delving into research themes within the framework of my laboratory or research projects; in contrast, at the university, research themes are not subjected to such a framework, so I can freely set my themes. However, funds are scarce, so in addition to continuing the research I have been doing, I want to gain knowledge of things that no one else has done in a wide range of fields through experimenting (i.e., desktop theoretical research and thought experiments) while spending as little money as possible. The students I give guidance are not professional researchers like those at NTT laboratories, but apprentice researchers. The number of such students is increasing, and a good environment for expanding the scope of their research has been created. I also want to increase joint research with companies.

I recently attended the Fellow Committee of the Institute of Electrical and Electronics Engineers (IEEE), which is a meeting of 50 members selected from IEEE Fellows around the world to make the final selection of new IEEE Fellows who will become Fellows on January 1 of the following year. I was greatly inspired by the committee members and applicants who had made outstanding achievements. IEEE Fellow is a prestigious honor; however, I noticed recently that the number of Fellows selected from Japan has been significantly decreasing. As I am fortunate to be one of them, I want to contribute—even to a small extent—to increasing the number of Fellows selected from Japan.

Give it a try, let it lie, and think it from a different perspective

—Please tell us what you keep in mind as a researcher.

I keep in mind four maxims that form my stance as a researcher: "question everything," "don't be content," "never say no," and "let it lie."

Many researchers are aware of the importance of questioning everything. Questioning experimental results and phenomena, rather than accepting them on face value, can lead to the truth or falsehood of the results, further results, and new discoveries. Questioning is truly an attitude of pursuit.

The "don't be content" maxim has its origins in my father's greeting speech at my wedding reception, when he said, "My son has done too much (things have gone too well)." I took his words to mean that I had to be careful because I never knew when I might fail, get sick, or lose my footing. For example, when you received an award, if you are complacent about it, you will stop there. The moment you receive an award, it is a thing of the past. The next step has already begun. If you follow a predetermined route, you can only see the road ahead, but if you look aside a little, you will see a different view.

As I mentioned in the previous interview, "never say no" means to give without expecting anything in return. By continuing to give, you will be not only helped by many people but also able to make important contacts. Since you will be able to understand the feelings of those who ask you to do something, you will be able to make a request while considering the other person when you are in the position of the one who is asking. I have served as a committee member, officer, chairperson, and seminar organizer for several academic societies, and through these activities, I have come to realize that experience is the best teacher. I believe that taking on a variety of positions will lead to one's growth.

I will give you two examples of "let it lie." When I applied for the IEICE 100-Year Memorial Paper Award Competition, I first gathered a lot of information, continued gathering information without writing even though I wanted to, and only wrote the paper after "letting it lie" (leaving it as is and giving it time), and I received the Best Paper Award. In my research on uniform color space, I had been trying and failing to come up with a variety of methods to solve a problem. While relaxing at the beach on holiday, it suddenly occurred to me to apply a method used in structural analysis, and by applying that method, I was able to find a way to solve the problem which led to receiving the Niwa-Takayanagi Award (Best Paper Award) from the Institute of Image Information and Television Engineers. I think both of these awards were the result of having a distance from the research and being able to look at it from different perspectives.

—Please give a message to future researchers.

Some researchers carry out research in accordance with their rigid plans, and other researchers do in a more flexible way, but I think it is good to have both types of researchers. Although I tend more toward the flexible type, I still managed to proceed with my research. In other words, since research is often subject to direction changes due to unexpected results, I think that it has been better to be flexible and repeat

trial and error. That may seem contradictory to the above-mentioned “let it lie” maxim, but what I do is give it a try, let it lie, then change my perspective and think about it, and sometimes that kind of “give it a try” attitude is necessary. Being young has two advantages: you have relatively more free time, and you don’t have to be afraid of losing something since you don’t have many achievements. I believe that these advantages lead to freedom of ideas; therefore, I think it is good to think freely and give things a try.

■ Interviewee profile

Seishi Takamura received a B.E., M.E., and Ph.D. from the Department of Electronic Engineering, Faculty of Engineering, the University of Tokyo, in 1991, 1993, and 1996. His current research interests include efficient video coding and ultrahigh-quality video processing. He has served as associate editor of IEEE Transactions on Circuits and Systems for Video Technology (2006–2014), editor-in-chief of the Institute of Image Information and Television Engineers (ITE), executive committee member of the IEEE Region 10 and Japan Council, and director-general of ITE affairs. He has also served as chair of ISO/IEC Joint Technical Committee (JTC) 1/Subcommittee (SC) 29 Japan National Body, Japan head of delegation of ISO/IEC JTC 1/SC 29, and as an international steering committee member of the Picture Coding Symposium. From 2005 to 2006, he was a visiting scientist at Stanford University, CA, USA.

He has received numerous academic awards including ITE Niwa-Takayanagi Awards (Best Paper in 2002, Achievement in 2017), the IPSJ Nagao Special Researcher Award in 2006, PCSJ Frontier Awards in 2004, 2008, 2015, and 2018, the ITE Fujio Frontier Award in 2014, and the Telecommunications Advancement Foundation (TAF) Telecom System Technology Awards in 2004, 2008, and in 2015 with highest honors, the IEICE 100-Year Memorial Best Paper Award in 2017, the Kenjiro Takayanagi Achievement Award in 2019, Industrial Standardization Merit Award from Ministry of Economy, Trade and Industry of Japan in 2019 (as an individual) and in 2020 (as NTT team), PCSJ/IMPS Best Paper Award and Best Poster Award in 2022, Certificate of Appreciation from IEEE Region 10 in 2022, IE Award in 2022 and 2023, and Certificate of Appreciation from APSIPA in 2023.

He is an IEEE Fellow, IEICE Fellow, ITE Fellow, IPSJ Fellow, AAIA Fellow, and member of Japan Mensa, the Society for Information Display, and APSIPA.

High-performance Optical Devices with Integration of Heterogeneous Materials Accelerating the Future of Photonics-electronics Convergence Technologies

Tatsurou Hiraki
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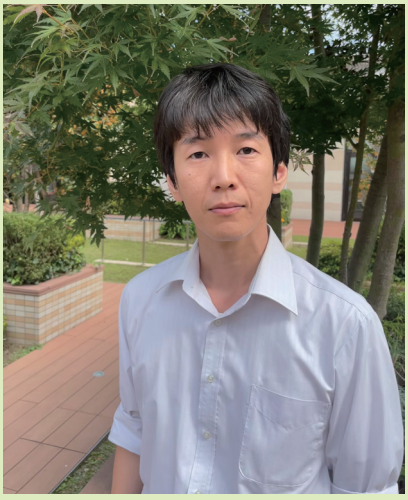


Abstract

The transmission capacity of electrical wiring has come to be viewed as a bottleneck in system processing performance in conjunction with increases in datacenter traffic and the development of high-performance large-scale integration (LSI) by transistor miniaturization. To solve this problem, there is a strong demand for photonics-electronics convergence technologies for applying optical transmission that can easily increase capacity to wiring positioned close to electronic circuits. In this article, we talk with NTT Distinguished Researcher Tatsurou Hiraki to learn about his research and development of "high-performance optical devices with integration of heterogeneous materials" as a rising researcher opening up a new future.

Keywords: photonics-electronics convergence, integration of heterogeneous materials, optical device

Achieving high-performance optical devices using the best features of different materials

—Dr. Hiraki, please explain "high-performance optical devices with integration of heterogeneous materials" that you are currently researching.

In high-performance optical devices with integration of heterogeneous materials, I am researching and developing means of drawing out high performance by combining two or more materials in an optimal arrangement in contrast to past optical devices fabricated with a single-material system. As background to this research, I can point out dramatic increases in datacenter traffic and ongoing improvements in large-scale integration (LSI) performance. Because

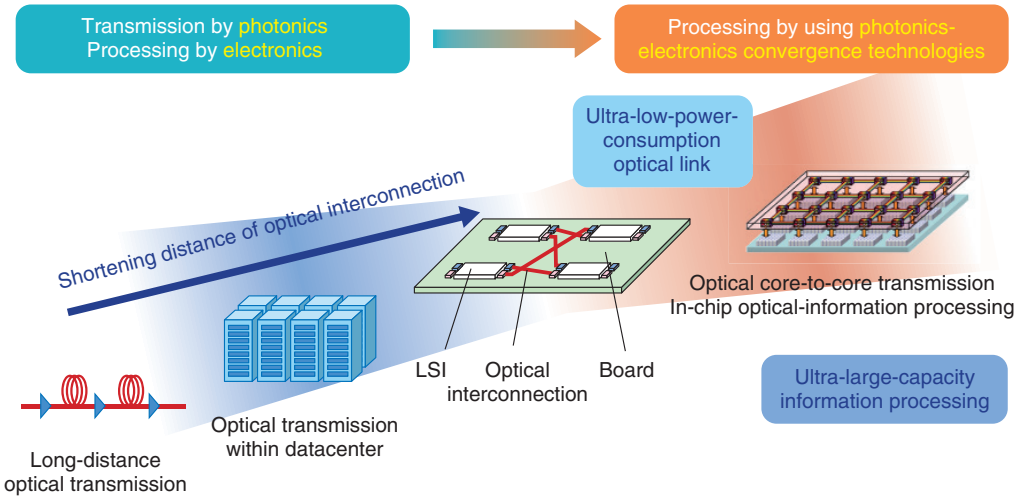


Fig. 1. Changes in application areas of photonics-electronics convergence technologies [1].

of these developments, transmission capacity of electrical wiring is becoming a bottleneck in system processing performance, and as a result, increasing the capacity and reducing the power consumption of optical wiring at datacenters and in computers is becoming increasingly important (**Fig. 1**).

Immediately after entering NTT, I took up the research and development of devices for optical communication using silicon. At that time, however, I had to face the fact that these devices were inherently limited in performance due to the material properties of silicon, something that I was not pleased about. Then, after several years had passed and worrying every day about what I should research, a reorganization of NTT laboratories combined the group I was in with a department working on the integration of compound semiconductor lasers on silicon substrates. At first, I was a bit confused about the change in research themes, but thinking that "well, we are all one group now," I actively took up the study of compound semiconductor technology that I had not been very familiar with up to then. As a result, since there were many things that I had so far given up on due to the material limitations of silicon, I came to think that maybe I could solve some of those problems by using compound semiconductor materials. But then, focusing on the fact that both silicon and compound semiconductors have advantages and disadvantages, I also came to wonder whether an optical device structure that combines only the best parts of both types of materials could be used to fabricate various types of optical devices superior to those of the past without being limited to lasers. This research that I began in this way is now my current research theme that aims to achieve high-performance optical devices that combine two or more materials.

—What are the issues surrounding conventional optical devices using only a single material?

In the past, optical devices were fabricated separately using silicon, compound semiconductor material, or amorphous material, for example. Each type of material has its advantages and disadvantages. For example, indium phosphide (InP)-based compound semiconductors widely used in the fabrication of lasers feature excellent emission efficiency. Additionally, the advantage of a diode structure having n-type (negatively charged) and p-type (positively charged) regions is low electrical resistance, low optical loss, and high phase modulation efficiency in the n-type region. The disadvantage here, though, is that optical loss in the p-type region is extremely large. As a result, p-type semiconductors have become a limiting factor in the structure and performance of lasers and optical modulators. Silicon, however, which is widely used in the fabrication of electronic circuits, features optical loss in p-type regions less than that of InP-based materials and has properties conducive to low-cost, mass production. The emission efficiency of silicon, however, is extremely low, and it is inferior to InP-based materials in terms of electrical resistance, optical loss, and phase modulation efficiency in the n-type region, so

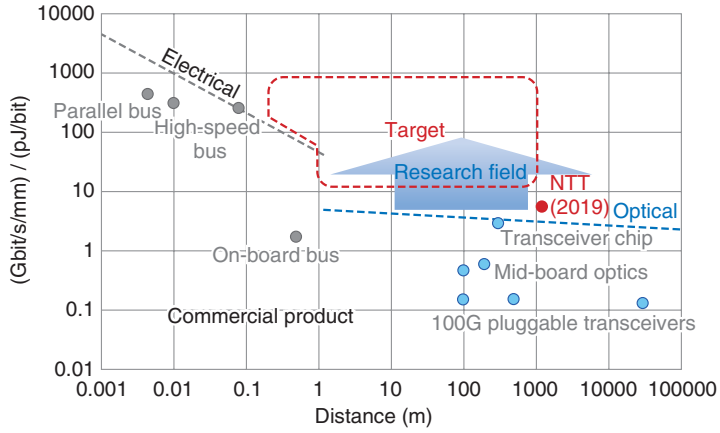


Fig. 2. Products and research and development trends related to interconnection [1].

those weak points of silicon material can limit the performance of optical devices and target applications. Additionally, while many types of materials exist for configuring optical devices, it is extremely difficult to find a material system that can satisfy all requirements by itself, so performance limitations governed by the properties of each type of material have been a major hurdle.

Moreover, given that each material has its strong points and weak points, the general approach today in the field of optical devices is to first fabricate each optical component with optimal materials and to then mount each in a single module. In this type of process, however, integration density is limited by the size of each component, mounting precision, etc. It is therefore very difficult to use this conventional technique in achieving photonics-electronics convergence that aims to achieve high-density integration of optical transceivers at positions near electronic circuits (**Fig. 2**).

With these problems in mind, I have undertaken the integration of heterogeneous materials—mainly compound semiconductors and silicon—with the aim of achieving both high performance and high integration in optical devices like optical modulators and semiconductor lasers by combining the strengths of both types of materials.

—Please tell us about some of the achievements you have already made in this research.

For example, a silicon Mach-Zehnder modulator fabricated by conventional silicon-photonics technology suffered from performance limitations due to a tradeoff between modulation efficiency and optical loss. In my research, I overcame this performance limitation by combining low-loss p-type silicon and high-efficiency n-type InP-based material and achieved approximately four times or greater modulation efficiency (0.09 Vcm) with low optical loss compared with conventional technology. Additionally, by fabricating a laser that combines a membrane InP-based laser structure and a compact and low-loss Si optical waveguide, I reduced the optical loss caused by p-type InP-based material and achieved a compact wavelength-tunable laser. Recently, moreover, by developing an electro-absorption modulator (EAM) that can be integrated together with such a membrane laser on a low-loss Si waveguide, I succeeded in integrating an O-band EAM and optical source, which had been difficult to achieve by silicon optical circuits, and demonstrated 100 Gbit/s high-speed modulation operation (**Fig. 3**). These research achievements combine the respective strong points of silicon and compound semiconductor materials thereby drawing out a level of performance beyond conventional levels. They can be viewed as examples of successfully achieving high-density integration using compact Si optical circuits.

Furthermore, to integrate a high-performance wavelength filter with such a laser or optical modulator, I am working on technology for fabricating a silicon-nitride (SiN) waveguide having optical propagation loss about one order of magnitude smaller than that of conventional optical waveguides using silicon. This technology opens up the possibility of fabricating low-loss waveguides in a low-temperature process that inflicts no thermal damage on compound

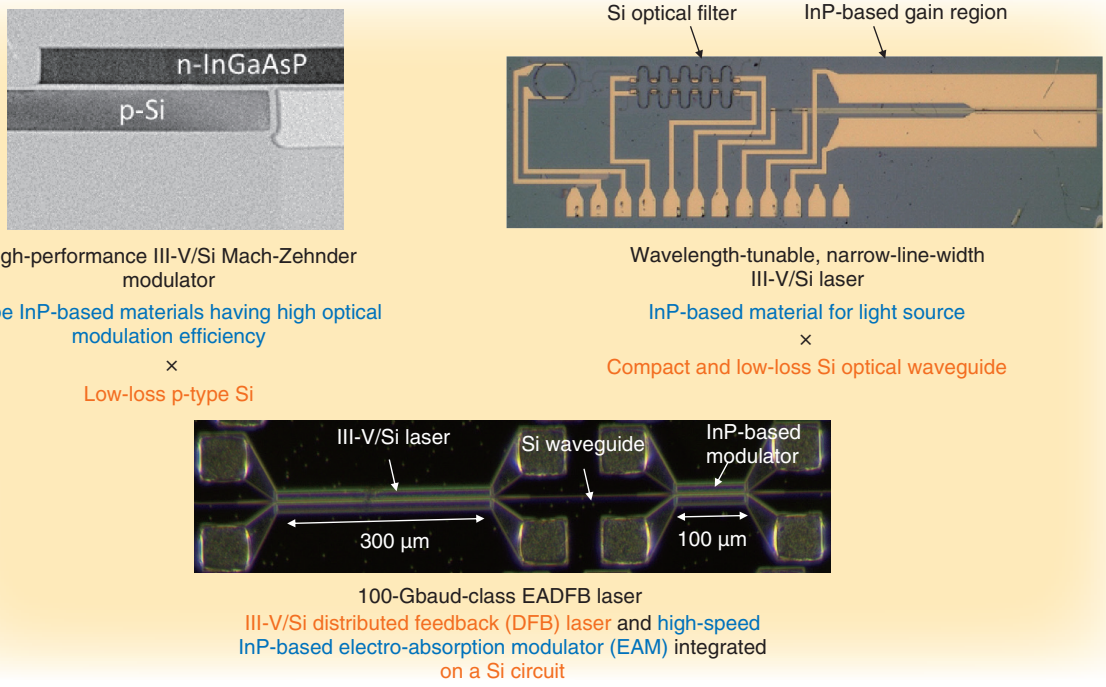


Fig. 3. Research achievements to date.

semiconductors.

—What hardships have you had to face in your research?

Looking at my research up to now, perhaps there are some people who would think, "It makes sense that combining materials with different features would improve performance." It certainly would be great if combining materials could immediately improve performance, but in actuality, attempting to do so often ends in failure. The true difficulty lies in "fabrication technology" that aims to achieve integration without losing the good features of each of the materials being used. For example, the technology required for fine processing differs between the two types of materials of silicon and compound semiconductors, and how to fabricate a device without negatively affecting the material properties of both is a major research issue. Even if the performance that can be drawn out by combining materials can be understood theoretically by calculations, there are many problems that must be faced at the fabrication stage, and if working with new materials or structures, there is nothing but failure at first. The research of such fabrication technology is a trial-and-error process from one day to the next, and most of that research period is kept private and hardly talked about in research papers or elsewhere. Indeed, it may take several years until a paper can be presented, and in this sense, research can be mentally challenging.

Believing in your research with all your heart is important to prevent yourself from becoming totally depressed during research, but it is also true that sometimes the direction of your research must be changed along the way. In actuality, there are many fatal problems that come to light when starting a fabrication project, and it may be necessary to remain calm and decide "staying on this course any longer is not going to work!" It is important that you do not cling to any one matter and that you retreat as needed. In addition, I believe that it is important within such a process of failing to actively search out the cause of failures and to increase the ratio of meaningful failures that can create a path to subsequent research. It is exactly an increase in meaningful failures that can be a major turning point in whether you eventually produce good research results.

Aiming for core technologies in photonics-electronics convergence while exploring new research for the future without clinging to the past

—Dr. Hiraki, what is your research vision going forward?

At NTT, I belong to three research laboratories: NTT Nanophotonics Center within NTT Basic Research Laboratories, NTT Device Technology Laboratories, and NTT Device Innovation Center. NTT Basic Research Laboratories is engaged in basic research covering a wide range of fields from theoretical research to device fabrication technology. Here, you get the impression that each of its researchers is academically taking on the challenge of new things. NTT Device Technology Laboratories is engaged in research that pursues academic novelty while also being conscious of social needs with a view to practical application in the future. While themes that reflect the mission of the organization advance steadily among all the research groups here, individual researchers also adopt original approaches. Finally, NTT Device Innovation Center is the organization that, among all the organizations that I belong to, is the most practical in its orientation. It is involved in the commercialization of devices while working in cooperation with NTT Group companies and other companies that actually produce the devices.

In this way, I am involved in research and development spanning a wide range of phases. This kind of environment where a researcher can undertake a wide variety of technical fields all at once from communication infrastructures to basic research is truly a great strength of NTT laboratories. In addition, it is an especially beneficial environment where I myself as a researcher can grow. Although I knew practically nothing about optical communications and optical devices before entering the company, I was able to start learning from the very beginning thanks to the gracious support I received from many top-class experts residing at NTT. There were also many times when I noticed the good points and bad points of my own technology through the discussions I had with researchers in other fields, so being able to come up with fresh ideas at any time in this way is likewise a great strength of NTT.

When taking up a new challenge, I am fortunate in having opportunities to receive the cooperation of experts having technology that I lack, which gives me many chances to produce research achievements having a speedy impact or to establish new technology that might give rise to a paradigm shift. Among the readers of this article, there might be many whose current field of specialization differs from the research themes at NTT laboratories, but I think that viewpoints from other fields have the potential of making great changes to existing research. To any readers who are looking for an opportunity to change fields and pursue new research, I would say, “Let’s work together in accelerating the coming of a new future in optical communications.”

Reference

[1] T. Sakamoto, N. Sato, and T. Segawa, “Photonics-electronics Convergence Technologies for Disaggregated Computing,” NTT Technical Review, Vol. 19, No. 7, pp. 58–64, July 2021. https://doi.org/10.53829/ntr202107fa8

■ **Interviewee profile**

Tatsurou Hiraki received his M.E. degree from Tohoku University in 2011 and entered NTT in the same year. He is a member of NTT Device Technology Laboratories, NTT Device Innovation Center, and NTT Nanophotonics Center within NTT Basic Research Laboratories. He received his Ph.D. degree in engineering from Tohoku University in 2017. Since 2022, he has been a Distinguished Researcher at NTT Device Technology Laboratories. He is engaged in the research and development of photonic integrated circuit technologies using silicon, compound semiconductors, and amorphous-material optical waveguides and optical devices for communications applying those technologies.

Innovating a Sustainable Future for People and Planet NTT R&D Initiatives

Akira Shimada
President and Chief Executive Officer, NTT Corporation

Abstract

This article presents the research and development (R&D) activities of NTT as it continues to innovate a sustainable future for people and the planet. It is based on the keynote speech given by Akira Shimada, president and chief executive officer of NTT Corporation, at the "NTT R&D FORUM 2023 — IOWN ACCELERATION" held from November 14th to 17th, 2023.

Keywords: IOWN, All-Photonics Network, large language model

1. Major challenges facing society

I would like to point out three of the major challenges facing society today.

The first challenge is the severe labor shortage. In addition to the decline in workforce, we in Japan are also facing the so-called "Year 2024 Problem" resulting from the enforcement of new overtime regulations, which has become a major issue in the construction and transportation industries.

The second challenge is the environmental impact of energy consumption that has become a global issue. The dramatic increase in data volume has led to a surge in electricity consumption, and energy demand, especially in urban areas, is growing. We need to harmonize the addressing of environmental and energy issues without stopping the progress of technological innovation.

The third challenge is that, with the advent of an aging society, rising healthcare costs have become a major factor contributing to the strain in Japan's fiscal situation. It is also necessary to create a well-being society that enables various people to live a healthy and fulfilling life.

We aim to address these challenges through NTT's research and development (R&D) centered on the Innovative Optical and Wireless Network (IOWN), a next-generation communication and computing infrastructure that achieves high capacity, low latency, and low power consumption, and NTT's large language model (LLM) "tsuzumi," a compact and power-saving large-scale language model with world-class language-processing capabilities.

2. IOWN

Our ultimate goal for IOWN is to increase power efficiency by 100 times and transmission capacity by 125 times and to reduce end-to-end delay by 1/200th.

As a roadmap for IOWN, we started the commercial launch of IOWN1.0 at the end of fiscal year (FY) 2022 (**Fig. 1**). I will explain some use cases of IOWN1.0 later. We plan to develop photonics-electronics convergence (PEC) devices for inter-board connection by FY2025 as IOWN2.0. Subsequently, we will develop a device for inter-chip connection as IOWN3.0 by FY2028 and aim to achieve intra-chip connectivity with PEC as IOWN4.0 by FY2032.

The important point of IOWN2.0 is to apply PEC devices to computing (**Fig. 2**). A high-capacity, low-power, and compact optical engine is key to achieving this goal. Using this optical engine and a switchboard equipped with the optical engine, the xPU (x processing unit) and memory can be connected with optics instead of electricity to achieve ultra-low power consumption IOWN computing. IOWN computing

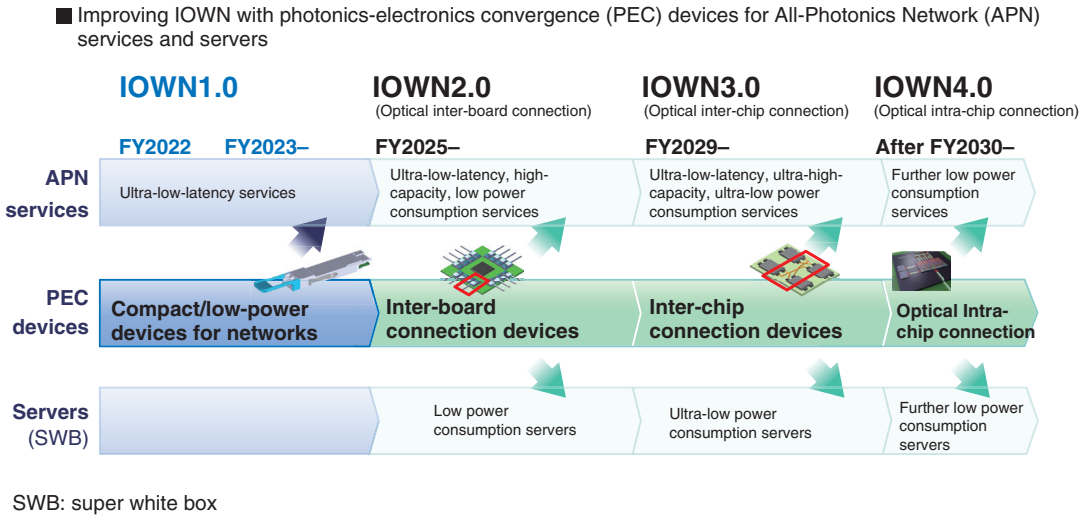


Fig. 1. Roadmap for IOWN.

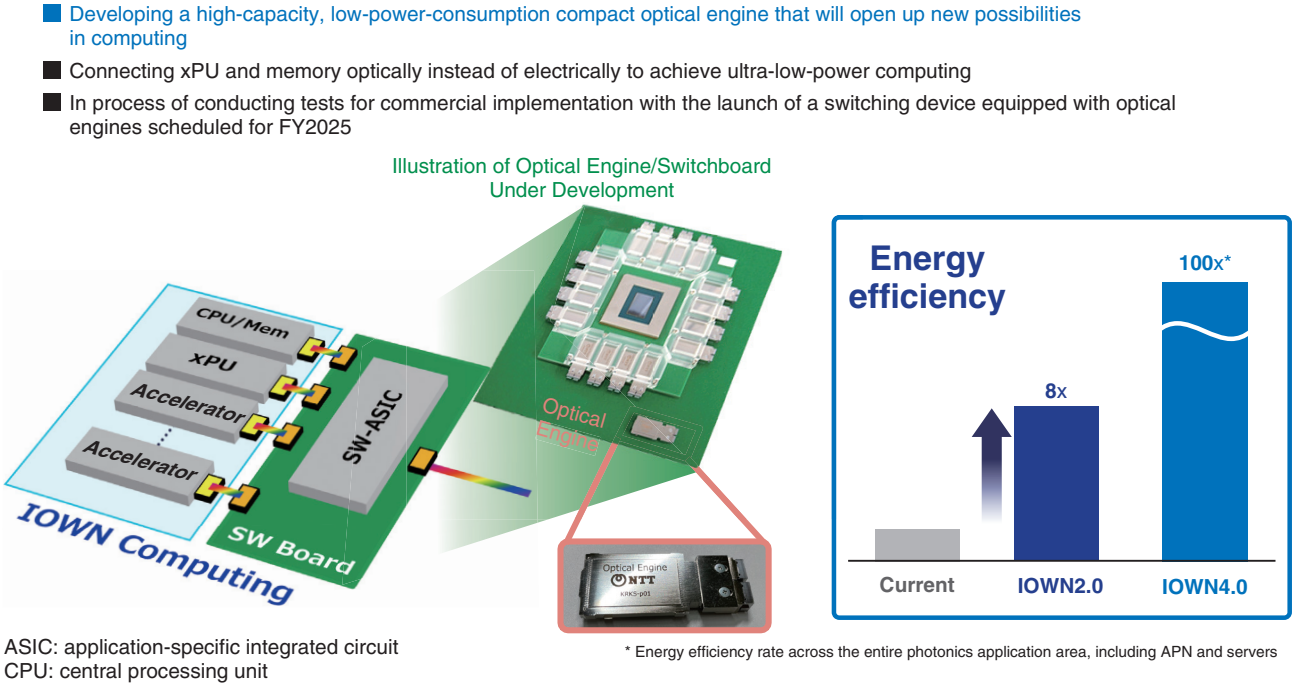


Fig. 2. IOWN2.0 – Optical-based computing.

can increase power efficiency by up to eight times compared with conventional computing.

The development of the optical engine is basically complete, and tests are being conducted for its commercial use. In FY2025, we plan to start providing switchboards equipped with optical engines. We are planning to let you experience such service using IOWN2.0 at EXPO 2025 Osaka, Kansai, Japan. The theme of NTT Pavilion is "Architecture with Emotion" (**Fig. 3**). The "living pavilion" will be represented by "cloth" covering the pavilion that moves according to the excitement of the visitors and

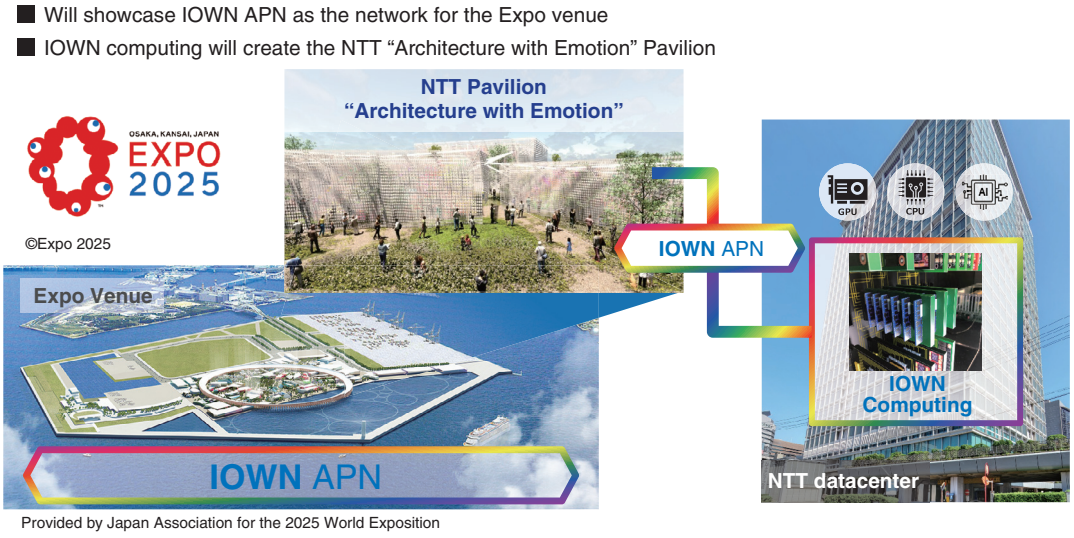


Fig. 3. IOWN at Expo 2025 Osaka, Kansai, Japan.

changes expression according to natural light and wind. These are achieved through remote artificial intelligence (AI) analysis using the All-Photonics Network (APN) and IOWN computing.

3. NTT's LLM "tsuzumi"

Next, I would like to introduce NTT's LLM, "tsuzumi," the result of over 40 years of research and expertise on natural-language-processing technology. This LLM has four key features.

The first key feature is its linguistic capabilities. It supports Japanese as well as English and a variety of other languages. We are very proud of its world-class performance in a variety of Japanese benchmarks.

The second key feature is its high level of cost performance. Demonstrating low power consumption and high graphics processing unit (GPU) performance while having the same high performance as OpenAI's Generative Pre-trained Transformer 3 (GPT-3) results in its sustainability.

The third key feature is its low cost of tuning. It is capable of frequent information updates and customization based on industry- and organization-specific data.

The fourth key feature is its functionality with various input formats such as diagrams, charts, and tables. It is the first Japanese model that can read contracts and invoices containing tables.

We compared tsuzumi's Japanese language capabilities with LLMs of other companies. It has world-class performance in Japanese, which is better than OpenAI's GPT-3.5 and significantly exceeds other domestic LLMs of the same class. It even shows English capabilities equivalent to Meta's world-class LLM and is capable of handling other languages.

A comparison of cost performance, a key feature mentioned earlier, with GPT-3-scale LLMs is shown in **Fig. 4**. Because it requires fewer GPUs, tsuzumi is able to achieve similar performance as GPT-3-scale LLMs with 1/25th the hardware costs for training. It also requires only 1/20th the cost for use. It uses less power because it requires fewer GPUs.

LLM tsuzumi will be launched in March 2024. We began expansive internal and external trials in October 2023 and are already starting to see the results. Beginning in April 2024, it will not only be able to read documents and graphics but will also be able to recognize voices and tones, such as children's voices, and will have successive releases in other languages in addition to Japanese and English.

4. Addressing social challenges using NTT's R&D technologies and services

I will now introduce our efforts to address social challenges using NTT's R&D technologies and services such as IOWN and tsuzumi.

4.1 Addressing the severe labor shortage

In the construction industry, labor shortages, long working hours, and the aging of engineers are

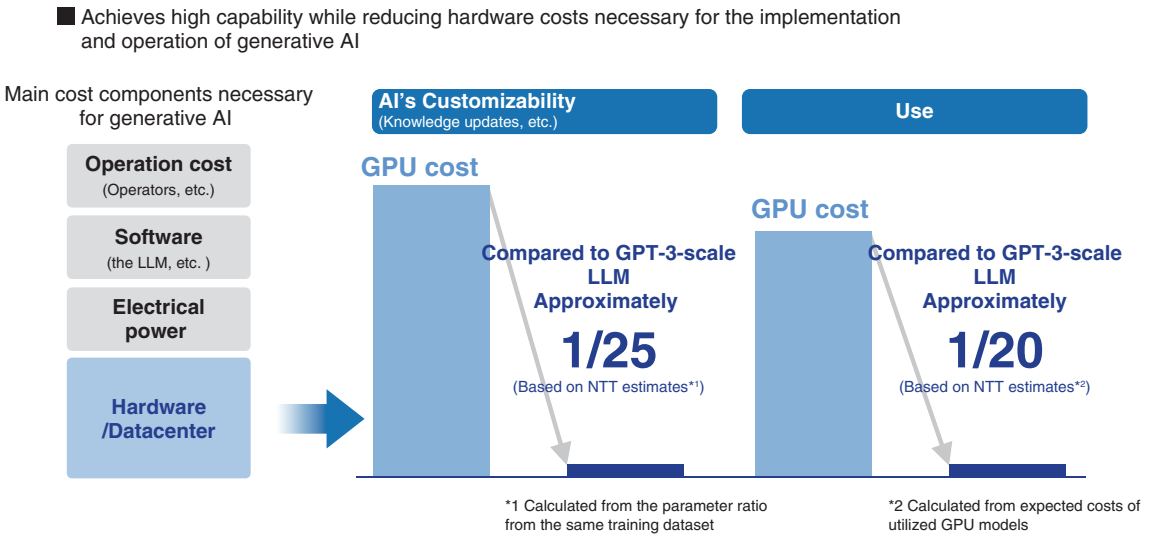


Fig. 4. High level of cost performance.

becoming more serious. Since the upper limit on overtime work will be enforced from 2024 in Japan, work-style reforms such as operational streamlining and employment diversification are required. In response, NTT, in cooperation with EARTHBRAIN, JIZAIE, and Takenaka Corporation, is promoting remote control of construction equipment for efficient and safe construction. Specifically, by using the IOWN APN—which has high-capacity, low-latency, and no lag fluctuations—in remote operations, it will become possible to operate construction equipment as if they were being operated onsite.

I will present a case study on remote content and broadcast production, which we are currently pursuing with Sony. Whenever there had been a match or event held at a stadium anywhere in the country, large-scale production spaces, personnel, equipment, broadcast vehicles, and other production items have always been needed. By using the APN to connect broadcast stations to stadiums around the country, it will become possible to achieve remote content production instead, which would reduce the amount of space, personnel, equipment, broadcast vehicles, and other production items needed at the time of the event. On November 13, we entered into an agreement with Sony to collaborate further on this.

I will now present another case study involving collaboration with Tokio Marine & Nichido Fire Insurance. We are aiming to improve the productivity of contact centers by using tsuzumi. Tokio Marine & Nichido Fire Insurance has more than 10,000 operators in the accident-response department nationwide who provide daily support for non-life insurance. Operators listen carefully to the circumstances of the accident and injuries on the phone, and after the call, they organize their responses and input necessary information into the system. This after-call work takes about 800,000 hours per year. We have already made small reductions through voice mining, etc., but by combining tsuzumi with voice mining, we can make progress in summarizing and organizing the content of the correspondence and expect to reduce the operation of after-call work by more than 50%.

I will talk about autonomous driving systems. Regarding public transportation, such as local buses and taxis, the shortage of drivers in the regions has become apparent. Autonomous driving technology is expected to address various social issues. NTT has invested in May Mobility, a U.S.-based company that has strengths in autonomous driving technology, and have acquired exclusive rights to sell their autonomous driving solutions in Japan. Through cooperation with several local governments facing transportation issues, we will first provide services through community buses then expand to many other types of autonomous vehicles to address various social issues, including driver shortages.

4.2 Addressing the environmental impact of energy consumption

In a data-driven society, huge amounts of power are required to process rapidly increasing amounts of

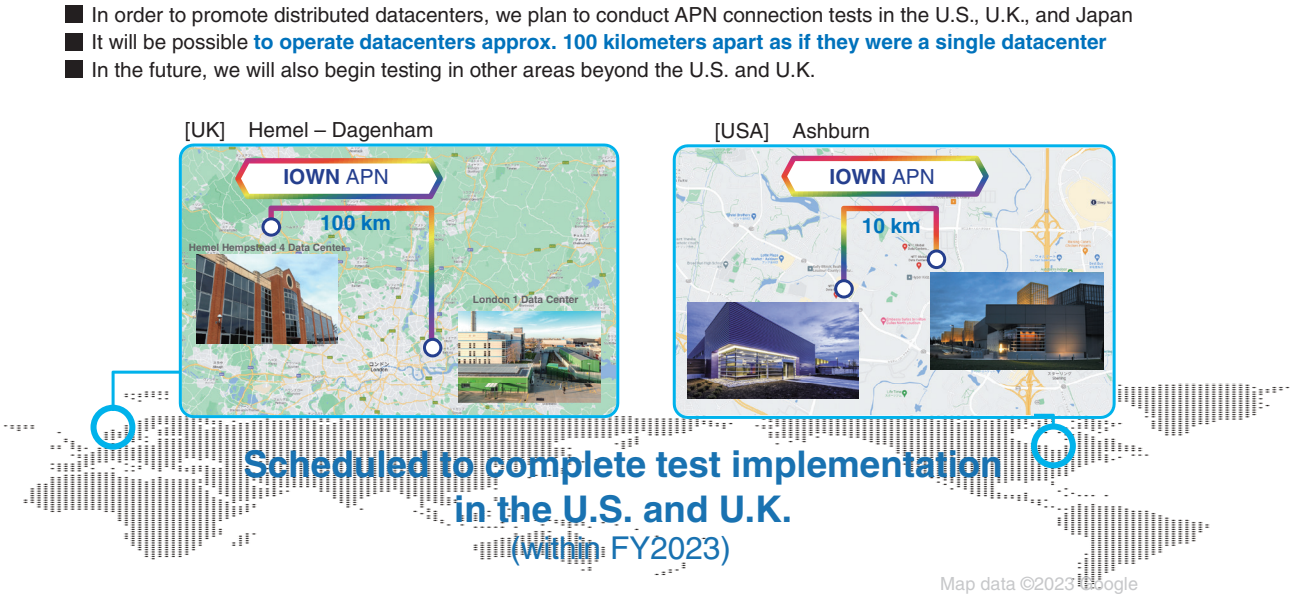


Fig. 5. Creating distributed datacenters – Implementing the APN between datacenters in overseas markets.

data. For example, the power consumption of datacenters is expected to increase by approximately 6 times in Japan and 13 times in the world from 2018 to 2030 as the volume of data handled increases. AI will continue to grow and expand, but LLMs such as ChatGPT require as much as 1300 MWh of power for one training session. This is equal or greater than the amount of electricity generated by operating one nuclear power plant for one hour. In this data-driven society, the need for datacenter computing will continue to grow and consume more power than ever before. NTT is addressing this expanding power-consumption problem with distributed datacenters using the APN. I introduce three use cases of how distributed datacenters can be used.

The first case study is using the APN to connect datacenters in Japan for use in training LLMs. To train tsuzumi, we used the APN to build a collaborative cloud and on-premises environment. We have a large volume of training data at our Yokosuka laboratory, but due to power issues, we found that it was difficult to install GPU equipment in that area. We therefore used the APN to connect the GPU cloud in our datacenter in Mitaka with our training data storage in Yokosuka to conduct the training. Therefore, we were able to create an environment that was completely comparable with the local environment.

The second case study is in collaboration with Oracle. We are currently conducting testing to use the APN to connect Oracle's cloud with NTT's datacenters. This will be possible to keep important data at hand while linking only the data necessary for analysis to the cloud in real time.

The third case study is an example of implementing the APN between NTT datacenters overseas. To achieve distributed datacenters, we are advancing APN-connectivity test preparations between datacenters, not only in Japan but also overseas, initially in the United Kingdom and United States. In the U.K. for example, it will be possible to operate a datacenter in London and another approximately 100 kilometers outside the city through transmission lines as if they were a single datacenter (**Fig. 5**). We plan to complete this testing during FY2023. We also plan to expand this to other regions of Asia and other areas beyond the U.S. and the U.K.

4.3 Addressing rising healthcare costs due to an aging society and the pursuit of a society with greater well-being

I would like to talk about the challenges in the medical field. While the introduction of digital patient records has been advancing in Japan, patient record-keeping methods for even the same symptoms, for example, differ among hospitals and doctors, making it extremely difficult to collect and use patient record data. As tsuzumi is lightweight, flexible, and capable of learning patient data securely, it

can interpret medical data recorded by doctors and arrange them in appropriate expressions and a uniform format to make data more suitable for analysis. At Kyoto University Hospital, tsuzumi is already being used to structure the data from digital patient records. Dr. Manabu Muto from Kyoto University said, "As digital patient record structuring and analysis advances by utilizing tsuzumi, it becomes possible to deliver effective personalized medical treatment for each individual, or what is called precision medicine." This will lead to the optimization of medical expenses across society as a whole. With structured digital patient record data, it will also be easier to analyze medical data relating to the effects and side effects of medication. We believe this will lead to the effective development of pharmaceuticals by reducing development time and costs.

Finally, I introduce our efforts to achieve a well-being society. DJ MASA, or Mr. Masatane Muto, is a former employee of the advertising firm Hakuhodo and has been active in music as a DJ. In 2014, at the age of 27, he was diagnosed with amyotrophic lateral sclerosis (ALS), an incurable disease in which the motor nerves that enable the body to move begin to break down, leading to gradual loss of movement. One can hear but is unable to respond. His first thought was, "Is this it, is my life over, why me?" Then he thought, "Even if my body is disabled, there has to be a way that I can express myself with technology." He now participates in many events as a DJ by playing music with gaze-control. NTT wanted to collaborate with him, so we asked, "What would you like to do if you could move your body?" To which he responded, "I would like to party with the audience." To make this a reality, we combined the virtual and real worlds to enable him to engage the audience using an avatar. At the Ars Electronica Festival, a world-renowned media art festival, DJ MASA communicated with the audience in English using his voice and performed live through an avatar. The audience responded enthusiastically when the avatar's hands were raised by him; thus, the performance was a great success.

NTT is researching and developing technologies that will give people with even serious disabilities, such as ALS, the ability to communicate. For people with serious disabilities, physical expressions can be difficult, but by using motor-skill-transfer technology that can respond to even small amounts of muscle movements and brainwaves, an avatar can be used to produce physical expressions. For people who have lost their ability to speak, we are working on cross-lingual speech-synthesis technology that can synthesize the voice they lost and make it possible for them to not only converse with their voice in Japanese but also in English and other languages.

Going forward, NTT will continue to take on challenges to innovate a sustainable future for people and the planet.

IOWN ACCELERATION —Imagination and Creation—

Sachiko Oonishi
Executive Vice President, Head of Research and Development Market Strategy, NTT Corporation

Abstract

This article introduces NTT research and development (R&D) efforts from two perspectives: the "product-out" approach and the "market-in" approach. It is based on the keynote speech given by Sachiko Oonishi, executive vice president, head of Research and Development Market Strategy of NTT Corporation, at the "NTT R&D FORUM 2023 — IOWN ACCELERATION" held from November 14th to 17th, 2023.

Keywords: IOWN, R&D, food, health, humanity

1. Introduction

The Research and Development Market Strategy Division in NTT Corporation was inaugurated in June 2023. Our mission is to create new value by fusing our traditional "product-out" research and development (R&D) approach with marketing. This article introduces our R&D work from two perspectives: the product-out approach and the "market-in" approach.

The Innovative Optical and Wireless Network (IOWN) has grown out of exploring and exploiting technologies that connect people, which originated from the telephone. It is the result of the product-out approach to R&D. There is also the market-in approach, in which we create a vision of people, society, and the planet and of how we can create a future that is sustainable yet also exciting to live in then push forward the kind of R&D we need to make this vision a reality.

A technology truly takes its first breath when it is implemented as part of society. Four years since the announcement of IOWN, I hope that you can now feel this idea coming to life and can create in your minds a mental picture of the exciting future that will ultimately make it possible.

2. NTT's R&D from the product-out perspective

2.1 The starting point of technologies that connect people

Figure 1 shows the very first telephone (in Japan) back in 1890, 133 years ago. This is the starting point of technologies that "connect people." When you telephoned someone in those days, how long did it take before you could actually start talking? You couldn't dial these early phones; after lifting the receiver, you had to connect to an operator. It worked as follows: in the morning, say, you'd tell the operator "Can I speak to Ms. A, please?" and in the evening, 6 hours and 7 minutes later, you'd finally get to talk to Ms. A. You could also pay double the fee for an "urgent" connection, which took only 2 hours and 26 minutes.

Following this first phase of telephone development, the Electrical Communication Laboratory under the Ministry of Communications was inaugurated 75 years ago. In 1966, our research into optical technology and optical fibers began. These technologies that connected people have ultimately made it possible to connect people and information, people and objects, and the real and virtual domains, and to

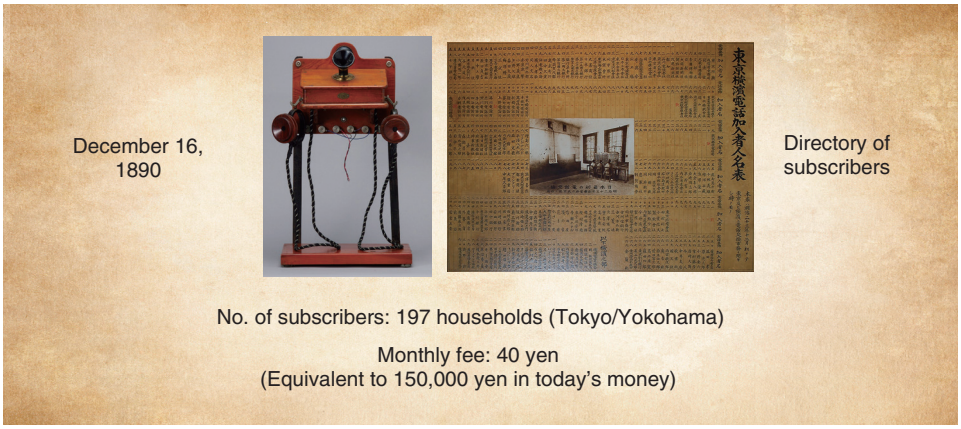
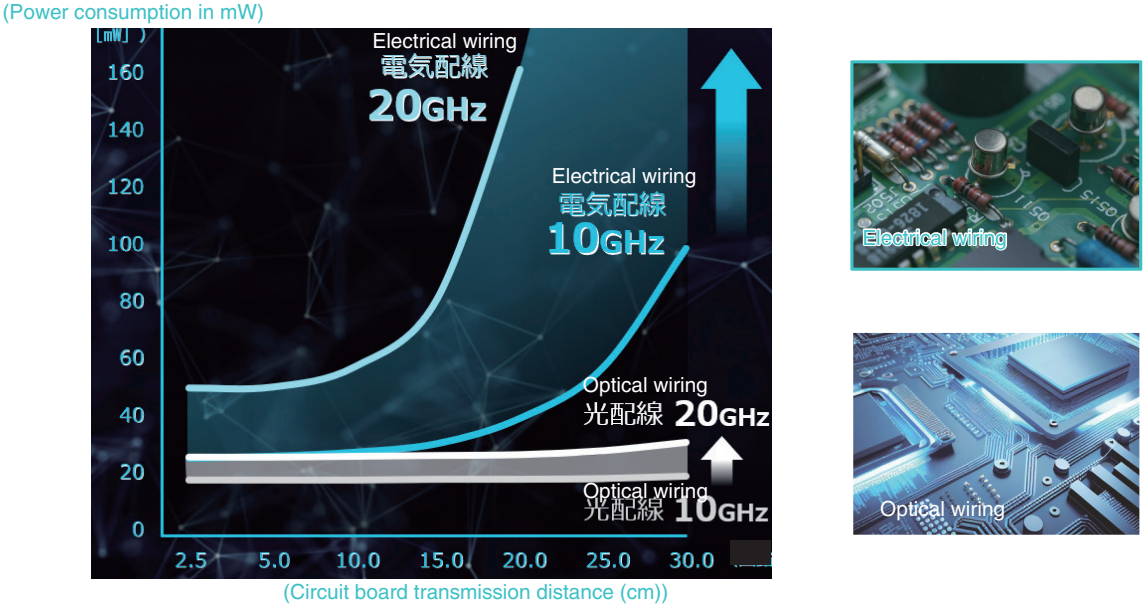


Fig. 1. The very first telephone in Japan.



Source: NEDO, Material of International Symposium on Photonics and Electronics Convergence (2015.6.16).

Fig. 2. Difference between electrical and optical technologies.

transmit not just sounds but images, data, skills, experience, and spaces.

Our 50 years of research into optical technology have now culminated in the concept of IOWN. This concept is about using light not just for conveying information but also in processing layers. Let us look at the differences between electronics and optical technology. As **Fig. 2** shows, with electronics, power consumption increases dramatically as transmission distance over circuits grows [1]. Moreover, as processing speeds increase, higher operating frequencies are also required, further increasing power consumption. However, with optical technology, even as the transmission distance grows longer and operating frequency increases, power consumption does not increase. This feature means power consumption can be reduced further by using optical technology not just for transmitting information but also in the information-processing layer.

By bringing optical technology into all layers from

the network to data-terminal processing, IOWN not only lets us reduce power consumption but also improve transmission capacity, quality, and latency. For example, the All-Photonics Network (APN) features optical technology end-to-end without the traditional switching between electronic and optical technologies, enabling latency-free speed and streamlined power usage. Let us use transport as an analogy. If you have to change trains several times to get to your destination, you are certain to arrive later. The APN works like taking the bullet train all the way to your destination, with no changes required.

At the Japan World Exposition, Osaka, 1970, the first cordless phone was exhibited, connecting people by transmitting sound. At this time, fixed landline phones were still the norm. Following the first-ever exhibition of cordless phones, pagers then cordless phones and smartphones quickly came into widespread use. At the Expo 2025 Osaka, Kansai, Japan, the IOWN APN will be used to transmit spaces in real time, by connecting NTT's datacenter (DC) with the NTT Pavilion venue. Using artificial intelligence (AI) to analyze the NTT Pavilion at the DC, we intend to virtually recreate the Pavilion, letting users experience the dynamically changing and exciting atmosphere of the real live venue.

2.2 Start of IOWN1.0

From the development of the first telephone, it took around 90 years for landline phones to become near-universal in Japan. With cars, it took 30 years for the penetration rate to exceed 80%, shrinking to 15 years for the Internet, and just 5 years for smartphones [2]. The household-penetration rate for services that have grown out of technological innovations is increasing faster and faster.

The growth of IOWN is also gathering speed. Our IOWN APN1.0 service was launched in March 2023, four years after the initial vision. As new services permeate people's lifestyles at an accelerating rate due to technological innovation, the power volume required for this is also growing faster and faster. Once generative AI is added as well, it is anticipated that by 2030 data volumes will have increased 16 times and power consumption 13 times from 2018 levels [3].

With demand for DCs continuing to grow as a result of this, demand forecasts at DCs already anticipate supply shortages [4]. Power consumption at DCs in the Netherlands and Singapore now account for a large proportion of the total power consumption, creating a very difficult environment. There are even moves to block or limit construction of new DCs [5–8].

The IOWN APN is a way to break through this barrier. By creating distributed networks of DCs linked through low-latency connections using the APN, we can operate the networks like a single large DC. We believe that by creating distributed networks of small/medium DCs in available spaces, putting DCs in places where there is slack in the power demand or where local-energy-for-local-consumption is possible, and connecting these DCs using APN technology, we can reduce power shortages at DCs.

Whereas the maximum distance between DCs to avoid latency was previously limited to 60 km, the APN allows DCs to be placed up to 100 km apart. In the UK, verification testing of DCs in London and Dagenham (around 100 km away) connected by the APN is underway. As shown on the left of **Fig. 3**, there is a lack of space for establishing DCs within a 60-km range of London due to high land prices; thus, expanding the range to a 100-km radius should bring in lower land prices, enabling potential sites to be found.

IOWN, which has grown out of the exploration of connection technologies and product-out research outcomes, uses technological innovation to make the new digital information society more energy-efficient and sustainable, enabling a 100-fold increase in energy efficiency and 125-fold increase in transmission capacity.

3. NTT's R&D from the market-in perspective

I would like to talk about NTT's R&D from the market-in perspective. As the communication domain has grown to include not only sound but images, data, the sense of touch, and spaces, R&D's job is to discuss how these concepts can function in our lifestyles, in society, and across the planet, and how R&D can use these to resolve social challenges and build an exciting future. How will these concepts change our lifestyles regarding a specific sense; the food, clothing and shelter we use; our health; entertainment; energy; and ultimately humanity itself? I'm going to talk about three of these areas below.

3.1 Food

As we are all aware, we face growing risks to the stability of our food supply. Effects on our diet are already becoming apparent. With prices of processed foods and condiments increasing by 20% on average and grocery bills by 150 or 200% in one year, people

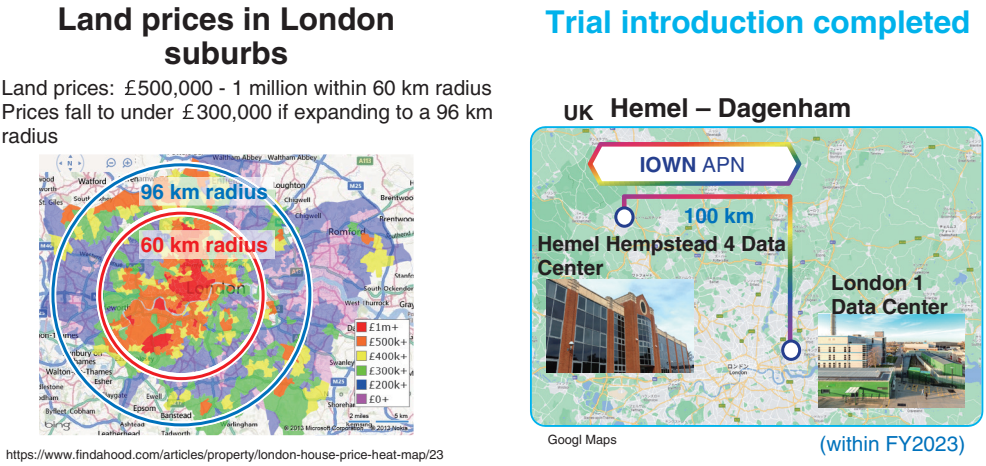


Fig. 3. Connecting DCs in London and Dagenham (around 100 km away) using the APN.

are now really feeling the pinch [9–12]. As you may know, Japan's food self-sufficiency rate is just 38%, 12th among the 13 major economies [13].

Japan's agricultural workforce has fallen to just over 70% of the number in 2000. The average age has increased to 68 [14]. Abandoned land has increased to 420,000 hectares, twice the size of Tokyo and 1.7 times the 1995 figure [15]. Yet in spite of population decline and challenging land and climate conditions, some countries are boosting their food self-sufficiency through innovation. The Netherlands is an agricultural superpower, yet 20% of its land is below sea level, and its agricultural land is just 40% that of Japan. Nevertheless, through widespread deployment of large-scale protected horticulture enabled through technological innovation, it has become the world's second-largest agricultural exporter. Although the UK's agricultural workforce has also declined, it has brought its food self-sufficiency rate up to 70% by developing agricultural science.

On the basis of technologies and solutions delivered by our R&D, NTT Group aims to create innovations in the food-value chain including breeding, agricultural production, livestock, fisheries, and distribution to create a stable supply of food. I will talk about three of these areas today.

3.1.1 Agricultural production and protected horticulture

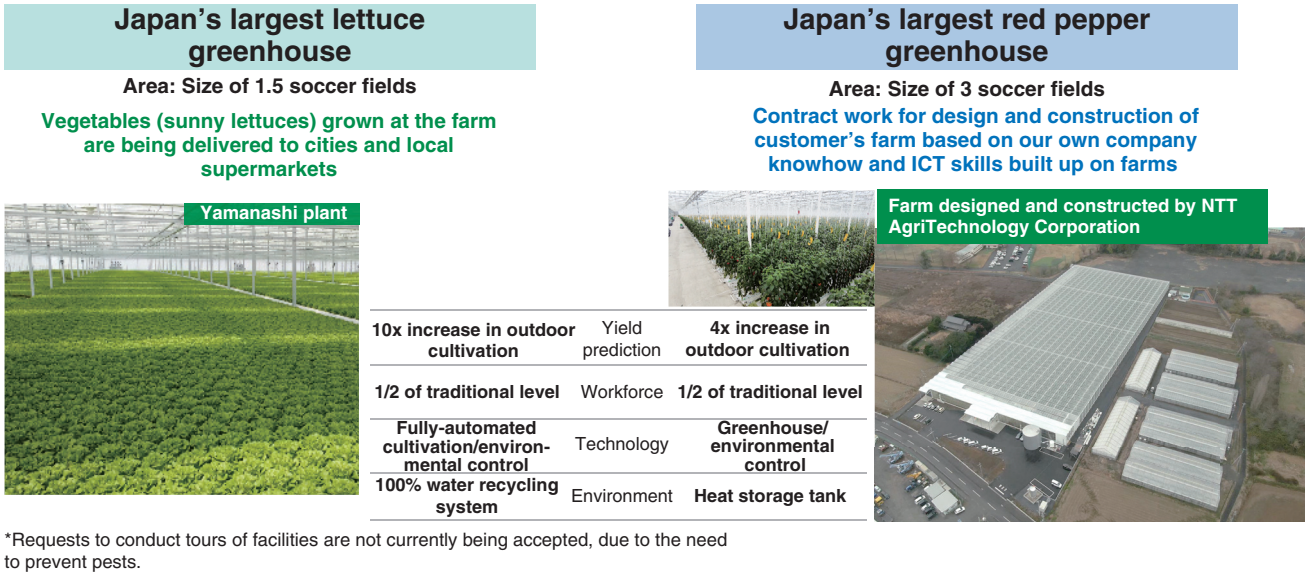
NTT AgriTechnology has set up Japan's largest lettuce greenhouse, the size of 1.5 soccer fields, for protected horticulture. We have succeeded in increasing yields more than 10-fold with half the traditional workforce. The expertise we have demonstrated has brought in inquiries from inside and outside Japan. The right photo in **Fig. 4** shows a farm we designed and constructed on contract after inquiries from a customer. This capsicum farm is the size of three soccer fields. The customer tells us that yields have increased four-fold with half the traditional labor. We are enabling both larger-scale agriculture and reduced labor needs and combining higher yields with a reduced environmental footprint.

We are also providing remote business support from our automation labs using high-definition video transmission and robotics, enabling those even with no cultivation experience to get started. By delivering agricultural support remotely, this system enables a single expert to provide assistance to several producers.

3.1.2 Produce distribution

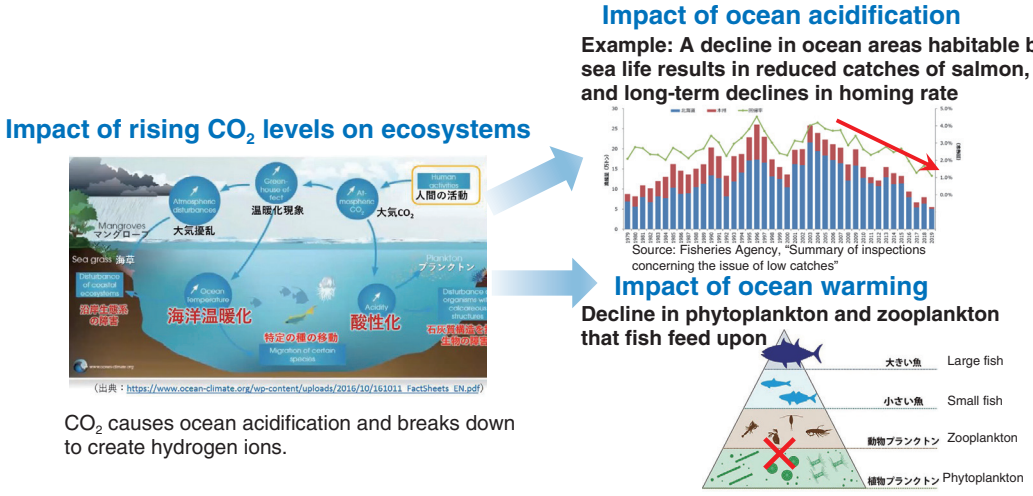
With prices undetermined, producers ship all produce to large markets where it is likely to be sold for high prices. Such produce is often taken a long way on all-day truck journeys, rather than going to markets closer to the places it was produced. Produce gathered together which remains unsold may then be sent on to another place, or in the last few years may even be thrown away because of failure to find enough trucks for distribution.

Using IOWN to enable more environmentally friendly produce distribution by analyzing and forecasting demand information for produce gathered in markets, we hope to ensure that produce will be sent to consumers in a higher state of freshness and only in the necessary amounts, reducing food losses and carbon dioxide (CO_2) emission. In our vision for the



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

Fig. 4. Reduced environmental footprint due to 100% water recycling system.



CO_2 causes ocean acidification and breaks down to create hydrogen ions.

Fig. 5. Impact of rising CO_2 levels on ecosystems.

near future, we will help people enjoy better-tasting food with peace of mind by connecting experts with producers, operators with the actual places where produce is produced and sold, and producers with virtual markets, using IOWN to bring consumers fresh produce they will want to eat and which is better for the planet while also improving Japan's self-sufficiency rate in food.

3.1.3 Fisheries

Rising levels of CO_2 are causing the warming and acidification of the oceans [16]. With ocean warming reducing areas that are habitable by sea life, we are seeing long-term declines in, for example, catches of salmon, as shown in the graph on the upper right of **Fig. 5** [17]. The acidification of the ocean is causing declines in numbers of the phytoplankton and zooplankton that fish feed upon. In spite of this, the production volumes from fisheries worldwide have doubled since 2000. While catches of fish have remained more or less flat, aquaculture has been

making up the shortfall. As we can see from the center graph, while global aquaculture production has doubled, Japan's production is actually on the decline. Therefore, having been ranked No. 1 worldwide for aquaculture in 1980, Japan has now fallen to No. 11 as of 2021 [18, 19]. In July 2023, NTT Green & Food was established as a joint venture between NTT and Regional Fish Institute to resolve issues of fishing industry decline, food, and the environment.

One aspect that we are working on is quality-improvement technology for the creation of sustainable foods. One example of sustainable foods is sea bream with an edible portion that is 1.6 times that of regular sea bream, while the algae it feeds upon is given extra-activated photosynthesis, resulting in faster growth, and the ability to fix higher-than-normal levels of CO_2 inside its cells.

Another aspect is sustainable land-based aquaculture plants. Atmospheric CO_2 is absorbed by the ocean, and the modified algae absorb larger-than-normal amounts of it within their cells; the fish eat the algae, absorbing and fixing this CO_2 in their bones and other parts, creating a sustainable production mechanism. We are currently constructing Japan's largest land-based aquaculture plant in terms of production scale in Iwata (Shizuoka Prefecture), as of October 2023. The plan for the plant is to produce whiteleg shrimp as a fully domestic production system using a rare variety of Japanese seedling.

3.2 Health, healthcare, and medical care

Which raises blood sugar levels more: a banana or a cookie? The glycemic index (GI) for food gives relative values for how high blood sugar rises after eating certain foods, with glucose given a baseline value of 100. According to this index, a cookie has a higher GI value at 77 compared with 58 for a banana. The correct answer is not straightforward. The correct answer varies from individual to individual. Among a group of people with pre-diabetes, 'patients' blood sugar values were measured after they had consumed bananas or cookies. For 445 patients, blood sugar rose after eating bananas and remained largely unchanged after eating cookies. For 644 patients, however, the exact opposite was the case [20].

We can see from this that changes in blood sugar are different for different individuals. The number of people with diabetes worldwide has increased 3.6-fold over the last 20 years [21]. Rapid rises and falls in blood-sugar levels increase the risk of cardiovascular disease as well as diabetes. Chronically high blood sugar damages blood vessels throughout the body, causing various health issues. Stabilizing blood sugar after meals is believed to reduce heart disease and cancer risks. In other words, blood sugar has a major impact on bodily health [22].

NTT's "wearable blood glucose sensor" is a technology that enables the user to measure their blood-sugar levels at any time, helping them understand what foods raise their blood-sugar levels. Blood glucose has traditionally been measured by drawing blood or using pinpricks, as shown in the lower left photo of **Fig. 6**. The round object attached to the person's arm contains a needle that is piercing the skin and measuring the blood glucose level. This means that continuous, real-time measurement is very difficult. Now, the user can measure their level simply by wearing NTT's wearable blood glucose sensor next to their skin. The version presented at R&D Forum 2022 was quite large, as shown in the central photograph of Fig. 6. However, its size was reduced in 2023 to that of a watch, as shown on the right. The watch-sized sensor directs electrical waves under the skin's surface. These are then bounced back to the sensor, creating signals that are analyzed using the technology measuring changes in the concentration of glucose under the skin (which enters the skin from the blood vessels). Therefore, the user wearing the device is able to obtain their blood-sugar levels in real time. By enabling users to measure their blood-sugar levels easily and in real time, this technology can ensure that patients classified as pre-diabetic can eat many of their favorite foods while keeping an eye on their levels to ensure they do not go up. Cases are being reported of patients who were able to bring their blood-sugar levels from pre-diabetic to normal within one week by sticking to a diet suited to them while monitoring their levels [23]. This enables people to control their blood-sugar levels on their own. NTT's wearable blood glucose sensor provides a way for patients to enjoy their food rather than having to endure a diet they do not like by thinking about the foods they enjoy and selecting those items that do not affect their blood-sugar level.

Does drinking coffee contract your blood vessels? Or could it actually rejuvenate them? The antioxidants found in coffee are said to rejuvenate the blood vessels, helping to maintain a healthy heart. However, it is also said that caffeine may cause constriction of the blood vessels. Research by Dr. Ahmed El-Sohemy, Toronto University suggests that while coffee-drinking may reduce the risk of myocardial infarction in people with a genotype that rapidly

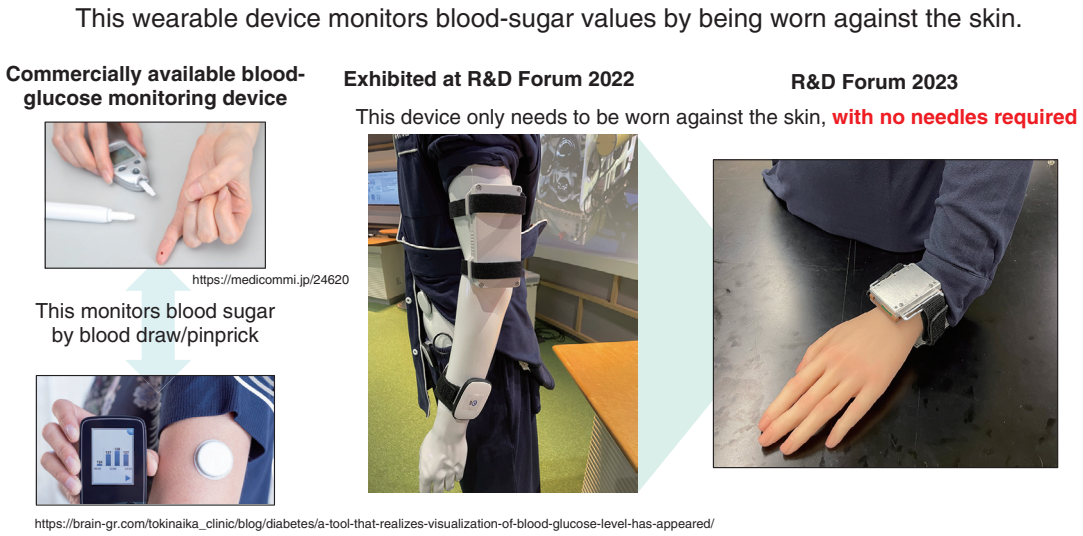


Fig. 6. Blood-sugar monitoring using a biodigital twin.

breaks down caffeine, drinking coffee may put stress on the heart in those whose genes cause them to break down caffeine slowly [24].

The ability to metabolize the components found in medications may also vary among individuals, as with caffeine. Take as an example warfarin, which dissolves clots in blood vessels. For Japanese, the required daily dose of this drug can vary by a factor of 20 from patient to patient, depending on genetic type. In other words, while some individuals can take a single pill daily, others must take 20 pills a day [24].

Analysis of genes and electronic medical records in terms of the ideal dosage of various medications for different people can open up the possibility of tailor-made dosage regimens and preventive medicine adapted to each individual. NTT Life Science is issuing reports analyzing disease risk and individual makeup in terms of alcohol metabolism as part of NTT's big data analysis and its genetic testing services, which use AI.

We are also using NTT's large language model (LLM) "tsuzumi" to automatically construct data, including electronic medical records, and use these data for analyzing individual differences. We believe that by using tsuzumi to analyze people's individual makeup, characteristics, environments, and medical histories, and developing sensors that can obtain various types of vital information through non-stressful sensing methods, it should be possible to personalize in many areas, including diet, medications, and optimized exercise levels. By enabling optimization of care and minimizing losses, this can also create more sustainable, socially responsible, and environmentally friendly healthcare.

3.3 Humanity, excitement, and the five senses

3.3.1 Hearing

It was through sound that NTT first brought people together with our first telephones, so this is an area representing over 90 years of NTT research. With certain sound waves, laying two sound waves over each other with a 180-degree offset (antiphase) can cancel out interference. Since the 2020 R&D Forum when we first exhibited our Personalized Sound Zone technology, which uses this principle to deliver high sound quality exclusively to the user's ears while minimizing leakage into the surrounding environment, we have continued to evolve this technology, culminating in the commercialization of our earphones in 2022. We will offer an extensive lineup under the Sonority nwm Earphones brand. As these open earphones do not block the ears or leak sound, they are ideal for use when running, cycling, and in construction environments. In fact, Sonority nwm Earphones transceivers were used by the R&D Forum 2023 Secretariat to run the event.

3.3.2 Touch

In addition to hearing and sight, we can also use touch to create sensations that feel a step closer to the real world. When the stethoscope shown in **Fig. 7** is placed on someone's chest, the heartbeat that you can hear is communicated via electric waves to the ball,

We created a connection between the United Nations (UN) Headquarters in New York (the venue) and NTT headquarters in Tokyo 6800 miles away, to bring the sound of the heartbeats of children in Tokyo to children listening at the venue.

Children's Conference of the Future in support of the UN: A project announcement event in New York

©Masahiro Noguchi ©Masahiro Noguchi

July 19, 2023: Disarmament, Demobilization and Reintegration (DDR) at the UN Headquarters

The heartbeats sound as though they were close by, despite being on the other side of the world

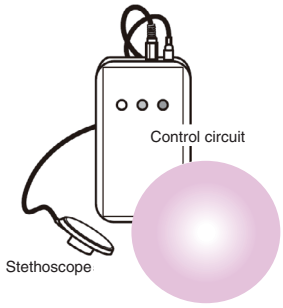


Fig. 7. The sensation of a heartbeat transmitted from Japan to the UN.

making it vibrate. At the Children's Conference of the Future held in July 2023, we connected Tokyo and the United Nation's New York headquarters in this way. A boy in Tokyo (shown on the projector displayed in the central photograph) had his heartbeat detected with a stethoscope. It was relayed via the Internet to the ball set up in New York, which vibrated in synchrony with the real heartbeat. "It feels like it's right there in front of me!" exclaimed the girl touching the vibrating ball.

We believe that conveying something through the sense of touch like this delivers not only instrumental value, such as "what we can do through this," in the same manner as communication through screens using the senses of sight and hearing but also intrinsic value—the value of feeling as though a person or object is right there in front of you. Although society has been returning to real-life experiences following the COVID-19 pandemic, we hope to develop technologies that can convey the sense of touch in this way, making the real world feel close by in a way we all want to experience.

Next, I'd like to talk about technology that makes the user feel as though they have been sent though space and time to a completely different location. By recording the vibration sounds of a real-world bike race and the bumps and depressions of the race track surface and converting all this into data, we can recreate these sensations for a user riding a bike in the metaverse, including the way the vibrations change with the different road surfaces and speeds.

3.3.3 Human augmentation

Moving beyond hearing, sight, and touch, the world of human augmentation enables us to experience abilities that go beyond our natural capacity. As we have explored and exploited the technologies that connect people together, the scope of what we are able to communicate to other people has grown over time. By digitalizing various phenomena, converting them into information and data, and using AI to analyze them efficiently and at low cost thanks to IOWN, we can deliver not only visualization, optimization, and energy-saving but also personalization as values. Our hope is to bring these values back to the notions of humanity and the five human senses in the context of social activities including food, shelter, and clothing; healthcare; and entertainment, while using these values to build a future centered on individual well-being and social well-being that cares for the planet.

AI can set out information systematically and present us with options; however, deciding how we feel about these options and what kind of future we want to have are tasks that require the powers of imagination and conceptualization using the five senses that humans possess.

We want our R&D to be about imagining and creating the sustainable yet exciting future that is coming together in our minds as we use our imaginations to create a vision of people, society, and the planet.

4. Concluding remarks

Four years since the announcement of IOWN, I truly hope that you can now feel this idea coming to life and imagine the exciting future that will ultimately make it possible.

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LLM+×IOWN —The Advancement of IOWN, the Launch of NTT's LLM, and Their Synergy—

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Abstract

This article presents tsuzumi, NTT's large language model (LLM), and the advancement of the Innovative Optical and Wireless Network (IOWN). It is based on the keynote speech given by Shingo Kinoshita, senior vice president, head of Research and Development Planning of NTT Corporation, at the "NTT R&D FORUM 2023 — IOWN ACCELERATION" held from November 14th to 17th, 2023.

Keywords: large language model, IOWN, photonics-electronics convergence, AI

1. Launch of NTT's large language model

We announced at a press conference on November 1 that we have developed tsuzumi, NTT's large language model (LLM). This LLM has four main features.

1.1 Lightweight

Its first feature is that it is lightweight. Today's LLMs are in competition for the number of parameters, thus becoming very large in scale. As such, the challenge now is achieving sustainability. For example, OpenAI's Generative Pre-trained Transformer 3 (GPT-3) has 175B parameters and requires about 1300 MWh of electricity for one training session. This is equivalent to an hour's worth of electricity produced by one nuclear power plant. In contrast, we have adopted the following strategy.

In terms of direction being pursued, we do not aim to build one massive LLM that knows everything but small LLMs with specialized knowledge. Our approach to this is not simply to increase the parameter size but to make the LLM smarter by improving the quality and quantity of training data added to it. Therefore, we developed and announced two types of tsuzumi. The ultralight version, tsuzumi-0.6B, is 0.6B in parameter size, which is about 1/300th that of GPT-3. The light version, tsuzumi-7B, is 1/25th that of GPT-3.

What are the benefits of reducing size? The first is that training can be carried out at very low cost. For example, GPT-3-scale training is said to cost about 470 million yen per session. In contrast, tsuzumi-7B and tsuzumi-0.6B cost 19 and 1.6 million yen, respectively, enabling reduction in costs by 1/25 and 1/300. The second benefit is the cost of inference, i.e., the cost of using the LLM. For example, GPT-3 would need about 5 high-end graphics processing units (GPUs), which cost about 15 million yen. The 7B and 0.6B versions, however, would cost about 0.7 and 0.2 million yen, respectively. In terms of the number of GPUs, cost is reduced with the use of only

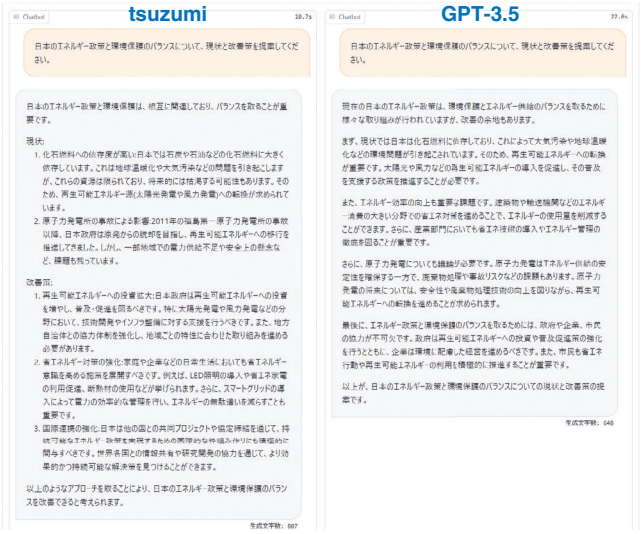

Fig. 1. Comparison of tsuzumi and GPT-3.5.

one low-end GPU and only one central processing unit (CPU), respectively.

1.2 Proficiency in Japanese

Its second feature is its high linguistic proficiency, especially in the Japanese language. **Figure 1** shows example answers of tsuzumi on the left and GPT-3.5 on the right to a question about the current situation and possible improvement measures for attaining a balance between Japan's energy policies and environmental protection. The left answer presents a well-analyzed response in Japanese. Comparisons of tsuzumi with GPT-3 and other LLMs were made using the Rakuda benchmarks. For example, tsuzumi was compared against GPT-3.5. They were asked the same questions, and their answers were input to GPT-4 to determine which gave the better answer and which is superior or inferior. As a result, tsuzumi beat GPT-3.5 at 52.5% probability. Comparisons with the four top-class LLMs in Japan revealed that tsuzumi had an overwhelming win rate of 71.3 to 97.5%.

Furthermore, tsuzumi can not only give answers in Japanese to questions in Japanese. For example, when tsuzumi was asked to extract four data items, namely, device name, achievement, exhibition event, and future plans in JSON format from a text of a recent press release about an artificial photosynthesis device developed by NTT, it gave a properly structured response as requested. Its performance in English is in fact on par with the world's top-level language models. In comparison to Llama 2, an English language model developed by Meta, tsuzumi produced almost the same English benchmark results. For example, tsuzumi gave a smooth and quick response when asked to translate the Japanese text into English. It is also proficient in programming language. When asked to write code in a specific format, it gave a proper response in the requested format. It is currently being trained in Chinese, Korean, Italian, and German, so it will also eventually be able to give answers in those languages.

1.3 Flexible customization

Its third feature is flexible customization. Language models have a base model, which can give fairly adequate answers to general questions. However, to construct models that can give specific answers in the field of finance or the public sector, for example, tuning must be executed. There are three tuning methods available (**Fig. 2**). On the left of Fig. 2 is a method called prompt engineering. With this method, prompt inputs to the base model are added with financial information to enable the model to give a more finance-specific response. In the middle is a method called full fine-tuning, which creates a model specialized in finance by re-training the base model with financial data and changing the entire set of parameters. On the right is a method called adapter tuning, with which the base model is used as is, and these blue adapter components on finance-specific knowledge are added on top of the base model like a hat. They have different advantages and disadvantages in

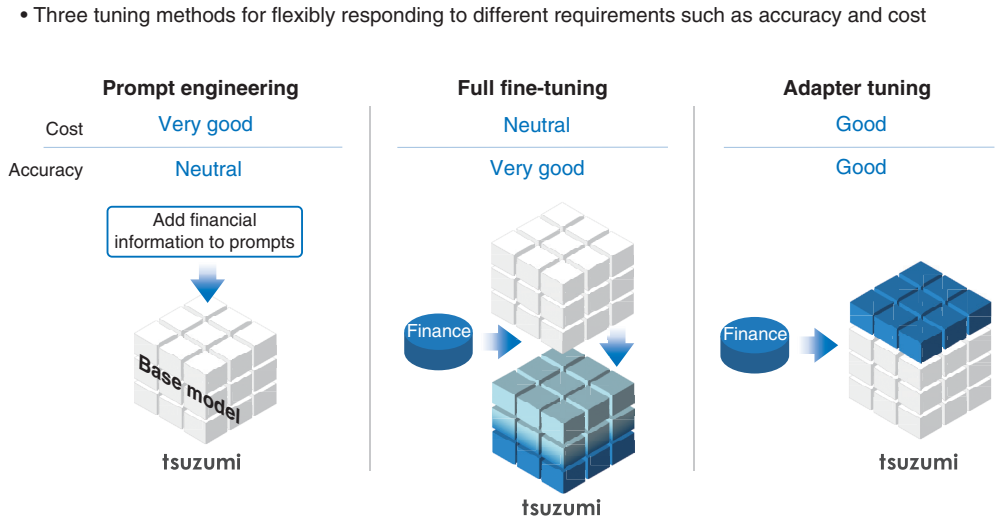

Fig. 2. Different tuning methods.

Fig. 3. Example of fine-tuning in financial industry.

terms of cost and accuracy. As an example of the advantage of tuning, the base model can be made more specific to a particular industry, company, or organization or can be updated with the latest information. One can also add functions by training the model with new tasks, such as summarization and translation, to make it more task specific.

Figure 3 shows an example of fine-tuning in the financial industry. On the right is the response using data before tuning, and on the left is the response after fine-tuning the data for the financial industry. LLM tsuzumi was asked to explain the market segments of the Tokyo Stock Exchange (TSE). The right response shows the old segments, such as 1st section, 2nd section, JASDAQ, and Mothers. The left response shows the new segments established by TSE on April 4, 2022. The LLM properly learned and gave the correct segments, i.e., Prime, Standard, and Growth.

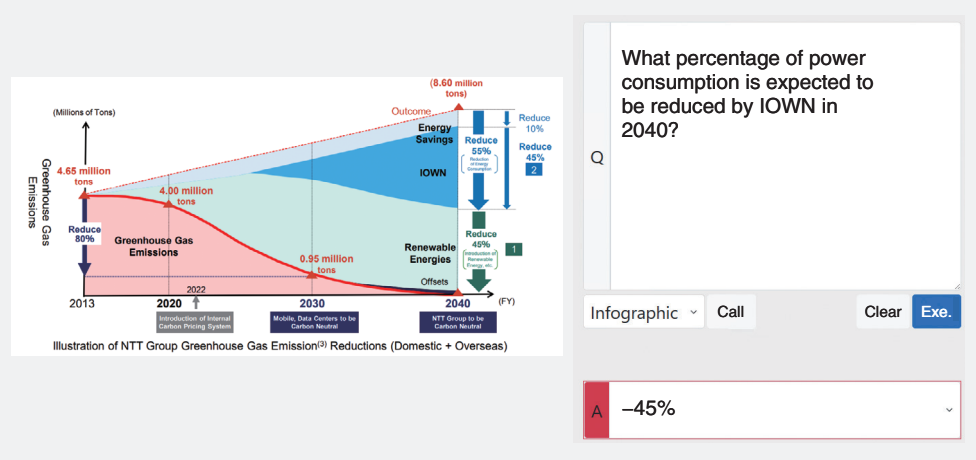

Fig. 4. Modality extension: Language + Visual.

1.4 Multimodality

Its fourth feature is multimodality. Language models in general have received language inputs and produced language outputs. Multimodality refers to the ability to handle modals other than language. For example, one can now add visual and audio capabilities. For example, when tsuzumi was shown a receipt and asked, "What is the total amount excluding the 10% consumption tax?" It then calculated the total by looking at the unit price and quantity columns on the receipt and correctly replied that the total is 9500 yen.

Figure 4 shows another example. This is a graph from NTT's Green Vision. While being shown this complicated graph, tsuzumi was asked "What percentage of power consumption is expected to be reduced by IOWN in 2040?" It correctly analyzed the graph and replied 45%. Thus, it is capable of providing answers by analyzing the question in combination with figures.

2. Technological capabilities of NTT laboratories

Next, I would like to talk about the technological capabilities of NTT laboratories that enabled us to achieve these four excellent features.

Figure 5 shows a table listing the ranking of companies based on the number of publications in the field of artificial intelligence (AI). NTT is ranked 12th in the world and 1st in Japan in this report published annually by a U.S. venture capital firm. In the top 1 to 11 are GAFA (Google, Apple, Facebook, and Amazon) and other major information technology (IT) vendors in the U.S. and China. Compared with NTT, they probably have ten times more research funding and have many times more researchers. Nevertheless, NTT has been able to conduct research quite efficiently, enabling us to achieve these rankings. In AI, natural language processing is a very important area in the development of language models. NTT is number one in Japan in terms of the number of publications in this particular area. It is also number one in the number of awards for excellence given by the Japanese Association for Natural Language Processing. The development of tsuzumi is backed by a long history and solid track record in research. We used excellent data for training tsuzumi, which is its distinguishing feature. We used more than 1T tokens, which can be thought of as the number of words, for pre-training. We used not only Japanese and English but also 21 other languages as well as programming languages to train tsuzumi. These data cover a very wide range of domains, from specialized fields to entertainment. For instruction tuning, which makes the pre-trained data more human-like in response and behavior, we used Japanese corpora created from NTT's over more than 40 years of research. We also used new tuning data we created specifically for generative AI.

In this R&D forum, we presented 11 exhibits on tsuzumi. I will briefly introduce representative exhibits in the following sections.

2.1 LLM tsuzumi comprehensively understands the real world

A supervisor and junior member are having a

Rank	Company name
1	Google (USA)
2	Microsoft (USA)
3	Facebook (USA)
4	Amazon (USA)
5	IBM (USA)
6	Huawei (China)
7	Alibaba (China)
8	NVIDIA (USA)
9	Tencent (China)
10	Samsung (South Korea)
11	Baidu (China)
12	**NTT** (Japan)
13	Apple (USA)
14	OpenAI (USA)
15	Intel (USA)
16	Adobe (USA)
17	Salesforce (USA)
18	Yandex (Russia)
19	NEC (Japan)
20	VinAI (Vietnam)

Top 100 Global Companies Leading in AI Research in 2022[*1]

*1 https://thundermark.medium.com/ai-research-rankings-2022-sputnik-moment-for-china-64b693386a4

Fig. 5. Number of AI publications: 12th in the world & 1st in Japan.

• Multimodal comprehension of communication between supervisors and junior members to address power-harassment by supervisors

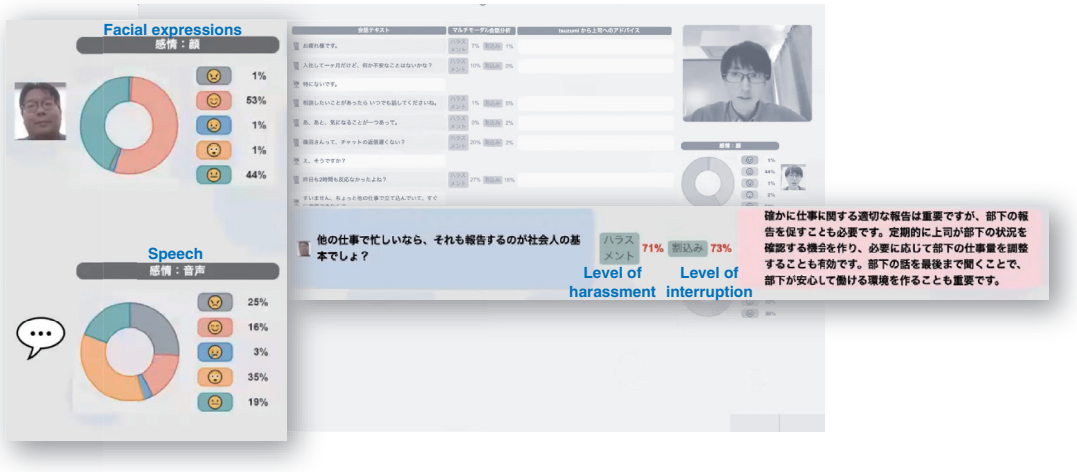

Fig. 6. LLM tsuzumi comprehensively understands the real world.

conversation via online communication, during which the supervisor displays power-harassment behavior. LLM tsuzumi detects the power-harassment behavior and calls it to the supervisor's attention. "I'm sorry. I'm a little busy with other jobs so I couldn't reply immediately." "If you're busy with other work, isn't it your basic responsibility as a working adult to report that, too?" The person on the left of **Fig. 6** is the supervisor making power-harassment statements. The LLM then analyzes the emotions on the basis of the supervisor's facial expressions and speech. It determines to what degree the person is laughing or angry as percentages. The blue area on the left in the below column shows what the supervisor said. The middle shows that the level of harassment is about 71%. It also shows a 73% level

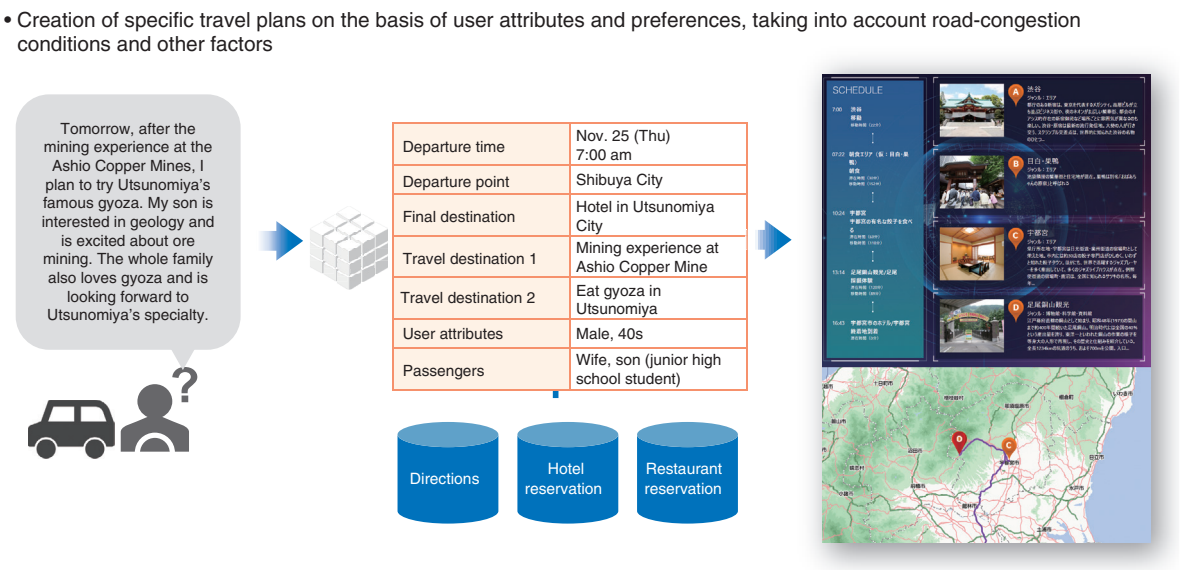

Fig. 7. LLM tsuzumi understands the user situation.

of interruption while the other person is speaking. These percentages show a relatively high level of harassment. In response, as shown in the pink area, tsuzumi gives advice to encourage behavioral change in the supervisor. It says, "While it is important to properly report on their work, it is also important to encourage junior members to do so. An effective way to encourage them is for the supervisor to create opportunities to check on junior members on a regular basis and adjust their workload as necessary. It is also important to listen patiently to junior members to create an environment in which they can work with peace of mind." Thus, tsuzumi can give appropriate advice to supervisors to address their behavior.

2.2 LLM tsuzumi understands user situations

LLM tsuzumi can create specific travel plans on the basis of user attributes and preferences, taking into account road-congestion conditions and other factors. The gray text on the left of **Fig. 7** shows the user's requests. It says, "Tomorrow, after the mining experience at the Ashio Copper Mines, I plan to try Utsunomiya's famous gyoza. My son is interested in geology and is excited about ore mining. The whole family also loves gyoza and is looking forward to Utsunomiya's specialty." Once the car-navigation system with tsuzumi hears this, it structures and analyzes the inputs into specific information such as departure time and departure point, as shown in the middle. It then searches the web to gather information on directions, hotel reservations, and restaurant reservations. Finally, it creates an action or travel plan to propose to the user.

2.3 LLM tsuzumi with physical senses and a robot body

A robot equipped with tsuzumi can create a menu and set a table according to the user's request. In this example, the user says, "Prepare a dinner table that will warm the body up on a cold winter's day. Make considerations for left-handedness." The robot then analyzes the request and actually serves the food while explaining the arrangement. For example, it says, "Curry is good for warming the body up, and salad. They pair well with spring rolls for a seasonal feel. Tea warms the body, too. In consideration of left-handers, the chopstick and spoon are placed in the opposite direction." The robot servs food while giving such explanations.

2.4 Ultra-high-speed software development

How to add a new function, i.e., a review function, to a shopping site with tsuzumi was demonstrated. The website on the left of **Fig. 8** only gives the usual introduction of a product, without a review function. One can then instruct tsuzumi to add a product review function. In response, it analyzes the source code and carries out these actions. The demonstration showed how tsuzumi can write a new source code to create a review section on a website.

• Demonstration of adding a new function (review function) to a shopping site using tsuzumi

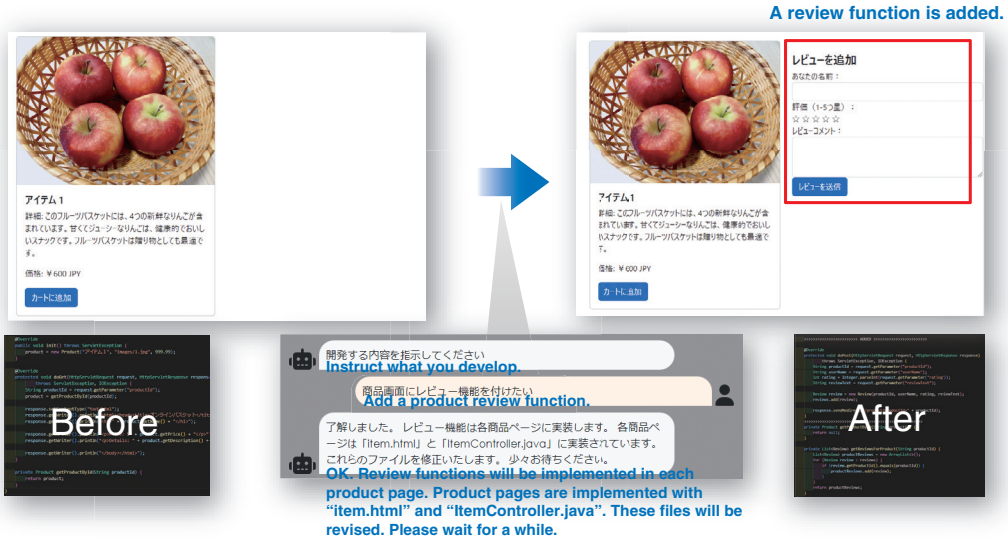

Fig. 8. Ultra-high-speed software development.

2.5 Next-generation security operations

LLM tsuzumi can handle incident responses on behalf of security experts in a dialogue format. For example, if a virus is detected on a user's computer, tsuzumi analyzes the virus, informs the user, asks the user whether they have accessed the malicious site, and instructs the user to respond as soon as possible via chat. The demonstration showed how tsuzumi interacts with the user step by step to urge users to respond to security issues.

2.6 Phishing-site detection

LLM tsuzumi analyzes the input website and determines whether it is a phishing site. It's accuracy in detecting phishing sites is more than 98%, which is much more accurate than checking by humans.

3. Advancement of IOWN

Next, I would like to move on to the advancement of the Innovative Optical and Wireless Network (IOWN). First, I would like to explain the IOWN roadmap (**Fig. 9**). IOWN1.0 is a networking technology that connects datacenters (DCs) using optical fiber. IOWN2.0 optically links the boards inside the server in the DC. Evolving further, IOWN3.0 will optically connect the chips, while IOWN4.0 will enable optical connection inside the chip. Now, let's look at the roadmap by generation. There are a number of elemental technologies that make up IOWN for each generation. An example is a device called the photonics-electronics convergence (PEC) device. Along with the evolution of IOWN generations 1.0 to 4.0, PEC will also continue to evolve from the 2nd to the 3rd, 4th, and 5th generations. The All-Photonics Network (APN) will evolve within IOWN1.0 through the addition of functions and increasing performance. The super white box of the data-centric infrastructure (DCI) will evolve from IOWN1.0, to 2.0, and to 3.0, along with the evolution of PEC devices, as Steps 0, 1, and 2. This roadmap shows how we will be moving forward with the advancement of these technologies.

I'll now introduce what we achieved for IOWN1.0 in 2023. One achievement is the significant progress in the commercialization of the APN. The APN consists of APN-I for the core network, APN-G for the edge network, APN-T installed in the user base, and OTN (Optical Transport Network) Anywhere in the user terminals. Different companies have launched specific products for the APN. In March 2023, NTT EAST and NTT WEST began providing specific network services using these products. This 100-gigabyte leased-line service enables users exclusive use of optical wavelengths from end to end. Using OTN Anywhere enables visualizing latency and provides functions for adjusting and aligning different delay times. Using this service, we have conducted various proofs of concept (PoCs), and many PoCs were in the

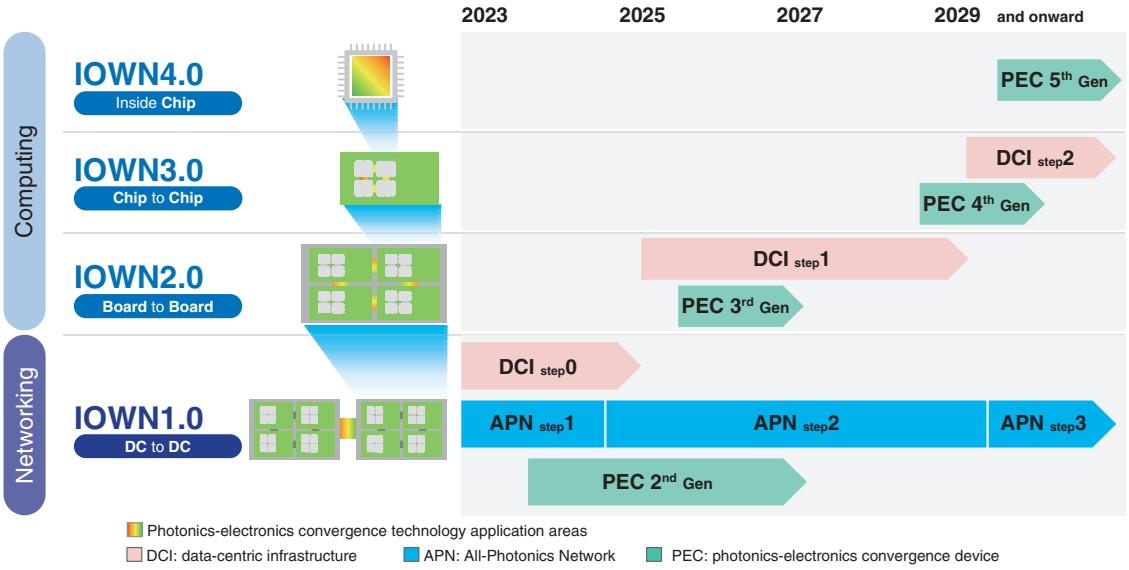

Fig. 9. Progress of IOWN.

entertainment field such as for concerts, e-sports, comedy, and dance.

Other than entertainment, we plan to use the APN to construct DCs of the future. Thus far, the range of DC-to-DC connections has been limited because of significant delays in conventional networks. The limit is about 60 km, but there is not enough land within this range, making it difficult to add more DCs. If the connection distance between DCs can be increased from 60 to 100 km by using the APN, then there will be more land available for constructing connected DCs. We believe that the APN is highly suitable for such expansion of connected DCs. We are currently conducting demonstration experiments at various locations to achieve this. By expanding beyond the Tokyo metropolitan area to major cities throughout Japan and even to other parts of the world, we believe that it will be possible to build a global APN network.

Next, I will report on the status of IOWN2.0 and 3.0. The first is concerning DCI. DCI is a next-generation computing architecture for achieving high performance with low power consumption by allocating optimally subdivided computer resources centered on data (**Fig. 10**).

In Step 0, the units for computer-resource subdivision are the server and storage, and the APN is used for connecting them. In Step 1, the unit of subdivision is the board inside the server. By connecting boards with a 3rd-generation PEC device, we aim to achieve ultra-low power consumption and ultra-high-speed switching. In Step 2, computing resources are subdivided by chip units, which will be connected with a 4th-generation PEC device. This will enable achieving even lower power consumption and higher performance. The key device to achieve Step 1 is the 3rd-generation PEC device called the optical engine. The yellow areas of Step 2 in Fig. 10 correspond to each optical engine. We have been conducting experiments with Broadcom on this chip in the middle, which has a switching capacity of about 5 Tbit/s, with each optical engine having a transmission capacity of 3.2 Tbit/s. It is therefore possible to configure a single device with 5 Tbit/s of switching capacity. The 4th-generation PEC device will optically connect chips at an implementation efficiency six times higher and a power efficiency two times higher than the 3rd generation. This will enable further improved performance and lowering power consumption.

4. Synergy between LLMs and IOWN

The third topic is about the synergy between LLMs and IOWN. For IOWN, we are conducting experiments combining DCI Step 0, the APN, and LLMs. We have this amount of training data in Yokosuka and wanted to install GPUs nearby, but there was not enough power or space. Therefore, we used a GPU cloud in Mitaka and connected it with the database in Yokosuka by the APN for remote access. At this

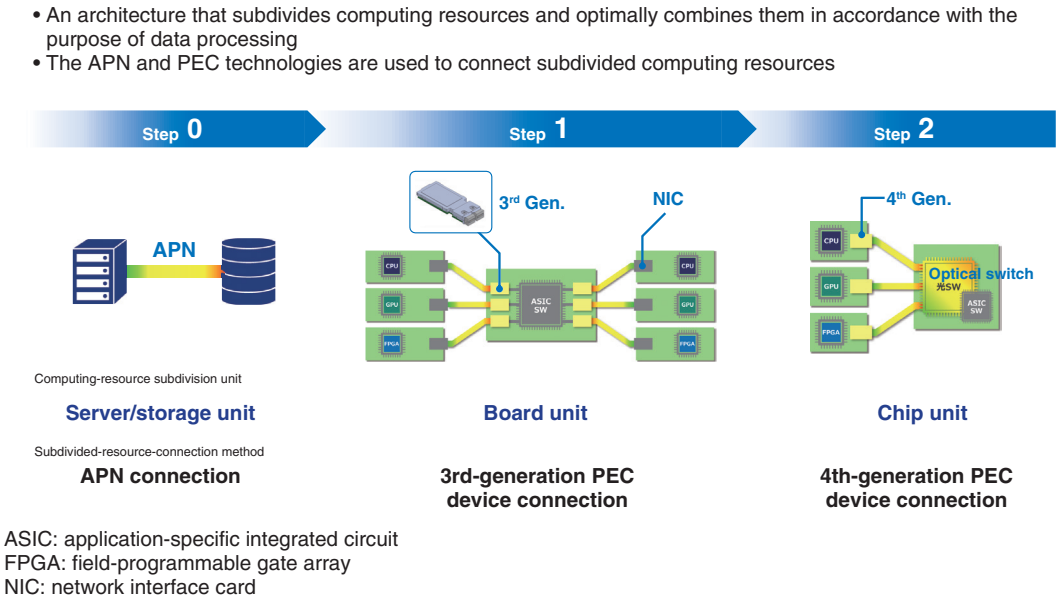

Fig. 10. DCI.

distance, the network file system would be quite slow and there would be considerable performance degradation. With the APN, however, we were able to achieve connection with almost zero performance degradation even at 100-km distance. Specifically, the performance degraded only by about 0.5%. By optically connecting each CPU and GPU directly using an optical switch, we can carry out LLM training and inference with the minimal and optimized combination of computing resources. We currently use many GPUs to train LLMs, but many of these GPUs are sometimes idle. We aim to implement training with as few computer resources as possible while making all devices work at full capacity.

NTT's future vision for the world of AI is to create an AI constellation. We envision a next-generation AI architecture to more smartly and efficiently address social issues by combining multiple, small, specialized LLMs, instead of creating a single monolithic massive LLM. For example, AI with personas representing a human resources manager, clinical psychologist, truck driver, and elementary school teacher talk about "what is needed to revitalize our shrinking community." They offer their opinions and come up with a consensus on what to do, with the involvement of humans when necessary. We believe we can create a mechanism for building consensus through these interactions.

We formed a business partnership with sakana.ai to conduct joint research to build the AI constellation mentioned above. The venture company sakana.ai is in the spotlight right now. It was founded by well-known AI experts. David Ha was lead researcher at Google Brain and at Stability AI, the company that created Stable Diffusion image generation AI. While Llion Jones was one of the Google developers who created the basic algorithm for transformers, now being used in ChatGPT and other AIs. They established sakana.ai with a base in Japan to conduct R&D of new LLMs and AI constellations. We have entered into a business partnership to work together with them in these areas.

5. Three resolutions of NTT laboratories

Finally, I would like to conclude by talking about the three resolutions of NTT laboratories (**Fig. 11**). "Do research by drawing from the fountain of knowledge and provide specific benefits to society through commercial development." These words, proclaimed in 1950 by Goro Yoshida, the first director of the Electrical Communication Laboratory, embody the vision of NTT laboratories. They point to three elements built on top of each other. "Doing research by drawing from the fountain of knowledge" is the foundation. On top of this is the phase of "commercial development," and, on the topmost is "providing specific benefits to society."

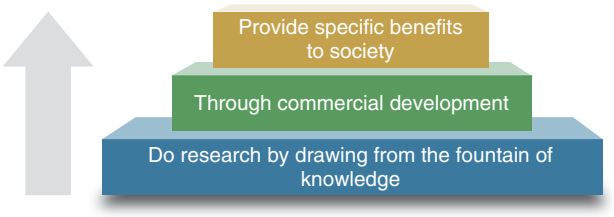

Fig. 11. Three resolutions of NTT laboratories.

Rank	Company	Country/Region	No. of papers
1	IBM	USA	8096
2	Microsoft	USA	7050
3	Siemens	GERMANY	6628
4	Samsung	SOUTH KOREA	6353
5	Google	USA	5926
6	Huawei Technologies	CHINA	5392
7	Intel Corporation	USA	4982
8	SINTEF	NORWAY	4602
9	General Electric	USA	4309
10	Philips	NETHERLANDS	3822
11	**NTT**	**JAPAN**	**3439**
12	Nokia Corporation	FINLAND	3352
13	Bosch	GERMANY	2821
14	Samsung Electronics	SOUTH KOREA	2782
15	China Electronics Technology	CHINA	2727

Source: Survey by NTT using Web of Science, InCites Benchmarking

Fig. 12. Research publications ranking: 11th in the world & 1st in Japan (ICT and engineering companies, 2017–2021).

The most important is the research at the bottom, done "by drawing from the fountain of knowledge." Not only in AI, as mentioned earlier, but also in all engineering fields, NTT is ranked 11th in the world in the number of publications (**Fig. 12**). In world-class research areas, such as speech recognition, information security, optical communications, and quantum computing, NTT boasts the world's highest number of publications, beating Google and IBM. We would like to build on these accomplishments and solidify our position as a world leader in research by further aiming for the top and expanding our world-class research areas. This is our first resolution.

Next is the phase of "commercial development" in the middle. IOWN and LLMs are the two key technologies that we would like to robustly develop and put into commercial use as an embodiment of our second resolution.

Last is the social implementation phase of "providing specific benefits to society." In this regard, we newly established the Research and Development Market Strategy Division in June 2023. Thus far, the laboratories and the Research and Development Planning Department, to which I belong, have been working together in various ways with customers, partner companies, and business companies. Under the new organization, we established the Marketing Planning and Analysis Department, wherein the Research and Development Planning Department will work together with both the Marketing Planning and Analysis Department and Alliance Department to enhance and broaden the scope of our activities. Thus, our third resolution is to implement research and development results into society going forward.

Forefront Initiatives of NTT Space Environment and Energy Laboratories

Yuji Maeda

Abstract

Having established unconventional research themes that had not been targeted at NTT laboratories, NTT Space Environment and Energy Laboratories is taking on various challenges to change the future of the global environment. By looking at the Earth from the perspective of space, we are aiming to regenerate the global environment and create an inclusive and sustainable society. In this article, the latest activities and future prospects of NTT Space Environment and Energy Laboratories, which has existed for three and a half years, are introduced.

Keywords: space, environment, energy

1. Introduction

NTT Space Environment and Energy Laboratories was established in July 2020 to contribute to the revitalization and reform of the global environment. We will achieve this by reviewing the Earth and social environment we live in from the broad perspective of space above the Earth in a manner that is not bounded by the conventional framework of environment and energy. Three and a half years after our establishment, we have revised our vision as follows: "With the ultimate goal of regenerating the global environment and creating an inclusive and sustainable society, we aim to create innovative next-generation energy technology and resilient environmental adaptation technology and contribute to achieving zero environmental impact."

The specific image of society that we hope to create through this new vision is the "sustainable and resilient society" described in the title of the Feature Articles. This is a society in which the impact of the society we live in on the global environment is reduced to zero and the varying impact that global environment changes have on society can be mitigated flexibly. This society will be based on the following innovations (i) next-generation energy technologies such as nuclear fusion and space power generation; (ii) zero power outages through local production and local consumption of clean energy, and autonomous, decentralized, and coordinated energy networks; (iii) reduction of carbon dioxide (CO_2) in the atmosphere and oceans through circular agriculture, forestry, and fisheries; and (iv) the use of highly accurate future prediction to not only prevent damage caused by natural disasters but also extract energy from typhoons and lightning ("disaster green energy").

We have been working hard to establish research systems, increase the number of researchers, collaborate with many research institutions, and quickly generate research results. We have frequently updated our owned media "Beyond Our Planet" [1] to raise awareness of the Laboratories and strengthen our acquisition of external human resources. The number of page views of articles on linear rainbands, in conjunction with sudden rainstorms and typhoon strikes, has increased significantly to about 18,000 per month (out of about 81,500 per month in June 2023 for the entire owned media), and our organization and activities have been highly ranked by search engines in a manner that shows we are gaining social recognition.

To accelerate the digital twinning of the global

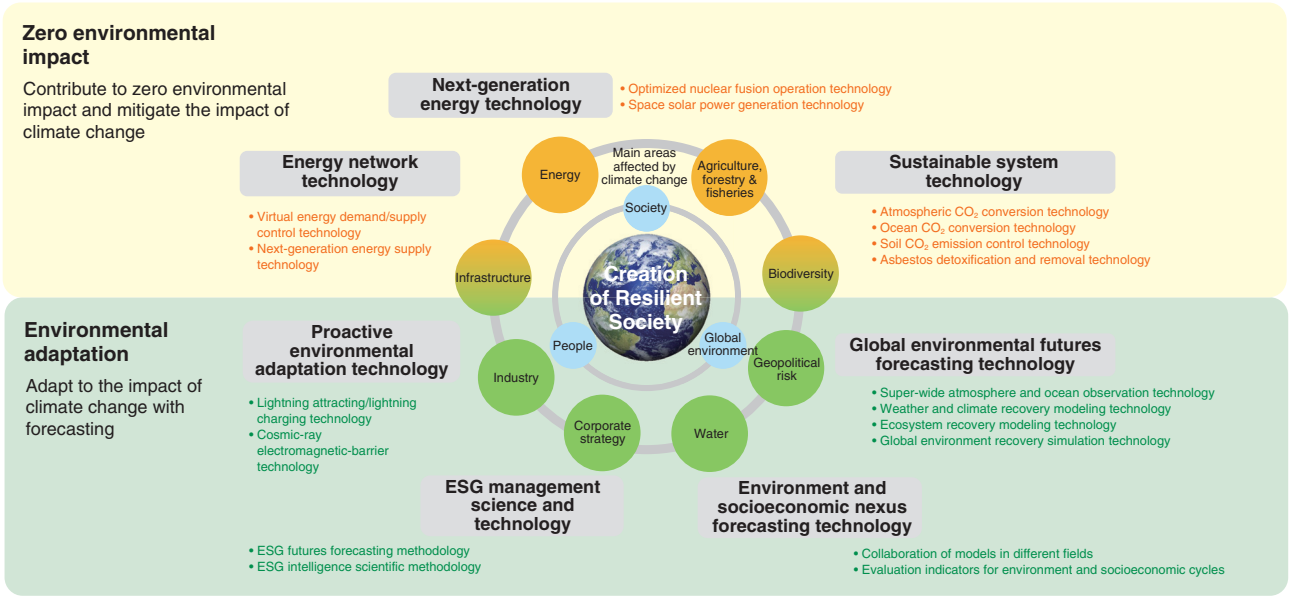

Fig. 1. Overall view of research themes.

environment and establishment of highly accurate future-forecasting technology, the Environment and Socioeconomic Nexus Forecasting Technology Group was established in October 2023. The number of researchers has increased 1.8 times since the establishment of the Laboratories, and more than 40 collaborations with external organizations and universities, including startups, have begun to produce a variety of results.

The research themes we are currently focusing on are shown in **Fig. 1**. NTT Space Environment and Energy Laboratories has separated these themes into two projects: the Zero Environmental Impact Research Project (at the top of the figure) and the Resilient Environmental Adaptation Research Project (at the bottom of the figure). Three research groups are involved in the Zero Environmental Impact Research Project, and four groups (including the newly established Environment and Socioeconomic Nexus Forecasting Technology Group) are involved in the Resilient Environmental Adaptation Research Project, and each group is pursuing research in collaboration with the others.

As shown in the center of Fig. 1, we aim to apply the results of our research to eight areas affected by climate change. Therefore, we hope to reach our goal of creating a sustainable and resilient society by regenerating the global environment and reducing the effects of climate change while maintaining a balance among the global environment, society, and people. Each project and its current status are described hereafter.

2. Forefront initiatives of Zero Environmental Impact Research Project

To contribute to NTT Group's vision of zero environmental impact, this project is focused on researching the following three technologies: (i) next-generation energy technology that is overwhelmingly clean and innovative, (ii) energy network technology that efficiently handles supply and demand of renewable energy, and (iii) sustainable system technology that reduces atmospheric and marine CO_2 through circular agriculture, forestry, and fisheries.

We are currently working on two themes regarding next-generation energy technology. The first is "optimum fusion reactor operation technology" for fusion power generation, a dream energy source. Fusion power generation is a safe and clean energy source that reproduces—on the Earth—the physical phenomenon occurring on the Sun, and it is being researched worldwide with the aim of commercialization by 2050. In collaboration with the National Institutes of Quantum Science and Technology (QST) and the ITER Organization, we are pursuing research on using NTT's Innovative Optical and Wireless Network (IOWN) to control the stability of

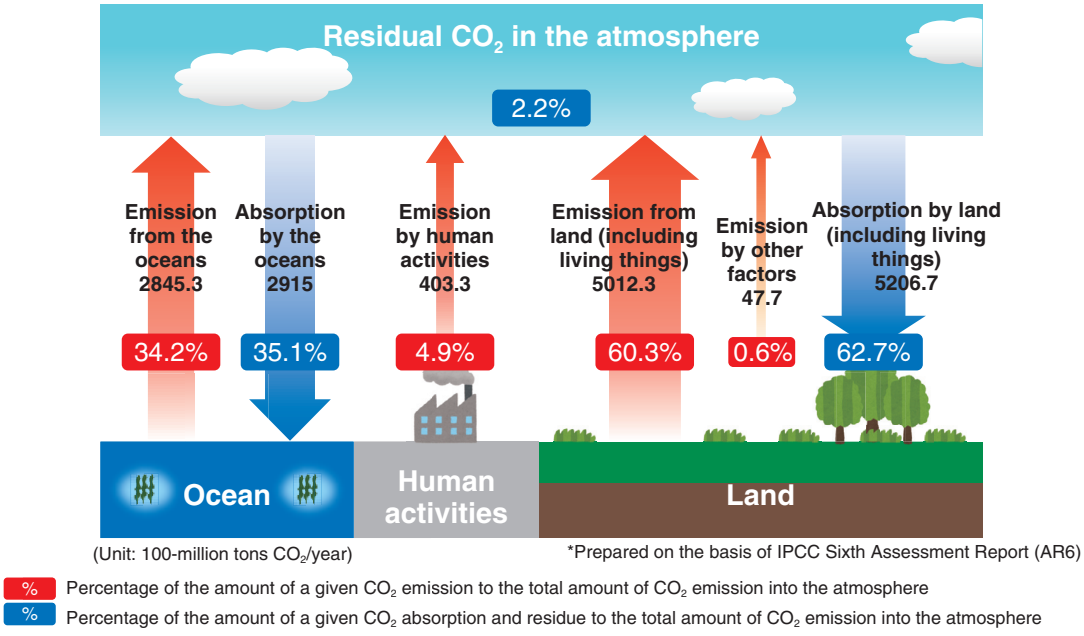

Fig. 2. Overall picture of global CO_2 flux.

plasma in fusion reactors. Venture companies are currently playing a prominent role in this field, and while exploring global trends, we are looking to form new partnerships with ventures and institutions that can use our technology. As the first step of such collaborations, we have started a joint experiment on anomaly prediction with the ITER Organization [2].

The other is "space solar power technology," which enables large amounts of energy obtained in space to be transmitted wirelessly to the ground in an efficient manner. As a grand research theme, space solar power generated from sunlight captured by geostationary satellites (about 36,000 km above the Earth) is wirelessly transmitted to the ground day and night via laser beams and microwaves. This theme is explained in detail in an article in this issue titled "Long-distance Laser-energy Transmission for Space Solar Power Systems and Their Application on Earth" [3].

To maximize the use of renewable energy regarding energy network technology, we are researching two technologies: (i) virtual energy-demand/supply control technology that absorbs fluctuations in renewable energy output through integrated control of information processing by information and communication technology (ICT) devices in NTT's datacenters, storage batteries, and electric vehicles (ii) and next-generation energy supply technology that enables local production for local consumption and ultra-resilient supply of renewable energy by using safe and highly reliable direct-current power supply.

Virtual energy-demand/supply control technology is beginning to attract attention as a new concept called "power to data", namely, surplus power from renewable energy is replaced with data (information processing) for efficient consumption. In collaboration with NTT operating companies, we have started to experimentally demonstrate this technology by connecting our laboratory to an actual datacenter. We plan to increase the number of connection sites and proceed with verification of this technology for practical use.

Regarding sustainable system technology, we are researching CO_2-conversion technology to reduce CO_2 in the atmosphere and oceans through circular agriculture, forestry, and fisheries. Carbon neutrality is often thought of as the reduction of CO_2 emitted from human activities, mainly from energy sources; however, the amount of CO_2 emitted from human activities account for only 4.9% of the global CO_2 emissions.

The latest data on the global CO_2 cycle is shown in **Fig. 2**. We have previously referred to the figures in the draft version of the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), but Fig. 2 shows the figures prepared with

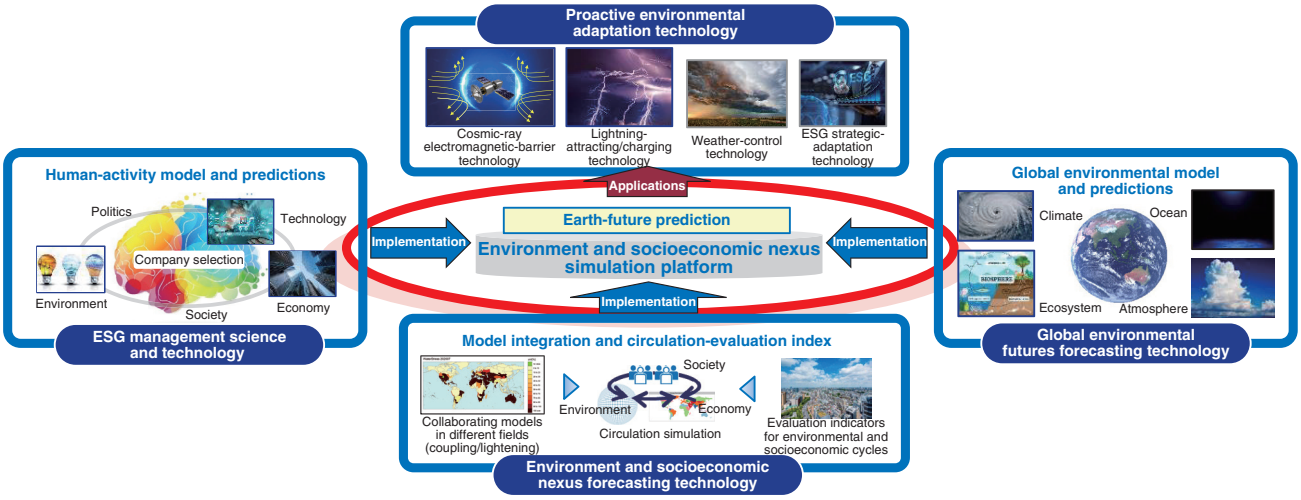

Fig. 3. Resilient Environmental Adaptation Research Project.

reference to the final version. The land (including living things) emits the largest amount of CO_2 (60.3% of the total annual amount of CO_2 emission into the atmosphere), and the oceans emit 34.2% of the total of CO_2 emission. The land (including living things) absorbs 62.7% of the total amount of CO_2 emission into the atmosphere, and the oceans absorb 35.1%. In other words, it is, of course, important to reduce emissions from human activities to virtually zero; however, in consideration of the balance and cycle of the entire planet, it is important to approach the land and oceans at the same time as reducing emissions from human activities. We need to reduce CO_2 emissions from human activities while simultaneously stopping or tackling deforestation, soil pollution, and ocean destruction and pollution. Given those needs, we are researching technologies to reduce CO_2 emissions through circular agriculture, forestry, and fisheries.

We are researching ways to increase the amount of CO_2 fixed in the long term in the ground as well as in living things and organic matter. We are applying genome editing to plants and algae to increase the amount of CO_2 that they absorb during photosynthesis. These genome-edited plants and algae are then fed to seafood and livestock. Thus, the amount of CO_2 in the atmosphere and oceans can be reduced by fixing it in the food chain and cycle.

Although we call this process "genome editing," we are not involved in genetic modification but rather selective breeding, which is safe. As an outcome of this research, we have succeeded in identifying a gene that dramatically improves the CO_2 absorption of algae [4]. As a regional revitalization business based on land-based aquaculture, NTT Green & Food, Inc., which uses the gene-edited algae that absorbs a large amount of CO_2 as feed, started business in July 2023 [5]. Producing new results and expanding our business has therefore become urgent. From now onwards, we will promote the use of marine and terrestrial plants with dramatically increased CO_2 absorption and extend their use to carbon credits.

These technologies are introduced in the article titled "Zero Environmental Impact Technology to Achieve a Clean and Sustainable Society" [6].

3. Forefront initiatives of Resilient Environmental Adaptation Research Project

An overall picture of the Resilient Environmental Adaptation Research Project is shown in **Fig. 3**. This project is researching environmental adaptation, namely, predicting the future by taking into account the mutual influences of human activities and the global environment, supporting proactive management decisions on the basis of the prediction results and avoiding or taking advantage of damage caused by natural phenomena. We are working on establishing four technologies: (i) ESG (environmental, social, and governance) management science and technology that predicts future scenarios (such as climate change) that will affect corporate management from a wide range of publicly available information;

(ii) global environmental futures forecasting technology that predicts the future of the global environment through observation and modeling of physical, biological, and chemical processes in the global environment; (iii) environment and socioeconomic nexus forecasting technology that predicts social and environmental cycles by integrating models from a variety of fields and creating new cycle-evaluation indicators; and (iv) proactive environmental adaptation technology that combines these three technologies and uses the results of future prediction to proactively adapt to the social environment.

With the ESG management science and technology, we aim to establish a future forecasting technology that contributes to the formulation of management strategies by combining two methods: ESG intelligence scientific methodology and ESG futures forecasting methodology. The ESG intelligence scientific methodology collects and analyzes global public information (such as government documents, academic conferences, and news) worldwide by using artificial intelligence (AI), text-mining techniques, and other methods. Information is analyzed by first removing human-thinking biases then generating multiple possible scenarios by extracting causal relationships between events and plans. The ESG futures forecasting methodology quantitatively predicts social and environmental changes on the basis of multiple scenarios. For this quantitative forecasting, we use a macroeconomic model called the computable general equilibrium (CGE) model. The CGE model is used for mathematically predicting changes in an overall market on the basis of production and consumption by industry and the interactions among industries. For example, fluctuations in energy prices can affect the sales volume and CO_2 emissions in industries that use a large amount of energy (e.g., steel manufacturing and transportation). By calculating these effects by using the CGE model, we can quantitatively predict future economic and environmental impacts while taking into account the interactions between industries. Using these methods, we can continuously forecast the combined impact of environmental and social changes on management over the short and long terms. With the ESG futures forecasting methodology, in collaboration with research organizations such as the National Institute for Environmental Studies since 2020, we have been conducting assessments regarding the impact of ICT development on society* and disseminating the results at international conferences. We will focus on the ESG intelligence scientific methodology and collaborate with the management divisions of operating companies with the aim of achieving more practical results.

To create a flexible society that can adapt to change, it is necessary to establish technologies for predicting the future of the global environment. These technologies involve observation of the atmosphere and oceans over an ultra-wide area to model weather and climate on the basis of the Earth's physical processes and model ecosystems on the basis of the Earth's biological and chemical processes. Meteorological and environmental observations are currently limited to land and near-shore waters, that is, real-time observation in the distant parts of the oceans from land has not been established. Therefore, satellite observation is the main method of such observations. However, it is difficult for satellites to measure water vapor, the energy source of extreme weather events, such as typhoons and linear rainbands, as well as environmental information about the ocean. With these difficulties in mind, we are attempting real-time observations in these unexplored areas by using satellite Internet of Things (IoT) [7] while upgrading weather and climate models. Since it is difficult for us to establish such sophisticated ocean observations and models on our own, we are also working with a variety of organizations to study this issue. Some of our recent accomplishments include (i) the world's-first successful simultaneous observation of the atmosphere and ocean under a Category 5 typhoon in the northwest Pacific Ocean in collaboration with the Okinawa Institute of Science and Technology Graduate University (OIST) [8] and (ii) the world's-first development of millimeter-wave radio frequency identification (RFID) tags to improve drone-navigation accuracy for advanced weather observation in collaboration with the University of Tokyo [9].

The aforementioned newly established Environment and Socioeconomic Nexus Forecasting Technology Group is working on technology for forecasting environmental and socioeconomic nexuses. To achieve inclusive sustainability, we are (i) constructing a global-scale simulation environment that reproduces the interaction between environmental and economic activities related to the global water cycle and (ii) researching large-scale coupled simulation technology to link simulation systems in different fields of expertise. These activities are described in detail in the article titled "Forecasting Technologies

* This research was funded by the Environmental Research and Technology Development Fund of the Environmental Restoration and Conservation Agency of Japan (JPMEERF20201002).

Fig. 4. Experimental demonstration of a lightning-resistant drone flight on a beach in a snowstorm.

for Environmental and Socioeconomic Cycles for Attaining Inclusive Sustainability" [10].

The proactive environmental adaptation technology predicts the future by coupling the three above-mentioned technologies (ESG management science and technology, global environmental futures forecasting, and environment and socioeconomic nexus forecasting) and adapts business practices to the environment in accordance with the prediction results. However, it will take time to establish these three technologies. Therefore, we have started research on lightning and cosmic rays, which can be predicted to some extent even now. We are researching technology for preventing lightning-induced damage to important equipment by capturing lightning by drones equipped with lightning rods, guiding it to the desired location, and using lightning energy. We are researching lightning-resistant drone technology, lightning induction technology, lightning prediction technology, and lightning charging technology.

We have completed verification of lightning-resistant drones using artificial lightning and natural lightning in the winter of 2022/2023 on the coast of Uchinada Town, Ishikawa Prefecture, which is an area with the most winter lightning in Japan. Unfortunately, we were unable to capture natural lightning. However, we gained much knowledge during the demonstration in the extreme cold and quite-hazardous winter storms (**Fig. 4**). For example, we developed technology for predicting lightning-induction areas by combining information on thunderclouds and lightning strikes with information from our observations and technology for operating drones under extremely bad weather conditions. Our challenge is not over yet, and to be the first in the world to capture natural lightning with a lightning-resistant drone, we will continue to refine this technology in winter 2023/2024.

We have been working to improve the technology for evaluating soft errors, namely, malfunctions of semiconductors in communication equipment due to cosmic rays. To further develop this technology, we are researching cosmic-ray electromagnetic-barrier technology for evaluating the effects of cosmic rays on space equipment and the human body and reducing the effects of strong electromagnetic fields. This topic is explained in detail in the article titled "Forefront Research Initiatives on Environmental Adaptation to Enhance Societal Resilience to Environmental Changes" [11].

4. Conclusion

The latest information on the efforts of NTT Space Environment and Energy Laboratories were explained in this article. The Feature Articles in this issue will discuss some of the themes that have achieved success. We hope you will keep abreast of the growth of the Laboratories as it takes on the challenge of creating innovative technologies in the environment and energy field from a space perspective.

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Zero Environmental Impact Technology to Achieve a Clean and Sustainable Society

Masaki Kozai, Naoki Hanaoka, Hazuki Hasegawa, Hiroaki Takebe, Sousuke Imamura, and Toru Tanaka

Abstract

To contribute to achieving zero environmental impact, NTT Space Environment and Energy Laboratories is engaged in research and development of new forms of energy, efficient and resilient energy transport, and effective absorption and conversion of carbon dioxide (CO_2). This article introduces virtual energy demand/supply control technology that makes the most effective use of renewable energy, next-generation energy supply technology that uses a direct current (DC) grid using reliable DC power supply, and oceanic CO_2 reduction technology that uses the ocean food chain, which will all contribute to achieving carbon neutrality.

Keywords: zero environmental impact, sustainable, carbon neutral

1. Virtual energy demand/supply control technology

Virtual energy demand/supply control technology (**Fig. 1**) is used to enable local production and consumption of renewable energy by adjusting power consumption through appropriately arranging workloads to be processed using information and communication technology (ICT) equipment installed in NTT telecommunications buildings distributed throughout Japan across time and space. In cooperation with NTT Network Service Systems Laboratories and the NTT Network Innovation Center, this technology is being established and tested [1].This technology consists of many elemental technologies, such as forecast of renewable energy generation, electricity-demand forecasts per building and per workload, and various forecasts related to ICT resources, optimization of energy demand and workload deployment based on the forecasts, and workload control technology to obtain the optimization result. We have verified the functionality of newly developed elemental technologies at a single site. To verify the effectiveness of this technology, we constructed a verification environment in fiscal year 2022 in which two sites approximately 1 km apart are connected by a 10-Gbit/s line.

We defined the workload as the central processing unit (CPU) and memory load applied to nine virtual machines (VMs) that provide a virtual desktop service. These workloads were moved between sites while service was running (live migration), and the evaluation was carried out in terms of energy, services, and operations.

Through experiments, we quantitatively determined the relationship between load conditions, the time taken to move workloads, and adjustable power consumption. For example, when all VMs are under heavy load (CPU usage 85%, memory usage 80%), 107 W of power consumption can be adjusted, which is about 35% of the server power consumption (270 W). Note that it took approximately 90 seconds from the start of the VM move to its completion, and during that time, there was almost no effect on the virtual desktop service from the user's perspective (**Fig. 2**).

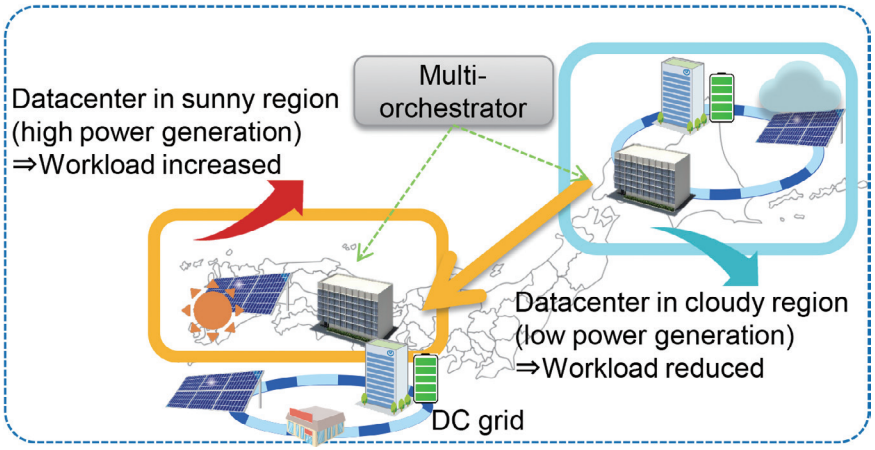


Fig. 1. Virtual energy demand/supply control and DC grid.

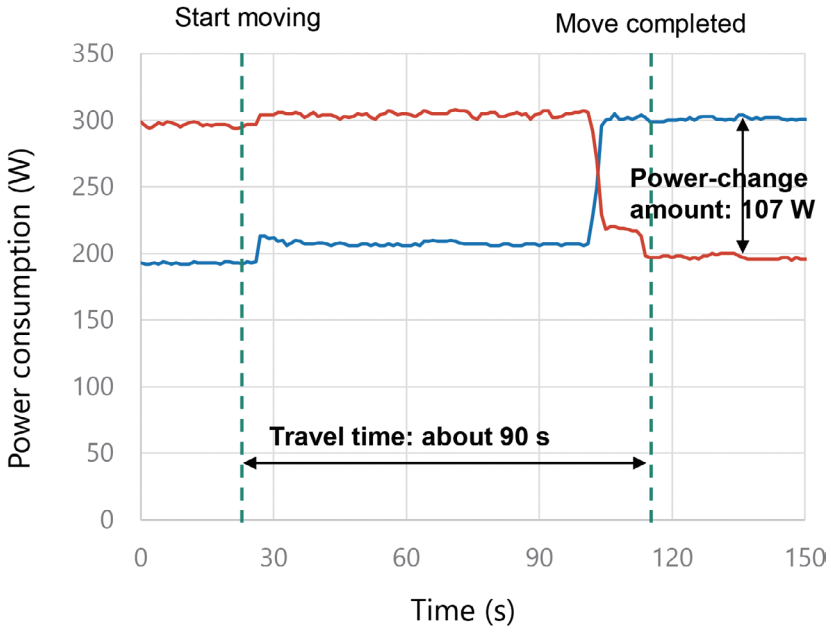


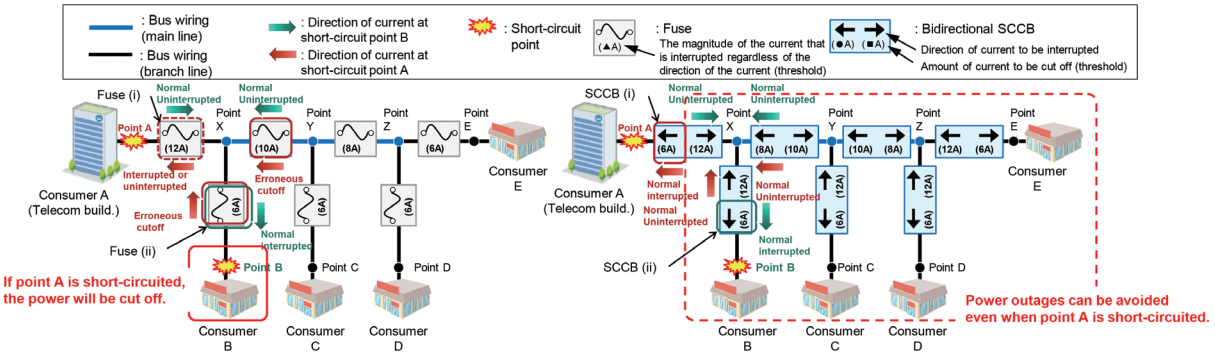
Fig. 2. Example of how power consumption changes over time when moving workloads.

This verification was conducted on two servers. By applying this technology to a large number of servers, power consumption may be adjustable on a large scale by moving workloads. In the future, we will examine feasibility by moving workloads over longer distances and at multiple sites. We will also examine the scalability of each elemental technology in parallel.

2. Next-generation energy supply technology

Next-generation energy supply technology uses safe and reliable direct current (DC) power feeding technology to enable effective use of renewable energy and flexible power interchange without power failure even in times of disaster.

The severity of natural disasters has been increasing, and the resilience of new forms of power interchange urgently needs to be improved for preserving



(a) When using fuses to protect against short circuits (overcurrent protection cannot be coordinated)

(b) When providing short circuit protection with a bidirectional SCCB (overcurrent coordination can be achieved)

Fig. 3. System configuration and short-circuit protection of bus-wired outdoor DC power supply system.

the global environment and improving energy self-sufficiency.

To solve this problem, we are researching and developing an outdoor DC power feeding system for DC microgrids (Fig. 1). A feature of this system is its reliability because the storage battery is directly connected to the power line and the power feeding system does not require electronic components that may fail. By taking advantage of its reliability, we are studying a system that connects a telecommunications building with storage batteries and multiple customers with renewable energy via power lines and that uses 380 VDC to provide power in both directions, focusing on electrical safety. In the first step in this study, we verified the basic characteristics and safety of electric power supply in a star wiring system that connects a telecommunications building to each customer on a one-to-one basis [1]. For the next step, we are studying a bus wiring system.

While bus wiring is more economical than star wiring in terms of the cost of laying power lines, if a short circuit (the positive and negative power lines come into contact) occurs at a certain point, a large current may flow through the entire system, causing power failure. For example, if a fuse is simply inserted to protect a short circuit in the bus wiring shown in **Fig. 3(a)**, a power failure will occur in the bus wiring. Because the direction of the short-circuit current through the bus wiring changes depending on the short-circuit point, the current at short-circuit point B (green arrow) can be blocked by the nearest fuse (ii) to the short-circuit point, but the current at short-circuit point A (red arrow) can be blocked due to the malfunction of a fuse other than the nearest fuse (i) to the short-circuit point. Therefore, overcurrent protection coordination*1 between fuses cannot be achieved, and multiple fuses may operate simultaneously, resulting in the system shutting down. Even if the direction of the short-circuit current changes, the circuit breakers need to cooperate to protect against the overcurrent and maintain the power supply of the users other than the short-circuit point.

To solve this problem, we installed one bidirectional semiconductor circuit breaker (SCCB) at each trunk line and branch line of the bus wiring, which can set the overcurrent-cutoff threshold for each direction of current, and clarified the conditions for this threshold.

As shown in **Fig. 3(b)**, a bidirectional SCCB is installed in the bus wiring, and the overcurrent-cutoff threshold is set to gradually decrease in the direction of power supply from one customer to another. Each bidirectional SCCB consists of unidirectional SCCBs connected in series in the opposite direction and features an overcurrent-cutoff threshold for each current direction. As shown in Fig. 3(b), when there is a short circuit at point B, only SCCB (ii) operates quickly and disconnects the short-circuit point. This is because SCCB (ii) has the smallest overcurrent-cutoff threshold in the direction of the short-circuit current and is the SCCB closest to the short-circuit point.

*1 Overcurrent protection coordination: Mutual adjustment (coordination) by intentionally creating differences in operating values and times of multiple protection devices. This makes it possible to detect fault currents such as short circuits and disconnect only the fault section, thus avoiding power outages in other healthy circuits. Regarding fuses, the operating value (fusing characteristics) cannot be changed depending on the direction of current, so fuses can only coordinate for current in one direction.

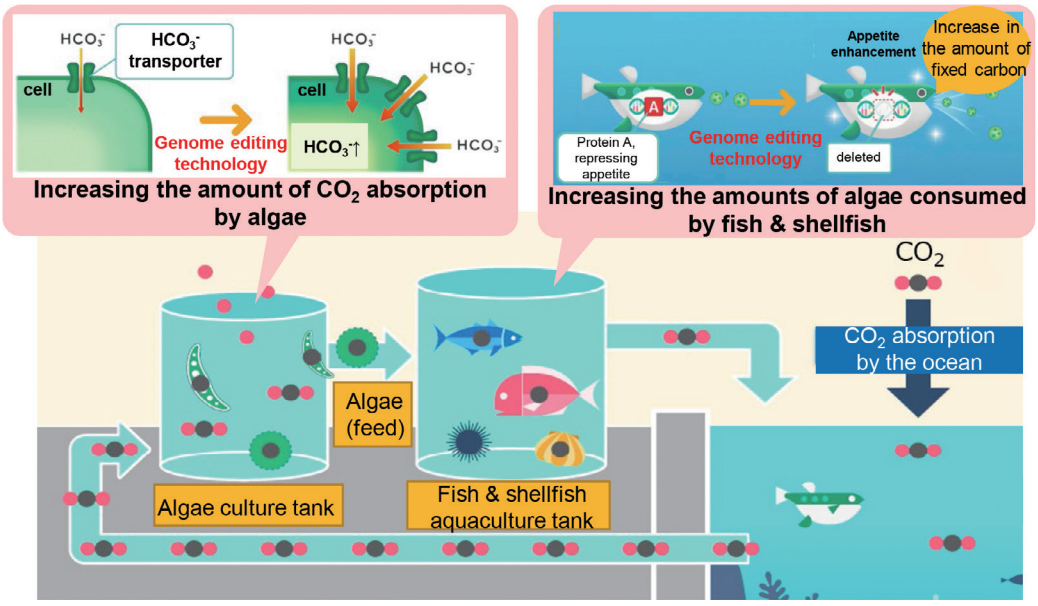


Fig. 4. Overview of CO_2 reduction in the ocean using the marine food chain.

Similarly, when a short circuit occurs at point A, SCCB (i), the closest to the short circuit, disconnects it. In this case, only the SCCB close to the short-circuit point operates at the other points C, D, E, X, Y, and Z as well, and the short-circuit point is disconnected. Therefore, when a short circuit occurs at any point in the bus wiring, only the SCCB immediately adjacent to the short-circuit point is shut off. This minimizes the area affected by the power failure during the short circuit and improves the reliability of the bus-wiring power feeding system.

In the future, we will research and develop a system that does not lose power during a short circuit even when the trunk line is a loop-wiring type. We will also contribute to enabling flexible, safe, and secure power feeding by further improving the reliability of the power feeding system.

3. Marine-food-chain-based CO_2 reduction technology in the ocean and its applications

Global warming has become a serious international issue. Since carbon dioxide (CO_2) in the atmosphere is considered to cause global warming, the need to reduce CO_2 in the atmosphere is urgent. According to the 6th Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), the ocean accounts for 35.1% of CO_2 absorption. The amount of CO_2 absorbed by the ocean mainly depends on the concentration of CO_2 dissolved in seawater. Therefore, it is expected that if CO_2 in the ocean is decreased, the amount of CO_2 absorbed from the atmosphere to the ocean will increase, which will lead to a decrease in CO_2 in the atmosphere.

In the ocean, algae*2 fix CO_2 through photosynthesis*3. Fixing refers to the process of converting CO_2 into organic compounds and incorporating it into living organisms. These algae are then directly or indirectly preyed upon by fish and shellfish in the food chain, eventually leading to the fixation of carbon within the bodies of the fish and shellfish. NTT is currently focusing on this carbon fixation process through the marine food chain to decrease CO_2 in oceans (**Fig. 4**). Specifically, NTT aims to enhance both the carbon fixation ability of algae and the feeding/growth abilities of fish and shellfish by using gene modification technologies such as genome editing*4. NTT also aims to optimize cultivation conditions to maximize and prolong the total amount of carbon fixed throughout the marine food chain. It is believed this research targeting algae as well as fish and shellfish can solve the problem of short-term

*2 Algae: Organisms that photosynthesize, excluding land plants.
*3 Photosynthesis: In plants and algae, a reaction system that synthesizes organic matter from CO_2 using light energy.
*4 Genome editing: A technology that specifically modifies any base sequence on the genome. Unlike genetic recombination technology, foreign genes do not remain within the cell.

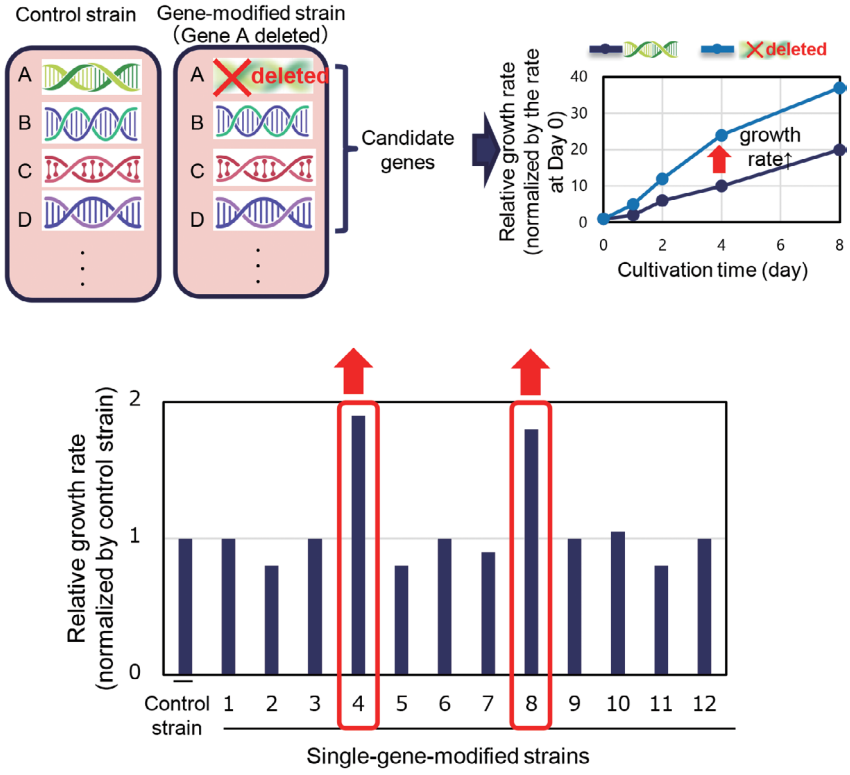


Fig. 5. The schematic model of evaluation method of gene function and the evaluation results of 12 single-gene-modified strains.

carbon fixation faced by traditional algae-related studies. NTT, in collaboration with Regional Fish Institute (RFI), a pioneer in fish-species improvement using genome editing technology, is advancing research towards synergistically reducing CO_2 in oceans by using the marine food chain. NTT is striving to improve the carbon fixation capability of algae; working on selecting target genes, and developing and evaluating productive strains by applying genome editing technologies.

While the carbon fixation mechanism of algae has long been studied, the genes involved in carbon fixation have not been fully clarified. Therefore, we first selected genes expected to enhance carbon fixation capacity. One method for evaluating gene function is to observe the proliferation of a single-gene-modified strain under specific conditions. For instance, since the activity of photosynthesis generally decreases in low CO_2 environments, the growth of algae slows when cultured under such conditions. If an algal strain, modified by removing a certain gene A, proliferates significantly more under low CO_2 conditions than the unmodified strain, gene A may function to inhibit carbon fixation under low CO_2 conditions (top of **Fig. 5**). If genome editing technology is applied to gene A, a resultant algal strain will likely show improved carbon fixation ability under low CO_2 conditions.

At NTT, we applied the aforementioned gene function evaluation method and narrowed down the genes involved in carbon fixation by varying the CO_2 concentration during cultivation. We first obtained genetically modified strains for each of the 12 candidate target genes then evaluated the proliferation of these strains. We found that genetically modified strains related to two types of genes (genes 4 and 8) proliferated significantly more than the unmodified strains (bottom of Fig. 5). This greater proliferation suggests that more CO_2 is being absorbed and fixed per unit time. In other words, the application of genome editing to genes 4 and 8 may dramatically increase the amount of CO_2 absorbed by algae. On the basis of the discovery of genes 4 and 8, we aim to breed algae strains with improved carbon fixation capabilities. Moreover, by identifying more target genes and applying genome editing technology, we

are committed to not only breeding strains with high carbon fixation abilities, such as photosynthetic activity, but also breeding strains that have industrial benefits, such as the accumulation of useful substances.

To implement this research in the real world, NTT Group, using useful algae breeding technology and telecommunication technology, along with RFI's state-of-the-art shellfish-species-improvement and aquaculture technologies, established a joint venture company, NTT Green & Food (G&F) on July 1, 2023 [2]. In accordance with the philosophy of "Making the most of nature's bounty with technology and designing the future of the earth and food," G&F aims to develop the Green & Food business composed of three axes: (i) production and sale of environmentally friendly algae, (ii) production and sale of environmentally friendly fish and shellfish that feed on these algae, and (iii) provision of a circular land-based aquaculture platform using these algae and shellfish. NTT will continue to advance technology for breeding and producing useful algae toward the establishment of the Green & Food business.

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Long-distance Laser-energy Transmission for Space Solar Power Systems and Their Application on Earth

Natsuha Ochiai, Yukiko Suzuki, Kazuto Kashiwakura, and Yohei Toriumi

Abstract

NTT Space Environment and Energy Laboratories is researching space solar power systems (SSPSs) to enable clean and sustainable next-generation energy. In this article, we explain what an SSPS is and introduce the issues and efforts regarding energy-transmission technology involving lasers, technology to convert sunlight into laser light, and technology to efficiently convert laser light into electric power.

Keywords: space solar power system, optical wireless power transmission, laser

1. What is a space solar power system?

A space solar power system (SSPS) is a next-generation energy technology that converts solar energy into laser light or microwaves on a geostationary satellite orbiting the Earth, transmits it to the ground, and uses it as power. Since the orbit of a geostationary satellite is 36,000 km above the Earth's surface, the satellite rarely enters the Earth's shadow, and unlike conventional solar-power generation, it can generate electricity day and night. Because there is no scattering or absorption by clouds or the atmosphere in space, the energy per unit area of sunlight is expected to be about 10 times that of the ground per year. An SSPS has been attracting attention as a clean and large-scale energy technology using solar energy, regarded as inexhaustible in unobstructed space. Microwave and laser have been proposed as media for transmitting energy from space to the ground. NTT is researching SSPSs using lasers, which have a smaller beam divergence than microwaves and expected to enable system-size reduction. A schematic of this SSPS is shown in **Fig. 1**. First, solar energy is converted to laser light on a geostationary satellite and transmitted to the ground for 36,000 km. The laser light is then converted to electric power by using photovoltaic devices[*1] such as solar cells at a light-receiving facility on the ground. Chemical raw materials such as hydrogen can also conceivably be generated using the energy of laser light on the ground.

We present the challenges and initiatives of the laser-energy-transmission technology necessary for SSPSs. We also describe the research status of technology for solar-pumped lasers and high-intensity beam-energy conversion and introduce examples of these technologies being deployed on the ground.

2. Laser-energy-transmission technology

2.1 Diffraction and atmospheric turbulence

In an SSPS, laser light is propagated from a

*1 Photovoltaic device: A semiconductor device that converts light into electricity. Semiconductors generate electromotive force when light is shone on them due to the photoelectric effect. By changing the composition of the semiconductor, the wavelength of light that can efficiently generate electromotive force can be changed. Solar cells are also a type of photovoltaic cell.

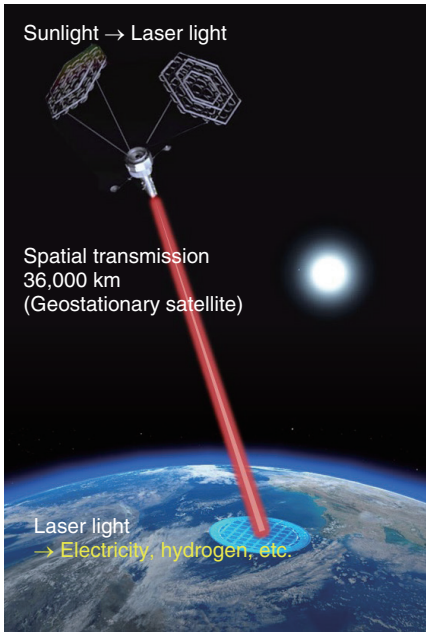


Fig. 1. Schematic of laser-SSPS.

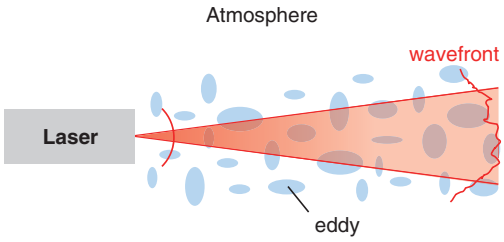


Fig. 2. Conceptual diagram of beam propagation in the atmosphere.

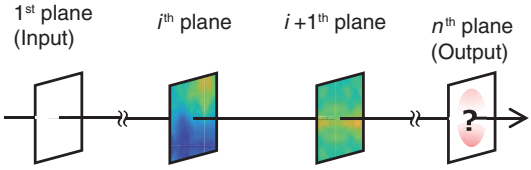


Fig. 3. Schematic of the model of split-step beam-propagation method.

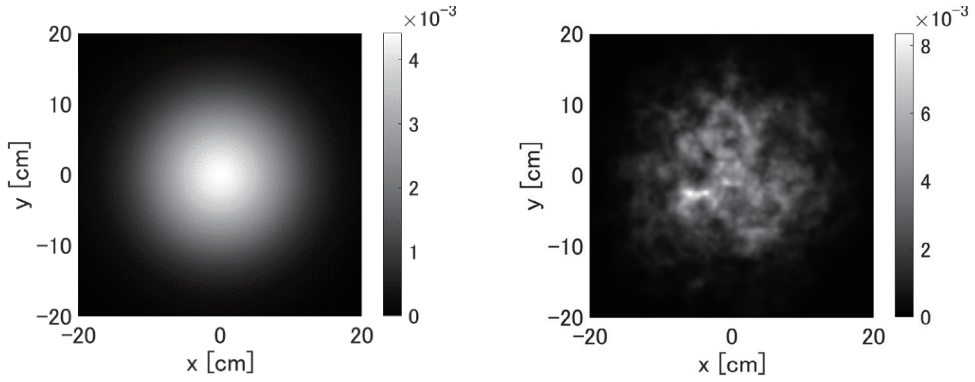
geostationary satellite to the ground over a distance of 36,000 km. Laser light diffracts, causing beam divergence as it propagates. Since a typical Gaussian beam*2 tends to diverge more the thinner it is, the beam needs to be widened to reduce the beam-divergence angle for long-distance transmission. For example, a beam with a diameter of 1 cm will spread to about 1 km when propagated over 36,000 km, which would require a massive ground-based receiving facility. To suppress beam divergence, the beam diameter of the transmitting side needs to be widened to several meters.

The atmosphere from the surface of the Earth up to about 100 km above contains eddies of various sizes, as shown in **Fig. 2**, causing the refractive index of the atmosphere to change randomly in space and time. When laser light propagates through the atmosphere, the wavefront is disturbed by air eddies, resulting in fluctuations in the intensity distribution of the beam. This is called atmospheric turbulence. If the intensity distribution of the beam fluctuates, there will be a reduction in power generation when converting laser light into electricity with a light-receiving panel consisting of multiple photovoltaic cells, as the light is not evenly projected on the panel [1]. Therefore, it is important to design a beam that is less affected by atmospheric turbulence and an optical system for the light-receiving panel that matches the shape of the beam.

2.2 Simulation of beam propagation through atmosphere

To predict the effect of diffraction and atmospheric turbulence on beam propagation, we conducted beam propagation simulation in the atmosphere. The split-step beam-propagation method effectively reproduces the propagation in a random medium such as atmospheric turbulence. With this method, the propagation is calculated by dividing the propagation optical path into multiple sections by using multiple phase screens, as shown in **Fig. 3**. By reflecting the refractive-index distribution of the atmosphere in these phase screens, the effect of atmospheric turbulence can be reproduced together with diffraction by normal propagation. To generate a phase screen, we need a spectrum model of the atmosphere. Commonly used models include the Kolmogorov spectrum, von Karman spectrum, and modified von Karman spectrum [2]. The Kolmogorov spectrum is widely used as a basic model, but it lacks accuracy because it does not take into account the size of air eddies that affect the spatial frequency of atmospheric

*2 Gaussian beam: One of the propagation modes of optical beams in which the intensity distribution follows a Gaussian function. The intensity decreases in accordance with a Gaussian function as the position moves away from the center of the beam.



(a) Propagation in vacuum (b) Propagation in atmosphere

Fig. 4. Gaussian-beam pattern after propagation.

fluctuations. The von Karman spectrum and modified von Karman spectrum, however, can take into account the minimum and maximum size of the air vortex, respectively. In this simulation, the modified von Karman spectrum was used as a spectrum model. This spectrum uses the minimum (called inner scale) and maximum (called outer scale) magnitudes of air eddies as well as a parameter called the atmospheric refractive index structure constant, which represents the strength of the refractive-index change. Typical values of the inner scale are on the order of 1 to 10 mm near the ground surface, and the outer scale usually decreases in proportion to the altitude in the area up to 100 m from the ground [2]. The atmospheric refractive index structure constant usually ranges from 10^{-17} to 10^{-13} $m^{-2/3}$, depending on the season and time. These parameters are assigned to the modified von Karman spectrum, and a phase screen is generated using Fourier transform [3]. **Figure 4** shows the beam pattern after atmospheric propagation of the Gaussian beam obtained through simulation (the parameters used in the calculation are listed in **Table 1**). By propagating through the atmosphere, the intensity distribution of the beam is finely disturbed.

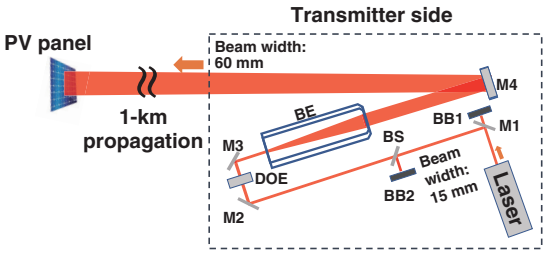
Table 1. Calculation parameters.

Wavelength	1064 nm
Beam width (full width at $1/e^2$ maximum)	60 mm
Wavefront curvature radius	250 m
Propagation distance	1 km
Inner scale	1 mm
Outer scale	1 m
Atmospheric refractive index structure constant	10^{-13} $m^{-2/3}$
Number of phase screens	21
Number of pixels	4084 × 4084
Pixel pitch	0.1 mm

2.3 Experiment

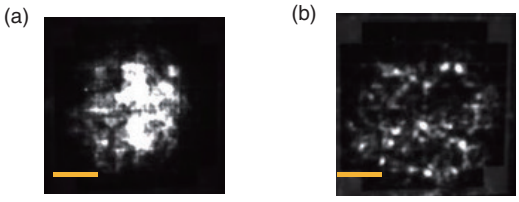
In an SSPS, laser light is irradiated from a geostationary satellite to the ground to transmit energy, so the transmission direction is vertical to the ground. However, in the vertical direction, it is difficult to ensure the safety of laser light and arrange appropriate test sites. Therefore, we first conducted an energy-transmission experiment in the horizontal direction on the ground in collaboration with Mitsubishi Heavy Industries, Ltd to verify the beam-propagation simulation in the atmosphere and examine the energy-conversion efficiency [4, 5]. In addition to the Gaussian beam with a laser wavelength of 1064 nm, a special beam called the Laguerre-Gaussian (LG) beam*3 was prepared to transmit 1 km in free space and irradiate a 400 mm × 400 mm light-receiving panel (**Fig. 5**). For long-distance and high-power beam propagation, the effect of aberration*4 of optical elements, such as lenses, and thermal lens effect*5 become problematic. In this experiment, the optical system of both Gaussian and LG beams was designed and adjusted to be

*3 LG beam: A beam with a different intensity distribution from a Gaussian one, forming a ring shape. As a beam with orbital angular momentum, it is attracting attention in various fields such as light communication.

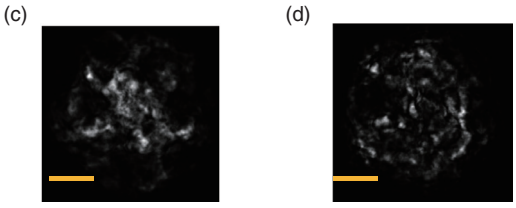


M1-M3: mirrors M4: direction-control mirror BB1, BB2: beam blocks
BS: beam splitter BE: beam expander DOE: diffraction optical element
PV: photovoltaic

Fig. 5. Schematic of optical system of energy transmission [5].



(a) Gaussian beam and (b) LG beam captured during the experiment



(c) Gaussian beam and (d) LG beam calculated through the simulation
Scale bar (yellow line): 100 mm

Fig. 6. Beam pattern after 1-km propagation [5].

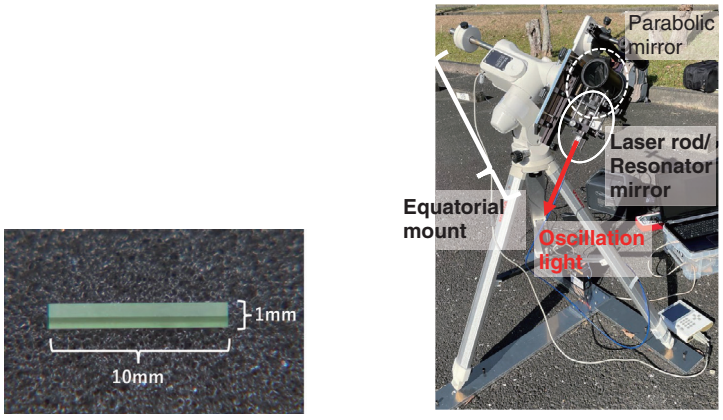
about 300 mm when irradiated to the light-receiving panel [3], and a large-diameter lens and low-aberration expander were prepared to prevent aberration. To verify the atmospheric-turbulence simulation, the beam pattern was captured with an infrared camera for 1 min and the intensity distribution was obtained. To examine the transmission efficiency, the power extracted from the light-receiving panel was measured through current-voltage (IV) measurement*6.

Figure 6 shows the experimental and simulation results of the beam pattern after 1-km transmission. In the simulation, the atmospheric structure constant measured during the experiment is used, but the phase screen that reproduces the effect of the turbulence was randomly generated, so the results of the experiment and simulation do not completely match. However, the beam's shape is generally consistent, such as the size of the beam and disturbance of the

*4 Aberration: Deviation from the ideal wavefront caused by distortions in optical components such as lenses and mirrors. In long-distance beam propagation, as in this article, the problem is that the beam divergence deviates from the ideal due to aberration, especially spherical aberration, which shifts the focal position in accordance with the distance from the optical axis.

*5 Thermal lens effect: A phenomenon in which the refractive index of optical components, such as a lens, changes when strong laser light is irradiated and that part is heated. Similar to aberration, it poses a problem because it affects the beam divergence and intensity distribution.

*6 IV measurement: A method for evaluating the IV characteristics of semiconductors, such as photovoltaic cells or diodes. By plotting current on the vertical axis and voltage on the horizontal axis, one obtains an IV curve showing the power generation capability of the solar cell.



(a) Image of laser single-crystal rod

(b) Solar incidence oscillation evaluation system

Fig. 7. Solar-pumped laser-oscillation experiment.

intensity caused by the turbulence. When the beam diameter was calculated from the integrated value of the acquired intensity distribution, the error between the experiment and simulation was within 5% for both Gaussian and LG beams [5]. The average value of the center of gravity deviation of the beam calculated in each frame of the video showed an error of 2% between the experiment and simulation [5], indicating that the simulation could accurately reproduce the disturbance in the experiment.

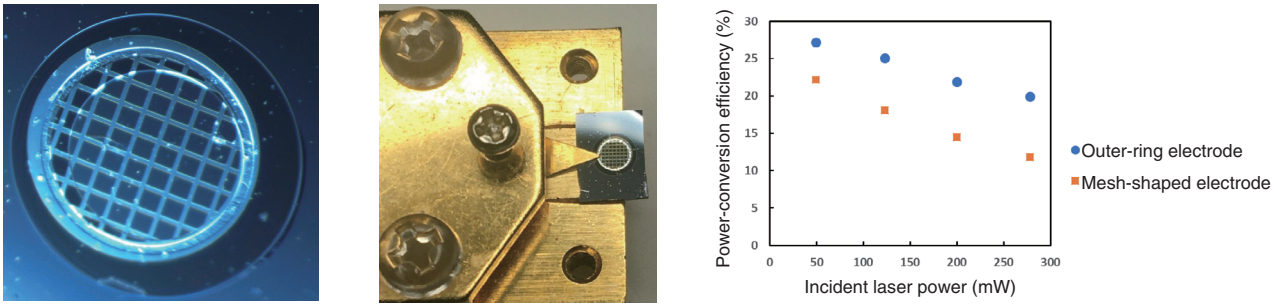
Next, IV measurements were conducted to calculate the energy conversion efficiency. The conversion efficiency of the Gaussian beam and the LG beam was as low as 3% [5]. As can be seen from Fig. 6, this is thought to be due to the intensity distribution of the beam being made non-uniform by atmospheric turbulence, and the light-receiving panel could not be irradiated with uniform laser light. Therefore, a turbulence-robust transmission system is required, such as a beam that can be uniformly irradiated even under atmospheric turbulences and a light-receiving panel that is less affected by variations in the amount of irradiation.

3. Other initiatives at NTT related to SSPSs

In addition to laser-energy transmission, we will introduce the technologies that NTT is researching to enable an SSPS.

3.1 Solar-pumped laser

If a laser device is used as a light source for an SSPS, it is necessary to receive sunlight with a light-receiving panel, convert it into electric power, and generate laser light using the electric power. However, this method involves many energy-conversion processes, which may complicate the system. Therefore, NTT laboratories are studying solar-pumped laser technology, in which solar light is directly irradiated to a laser medium for laser excitation. This technology is expected to reduce the size and weight of the system. Codoped media, such as neodymium and chromium-codoped yttrium aluminum garnet (Nd:Cr:YAG) and neodymium and cerium-codoped YAG (Nd:Ce:YAG), which absorb the energy of sunlight in a wide wavelength spectrum and capable of lasing at a wavelength of 1064 nm, have been investigated as solar-pumped laser media. However, most are made of ceramics, and high-quality single-crystal media have not been reported. In consideration of the possibility of application in space, where heat dissipation is difficult, NTT laboratories are researching single-crystal laser media in collaboration with the Graduate School for the Creation of New Photonics Industries. Thus far, Nd:Cr:YAG single crystals and Nd:Cr:Ce:YAG single crystals have been grown and processed into rod types for lasing (**Fig. 7(a)**). The authors constructed a system for measuring laser-oscillation intensity by concentrating sunlight on these laser rods with a parabolic mirror and conducted an oscillation experiment outdoors [6] (**Fig. 7(b)**). As a result of the oscillation experiment, laser oscillation by solar-light injection was confirmed for Nd:Cr:YAG and Nd:Cr:Ce:YAG single crystals.



(a) Image of outer-ring-electrode device

(b) Image of PV device evaluation

(c) Laser-power dependence of power-conversion efficiency

Fig. 8. Measurement-evaluation experiment of a prototype PV device [7].

However, compared with the ceramic medium of the same material, both single crystals were below the characteristics of ceramics at the oscillation threshold[*7] and slope efficiency[*8]. In the future, we will analyze the mechanism of laser excitation occurring in a single-crystal medium and investigate a laser medium that has higher oscillation efficiency and suitable for an SSPS.

3.2 High-intensity beam-energy conversion

We are also researching photovoltaic devices that can convert high-intensity laser light from space into electric power on the ground. As mentioned above, in an SSPS, energy of megawatt class is transmitted to the ground with a beam diameter of several meters. To use this energy as much as possible without waste, we are developing a photovoltaic device with high efficiency and high output in collaboration with University of Miyazaki. An indium gallium arsenide phosphide (InGaAsP) photovoltaic device with a high photoelectric conversion efficiency at a wavelength of 1064 nm, which is the assumed wavelength of the laser, has been prototyped, and studies are underway to improve the characteristics of photoelectric conversion and increase the device area. **Figure 8(a)** shows a device for reducing electrical resistance with an outer-ring electrode. The device was irradiated with 1064-nm laser light using the measuring jig shown in **Fig. 8(b)**, and the power-conversion efficiency was measured. The results are shown in **Fig. 8(c)**. For comparison, the characteristics of a photovoltaic device with mesh-shaped electrodes without outer-ring electrodes are also plotted. The power-conversion efficiency with outer-ring electrodes is up to 27%, indicating that the resistance of the conductor is reduced and the efficiency is improved by using outer-ring electrodes [7]. We will further improve conversion efficiency by improving the anti-reflection coating and electrode design.

When such a semiconductor photovoltaic device is used, however, the photoelectric-conversion efficiency is limited to about 50–60%, and the remainder becomes heat. Therefore, we are also studying ways to use laser energy efficiently in forms other than electricity, for example, by using laser energy as a heat source at extremely high temperatures to generate hydrogen and reduce carbon dioxide to produce fuels and chemical raw materials.

4. Ground use

Although SSPSs are expected to be commercialized after 2050, we aim to make early contributions to society by applying these elemental technologies on the ground before SSPSs are fully implemented. We believe that power can be supplied to areas such as remote islands where cables are difficult to lay, or disaster-stricken areas where the power grid has been cut off. We are also considering the potential for application to power supplies for mobile bodies such

*7 Oscillation threshold: The minimum incident light power at which oscillation occurs in an optically pumped solid-state laser. If the injected current is small, the amplification of light falls below the attenuation, and oscillation does not occur. As the current is increased, the amplification increases and oscillation is initiated. The lower the oscillation threshold, the higher the performance of the laser.

*8 Slope efficiency: Beyond the lasing threshold, the laser output increases proportionally to the incident light power. This rate of increase is called the slope efficiency. The higher the slope efficiency, the higher the performance of the laser.

as drones and high altitude platform stations (HAPSs)[*9], where miniaturization and weight reduction are key issues. Flight-time limitations and hassle involved in power supply are also factors that restrict applications. Therefore, if energy supply to mobile bodies during flight is made possible with laser-energy-transmission technology, we will be able to minimize the amount of batteries that need to be installed and extend flight time, which suggests a widening of application possibilities.

5. Future work

Toward developing and implementing SSPSs, we will continue to advance the laser-energy-transmission technology, solar-pumped laser technology, and high-intensity beam-energy conversion technology introduced in this article. Various other technologies are also needed to develop SSPSs, including technology for controlling the attitude of geostationary satellites and accurately beam to ground receiving facilities, and heat-dissipation technology in the vacuum of space. While cooperating with other institutions, we aim to mature these technologies and achieve a sustainable society through SSPSs. We will also promote the early deployment of ground applications such as wireless power-supply systems using laser-energy-transmission technology.

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*9 HAPS: A system that mounts communication equipment on aircraft or balloons flying at an altitude of more than 20 km above the ground to provide communication infrastructure and other services.

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Forefront Research Initiatives on Environmental Adaptation to Enhance Societal Resilience to Environmental Changes

Hidenori Iwashita, Masaki Hisada, Madoka Takahashi, and Asami Miyajima

Abstract

NTT Space Environment and Energy Laboratories aims to create a resilient society that can respond flexibly to environmental changes by predicting patterns in the environment and human activities and developing technologies for environmental adaptation. In this article, we introduce the latest topics of research in cosmic-ray barrier technology and global environmental futures forecasting technology.

Keywords: cosmic ray, typhoon forecast, ocean ecosystem

1. Introduction

The Resilient Environmental Adaptation Research Project at NTT Space Environment and Energy Laboratories has been promoting research toward a resilient society that can respond flexibly to future environmental changes. The resilient society we aim for is a world in which we can adapt to environmental changes. We will not only be able to avoid or forestall the damage to human society caused by natural phenomena but will also be able to take advantage of natural phenomena that have been regarded as scourges. In October 2023, our project welcomed a new research group, the Environment and Socioeconomic Nexus Forecasting Technology Group. Together with this research group, we are working to accelerate research aimed at sustainable prosperity for people and the global environment (comprehensive sustainability), which requires anticipating more long-term and complex events and taking early action.

The technological themes we are working on to achieve these goals can be roughly categorized into the following two phases. The first is adapting to environmental changes to enable more proactive measures in advance to be taken in response to extreme natural phenomenon, and the second is predicting future environmental changes for the adaptation by taking into account the mutual effects of the global environment and human activities. With respect to these themes, we introduce the latest research topics in cosmic-ray barrier technology and global environmental futures forecasting technology, respectively.

2. Forefront research initiatives of cosmic-ray barrier technology

This section introduces findings in cosmic-ray research (solar flares and radiation from galaxies), which is part of our ongoing research aimed at environmental adaptation to avoid or lessen damage caused by natural phenomena. Sophisticated electronic devices support our lives in numerous ways, but they increasingly fall victim to soft errors caused by cosmic rays. When cosmic rays, which rain down from space, collide with oxygen or nitrogen atoms in the atmosphere, neutrons are generated. When

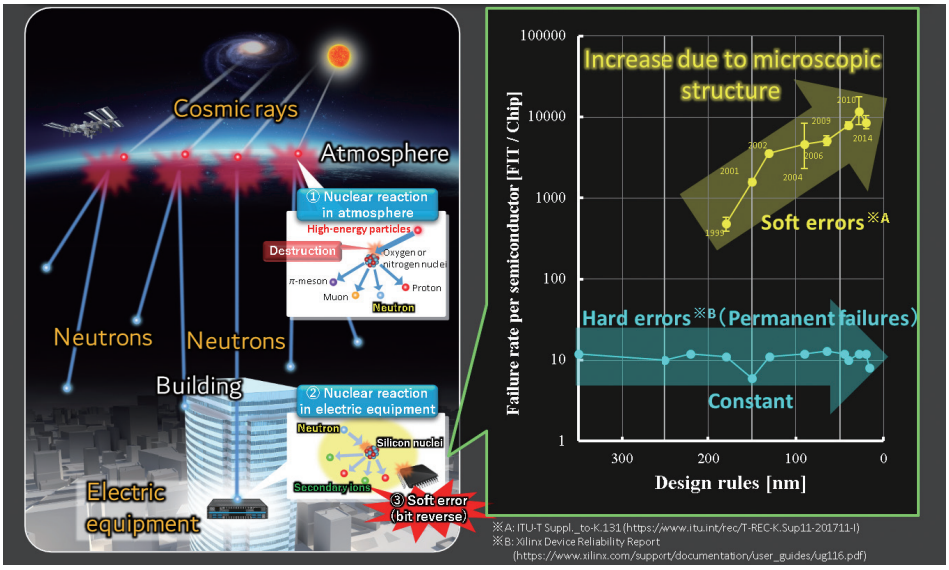

Fig. 1. Mechanism of soft error occurrence.

neutrons collide with a semiconductor in an electronic device, they can cause soft errors, a phenomenon in which the data stored in a semiconductor are changed. Soft errors have the potential to negatively impact social infrastructures, such as telecommunication failures (**Fig. 1**). In considering measures against soft errors in electronic devices, it is important that the system design takes into account the frequency of the soft-error-induced failures of each device. The frequency of soft-error-induced failures varies greatly depending on the energy of neutrons reaching the device. Therefore, it is critical to clarify the energy dependence of the soft-error rate (SER)[*1] (SER at different neutron energies).

NTT Space Environment and Energy Laboratories and Hokkaido University have joined forces and successfully measured the semiconductor SER at continuously varying neutron energies in the low energy range of 10 meV (milli-electron volt) to 1 MeV (mega-electron volt), a range which has not been previously measured [1]. The findings revealed a complete picture of the neutron energy dependence of semiconductor soft errors in conjunction with our measurements in the high-energy region, which were successful in 2020 (joint research between Hokkaido University, Nagoya University, and NTT) (**Fig. 2**). Taking countermeasures against soft errors is essential for electronic devices that support our current social infrastructure. Clarifying the SER for different neutron energies is of utmost importance for studying such countermeasures since the SER varies greatly depending on neutron energy.

We measured soft errors caused by low-energy neutrons below 1 MeV using the time-of-flight method with a high-speed soft-error detector developed in 2020. The time-of-flight method is a means of calculating the neutron speed and converting it to kinetic energy by measuring the time taken for the neutron to travel a certain distance. The experiment was conducted by connecting a high-speed soft-error detector developed by NTT to the instrument for neutron source characterization (neutron beamline for observation and research use (NOBORU)) installed at the Materials and Life Science Experimental Facility of the Japan Proton Accelerator Research Complex (J-PARC) (J-PARC Proposal No. 2022A0249). The intensity of neutrons used for irradiation at this facility was evaluated by Hokkaido University using the gold foil activation method[*2]. The SER in a field-programmable gate array (FPGA)[*3] was measured for continuously varying energies with high resolution.

*1 SER: The probability at which one neutron causes a soft error in a unit area. In more technical terms, it is defined as a single-event upset (SEU) cross section or sometimes as the probability at which a soft error occurs within a unit time.

*2 Gold foil activation method: A method of calculating the number of neutrons used for irradiation by measuring gamma rays from radioactive Au-198 produced when gold foil is irradiated with neutrons.

*3 FPGA: A logic device with which the user can program a logic circuit in the field.

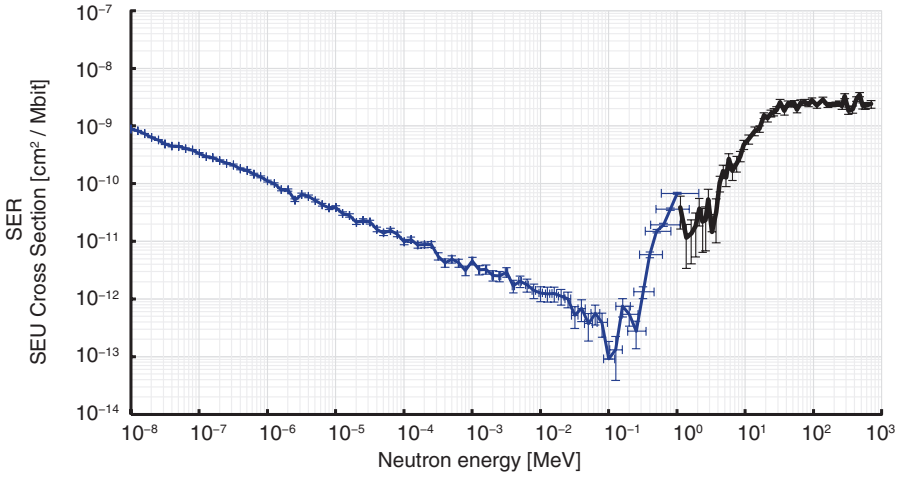

Fig. 2. SER at different neutron energies measured in this study.

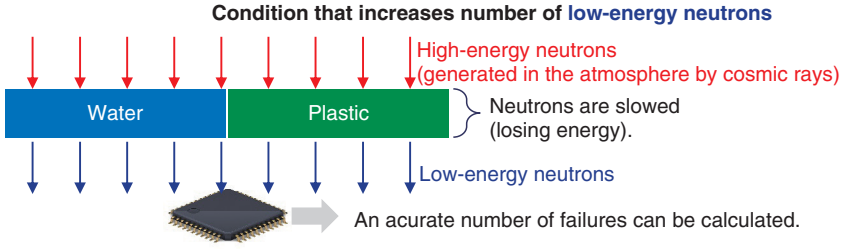

Fig. 3. Process of thermal-neutron generation.

The data show that the SER tends to be lowest around 0.1 MeV but increases as the energy decreases. We assume that this is due to boron (boron 10), which is present in trace amounts in semiconductors. Among the low-energy neutrons, we determined that the SER is higher with neutrons in the energy band around 25 meV (2.5×10^{-8} MeV), known as thermal neutrons[*4]. These thermal neutrons are produced when high-energy neutrons enter hydrogen-containing materials, such as water, plastics, and electronic substrates, and lose their speed. Therefore, their number varies greatly depending on the surrounding environment (**Fig. 3**). For example, if semiconductors are cooled by water, the thermal neutron count is expected to increase significantly. Thus, the data obtained in this study will make it possible to simulate the number of failures caused by soft errors, taking into account the surrounding environments of electronic devices, and to take measures appropriate for this energy region.

With the data obtained in this study, we have clarified the characteristics of the occurrence rates of soft errors caused by low-energy neutrons in cosmic rays. The findings make it possible to more accurately calculate the rate of failures caused by soft errors, which is the key to evaluating soft errors and studying countermeasures. Soft errors have the potential to cause malfunctions in all electronic devices that contain semiconductors. Evaluating soft errors and countermeasures against them is crucial to a variety of industries and business fields, from current information and communication technology equipment and transportation infrastructure to artificial intelligence-based automatic control and smart factories, which are expected to become more ubiquitous.

Going forward, we hope to contribute to the

*4 Thermal neutrons: Neutrons with an energy around 25 meV. When neutrons are repeatedly scattered in a material, they are called thermal neutrons because, on average, they equal the thermal kinetic energy possessed by the atoms of that material.

construction of a safer and more secure social infrastructure by simulating the number of failures caused by soft errors, taking into account the surrounding environments of electronic devices, and by studying soft-error countermeasures appropriate for low-energy regions. In due course, we will apply the results of our research to countermeasures in space against cosmic rays, thereby contributing to constructing the Space Integrated Computing Network [2], and the advancement of humankind in space.

3. Recent trends in global environmental futures forecasting technology

To improve societal resilience, global environmental futures forecasting technology is needed to predict and adapt to the changing environment as well as to restore the environment, which has been impacted by human activities [3]. Such technology is used to model and simulate physical phenomena, such as climate and weather, as well as biological and chemical phenomena, such as ecosystems and carbon cycles, on the basis of global-scale observations. Through highly accurate prediction of extreme weather events, such as typhoons and linear precipitation zones, as well as changes in marine ecosystems caused by human activities in conjunction with climate change, more proactive response measures can be taken. The following sections introduce the progress in typhoon observation toward improving the accuracy of typhoon forecasting and marine ecosystem circulation forecasting technology toward clarifying the path to restore the environment.

4. Progress in typhoon observation for improving forecasting accuracy

Typhoons, which can have a major impact on society, have been intensifying in strength and causing more damage as a result of global warming and other consequences of climate change. To prepare for typhoons more effectively, it is important to accurately predict the strength of typhoons at landfall as early as possible. However, typhoon forecasts based on the analysis of satellite images are limited in accuracy.

In 2021, in collaboration with the Okinawa Institute of Science and Technology (OIST), NTT began observing the area directly beneath typhoons, which cannot be observed by satellite, using a wave glider. In the summer of 2022, we successfully conducted the world's first simultaneous marine and atmospheric measurements at multiple locations in the northwest Pacific Ocean directly beneath a Category 5 typhoon, which is the strongest class typhoon, before it reached land [4]. In this experiment, Seiuchi-san, NTT's autonomous wave glider for atmospheric and ocean observations, came as close as 11 km from the center of the typhoon (**Fig. 4**) and was able to capture rapid changes in pressure in the storm area (top of **Fig. 5**). Compared with OIST's OISTER, Seiuchi-san measured a rapid decrease in sea-water temperature (approx. 2°C) closer to the center of the typhoon (middle of Fig. 5). Seiuchi-san also measured a maximum wave height of approximately 9 m (bottom of Fig. 5), providing information on the interaction between the atmosphere and ocean directly under the typhoon, which had not been available from satellite observations.

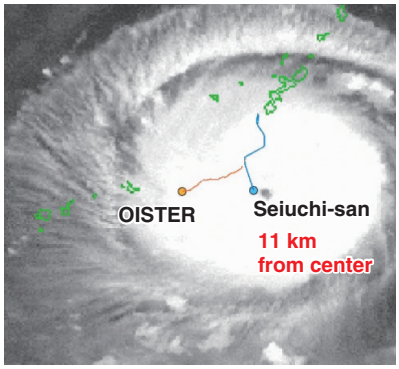

Fig. 4. Observation of No. 11, Hinnamnor/Henry.

In 2022, we started a joint research project with the Typhoon Science and Technology Research Center (TRC) of Yokohama National University, a research institute in Japan specializing in typhoon research, to improve the accuracy of typhoon forecasting [5]. We will continue to progress typhoon observation for real-time typhoon data collection and aim to improve the accuracy of typhoon forecasting by using the acquired atmospheric and oceanographic observation data and incorporating them into the TRC's typhoon forecasting model.

5. Progress of marine ecosystem circulation forecasting technology

The marine ecosystem circulation forecasting technology models the food chain and material cycle processes of marine ecosystems and predicts the impact of human activities on marine ecosystems in

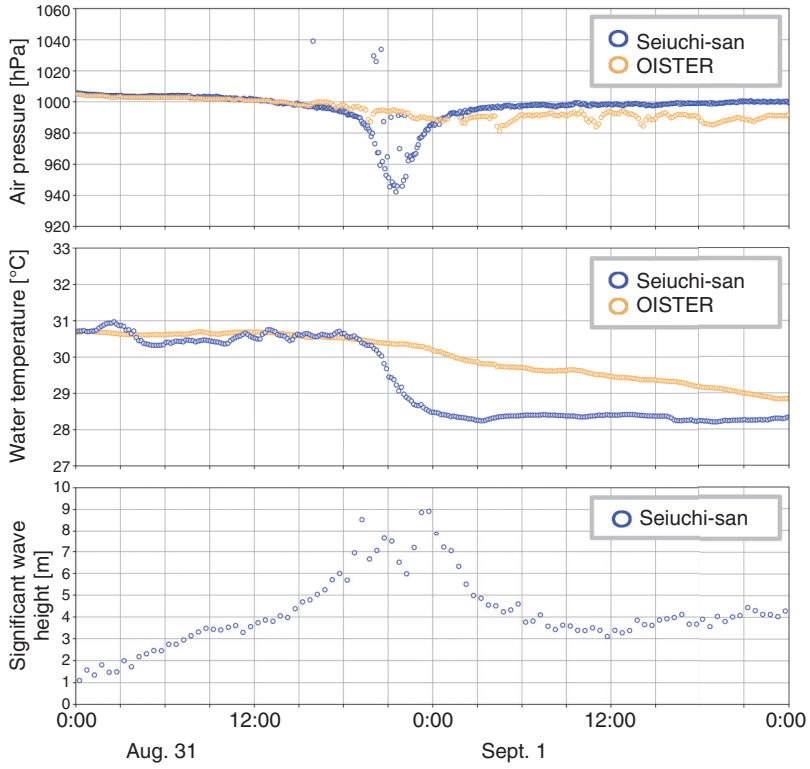

Fig. 5. Observation data: air pressure (top), water temperature (middle), significant wave height (bottom).

addition to the effects of climate change [2]. This technology contributes to the maintenance of ecosystem services such as the protection of fisheries resources and carbon dioxide fixation.

As a first step, we developed an ecosystem model for closed-cycle land-based aquaculture to predict changes in the ecosystem. We first hypothesized the impact of human activities on marine ecosystems on the effluent from closed-cycle land-based oyster aquaculture. We then developed a material circulation process model for oyster aquaculture, considering the simple food chain between oysters and phytoplankton, which is their diet.

Closed-cycle land-based aquaculture is a method of aquaculture carried out in a closed space on land without contact with rivers or the ocean. The water quality is maintained by removing food and excreted waste while circulating the water. In addition to oysters, phytoplankton (algae) are produced in the land-based oyster farm targeted in this study, and wastewater from the oyster tank is used to cultivate the algae, thus achieving completely closed land-based aquaculture without wastewater. Oyster cultivation is not simply a matter of increasing the amount of phytoplankton. Undigested feed left by oysters can lead to water contamination, which affects oyster growth. For efficient recirculation in land-based aquaculture, it is important to determine the balance of circulation, including the optimal amount of oyster excreta and feed, which can be done by predictive simulation. We developed a model for predicting changes in phytoplankton levels in recirculating land-based oyster aquaculture (**Fig. 6**). The model was also used to predict phytoplankton production from wastewater discharged from oyster aquaculture.

In the future, we will extend the model and the knowledge obtained and apply it to modeling ecosystems in coastal areas where human activities have a large and complex impact as well as in open ocean areas that are expected to be increasingly used in the future. We aim to develop a forecasting technology for marine-ecosystem cycles that will help to restore the ecosystems.

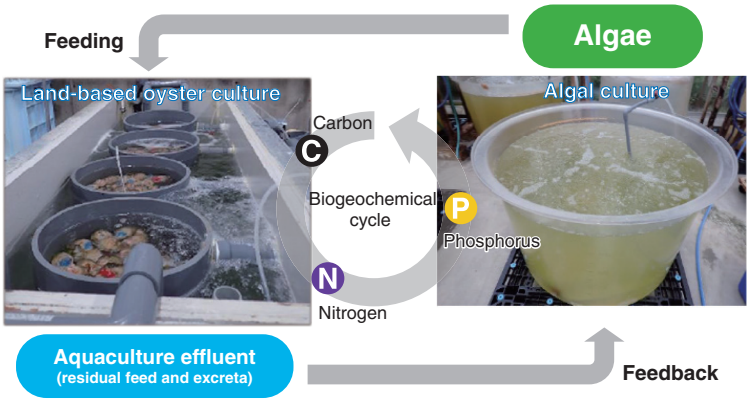

Fig. 6. Biogeochemical cycle in land-based oyster farm.

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Forecasting Technologies for Environmental and Socioeconomic Cycles for Attaining Inclusive Sustainability

Hiroaki Kawata, Daisuke Tokunaga, and Yuichi Muto

Abstract

The Environmental and Socioeconomic Nexus Forecasting Technology Group has been in the process of developing a computer-based circulation system consisting of several models (e.g. natural environment, economic, and social). We aim to forecast changes in global-scale inclusive cycles for inclusive sustainability, in which the environment, economy, and society are interrelated and more stable. In this article, we describe our developments for forecasting environmental impact considering the interplay between the environment and economy and introduce a new index of affluence in the beyond GDP (gross domestic product) era.

Keywords: climate and economic society, coupled simulation, inclusive wealth

1. Toward inclusive sustainability

The Environmental and Socioeconomic Nexus Forecasting Technology Group has been researching inclusive sustainability, which it defines as the sustainability made possible by the inclusive harmony between the autonomy of the Earth's environment and the autonomy of economic and social systems that are part of that environment [1].

The Earth's environment has autonomy, and problematic environmental changes are a result of the influence of human economic and social activities on this autonomy. This complex chain-reaction system can be viewed as an inclusive cyclical system that includes the environment, economy, and society on a global scale. However, it is difficult to understand all of these interactions through observation and measurement in the real world. It is also difficult to evaluate their impact on the environment, economic activities, and social activities due to implementation costs, time delays in the occurrence of impact, and irreversibility of mutual influence.

The goal of our group is to contribute to achieving inclusive sustainability by reproducing the environment model, economic model, and social model as a cyclical system on a computer, and making it possible to calculate changes in inclusive cycles on a global scale [2]. By being able to forecast changes in inclusive cycles using a computer, we hope to contribute to the global discussion on what social systems should be and the transformations they need to undergo to get there. Toward this end, we have been developing a proof of concept of the cyclical system to realistically evaluate the relationship between the water cycle and food production under the effects of climate change.

We introduce our research on forecasting the global environmental impact considering the interplay between the environment and the economy with regards to the global water cycle, as well as a new index of affluence in the beyond gross domestic product (GDP) era using a new market-evaluation model that emphasizes human social activities.

2. Forecasting global environmental impact considering the interplay between the environment and economy

2.1 Coupled simulation technology for inclusive sustainability

To reproduce the complex systems of the environment, economy, and society on a computer more precisely, we combine simulators developed by specialists in each of these fields.

Toward this end, it is necessary to exchange data following the causal relationship between variables in multiple simulators, and a method is needed to control execution while exchanging data at the appropriate timing by managing the internal time of each simulator in a unified manner. Such coupling technology is called coupled simulation. We developed a coupled simulation technology [3] that requires minimal modification to existing simulators and can be applied to various use cases.

2.2 Global-scale simulation considering the interaction between environmental and economic activities with a focus on the water cycle

We conducted an experiment to determine if inclusive sustainability could be investigated in more detail using the coupled simulation technology we developed, observe the difference with and without this technology, and verify its effectiveness. In this experiment, we focused on water, which is strongly related to both environmental and economic activities, and constructed a global-scale simulation that takes into account the interaction between environmental and economic activities, focusing on the global water cycle [4].

To reproduce the global hydrological cycle, we use the Integrated Land Simulator (ILS) developed by Prof. Kei Yoshimura's research team at the Institute of Industrial Science of the University of Tokyo [5], which reproduces the surface-water-cycle process, and the Global Change Analysis Model (GCAM) [6], an integrated assessment model for economic activities developed by the Joint Global Change Research Institute (JGCRI).

We hypothesized that changes in land-use patterns due to economic activity would affect the hydrologic cycle, which would then affect economic activity. To verify this, the ILS and GCAM were coupled using the coupled simulation technology to create a process that takes into account the annual land-use patterns due to changes in economic activity. The amount of water runoff calculated using the ILS and the amount of water consumption calculated using the GCAM were then compared. Through this comparison and observation of water-related changes in the environmental load (water stress[*1]) caused by changes in economic activities over time, we showed that large environmental loads can occur at times and places that could not have been predicted with conventional methods (**Fig. 1**).

We used one of the five Shared Socioeconomic Pathways (SSPs)[*2] (SSP126) and implemented a system in which two different simulators are linked to each other to conduct global-scale calculations. For the Niger River basin, for example, where many areas are projected to change from grassland to cultivated land between 2020 and 2044, it was found that water stress tends to increase due to climate change. Increased water stress is somewhat mitigated as land is converted to cropland. The results of this experiment indicate that the water stress of the Niger River basin tends to increase with climate change [7] and that linking different simulators is effective for calculating large-scale environmental changes.

2.3 Future developments

There are two major challenges in reproducing the interactive effects of the environment and economic activities while considering various policies. First, simulating the environment requires excessive computations, so the amount of calculations needs to be reduced (lightened) and the process should be coupled with other simulations. Second, current scientific calculations are based on scenarios of socioeconomic factors that assume changes in population, economic growth, rate of technological development, etc., making simulations based on other various socioeconomic scenarios difficult. Therefore, we aim to improve the accuracy of global-scale simulations and increase the number of trials while reducing the amount of calculations for efficiency. Furthermore, the combination of new models will enable a more detailed analysis of the challenges of limiting temperature increase to within 1.5°C, as discussed by the Intergovernmental Panel on Climate Change (IPCC), contributing to society's continued sustainable economic development on a scientific basis.

*1 Water stress: An indicator for evaluating the degree of water demand-related stress. In our experiment, water stress was determined to have occurred when it exceeded 20%, calculated monthly and yearly as the water consumption/runoff (water availability).

*2 SSPs: Five scenarios depicting how socioeconomic factors (population, economic growth, education, urbanization, rate of technological development, etc.) will change over the next 100 years.

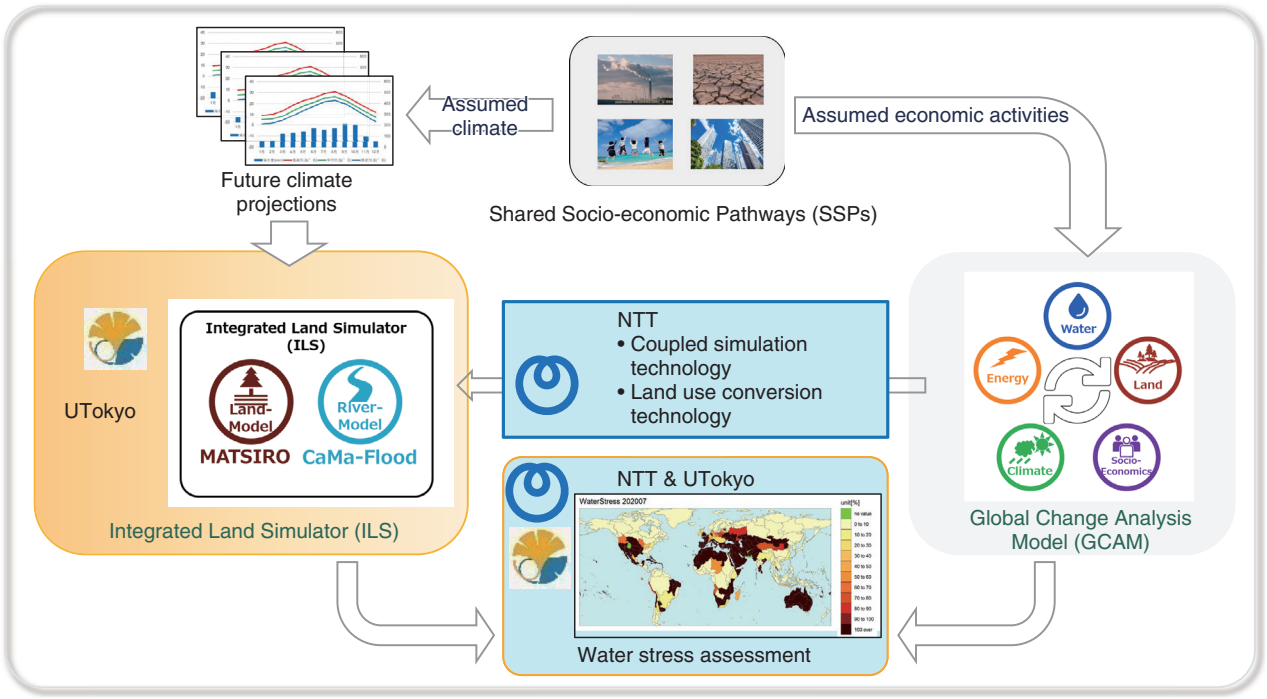

Fig. 1. Diagram of coupled simulation between the environment simulator and the economic activity simulator.

3. A new index of affluence in the beyond GDP era

3.1 Background

Due to the growing importance of environmental measures for reducing carbon emissions, carbon-emission trading measures such as carbon credits are being promoted at the national, regional, and local levels. For such measures to be continuously operated and effective, they need to contribute to achieving environmental goals and enrich society as a whole while balancing environmental measures, the economy, and our daily lives. Our challenge is to develop technologies to dynamically predict how the wealth of the world will change as a result of environmental measures in the long term and evaluate the inclusive sustainability of the environment, society, and economy.

3.2 Challenges with dynamic long-term forecasting and assessment of the world's overall wealth

It is necessary to take a holistic view of the world's overall wealth, environment, and social trends to replicate general behavior that will take place in the environment and society of the future. The wealth we are trying to measure is not limited to economic wealth, such as material wealth, but also the wealth of the natural environment and resources as well as health and education. Indicators are needed to evaluate the overall wealth of the environment, people, and goods.

The environment and society interact and behave as a complex system. Therefore, social changes caused by one of the environmental measures may result in a chain of unintended consequences, such as improved forest conservation but accelerated consumption of other resources, or slower-than-expected economic growth. When considering environmental measures, it is more important to determine the overall movement of a measure's various implementations and predict the general outlook than to reproduce and predict the precise movements of the environment and society over time.

3.3 Research approach

We focus on the inclusive wealth index (IWI) and system dynamics (SD) to address these challenges. The IWI is for conducting a comprehensive wealth assessment. GDP is the most widely known indicator of economic wealth. However, there is a growing awareness of the importance of measuring the overall

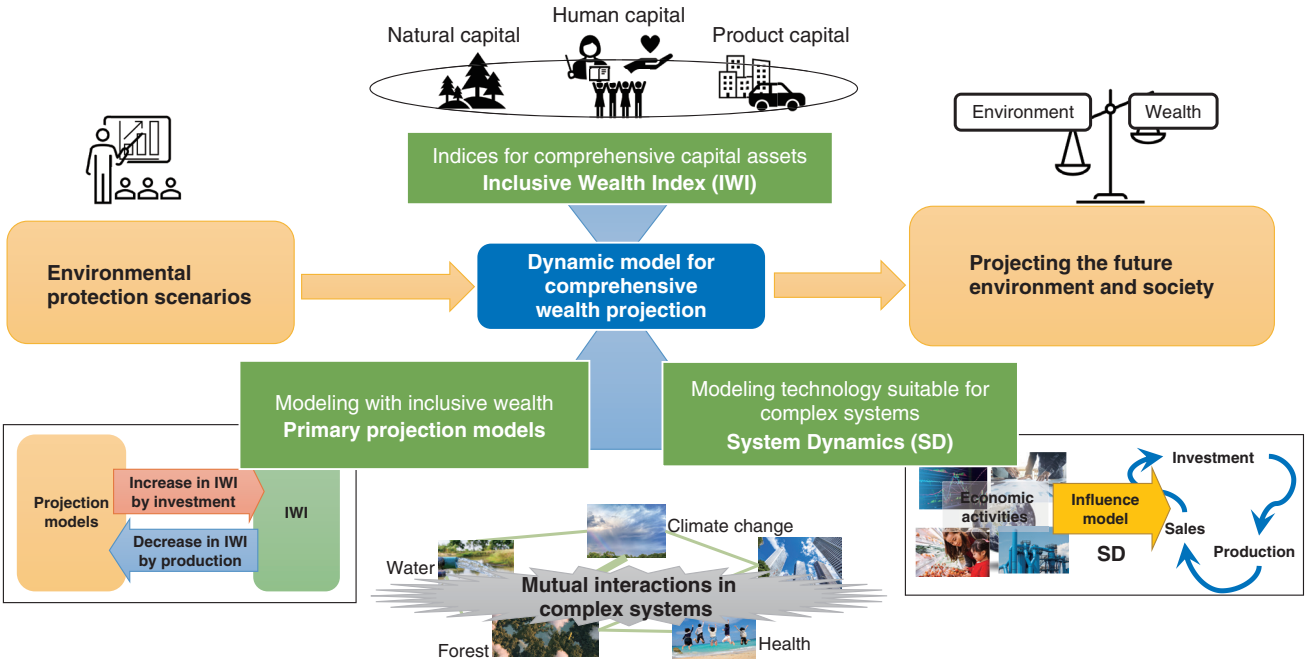

Fig. 2. A conceptual model for projection of affluence in environmental social cycles combining IWI and SD.

wealth of the world, including the wealth of the environment and people. Since it is difficult to measure wealth in terms of GDP, we have entered what is known as the Beyond GDP era. Therefore, we focus on the IWI, which is attracting attention internationally as an indicator for analyzing the comprehensive wealth of a country or region and measuring and evaluating natural wealth (environment, resources, etc.), people (education, health, etc.), and artifacts (products, facilities, etc.) in the region. Whereas GDP cannot assess resource depletion or health hazards, the IWI directly assesses the value of nature and people, thus can be used to assess such impact.

Predictive models for the environment and society are constructed using SD, a systems-thinking and modeling method for complex systems. SD generates numerical models by representing causal relationships among known elements in a graphical form. It is suited for simple description and trend forecasting of complex systems, making it suitable for predicting environmental policies.

Combining the IWI and SD, we examined the common structures between environmental social cycles and affluence and modeled the impact of environmental measures on affluence (**Fig. 2**).

3.4 Future developments

We are developing an IWI-based environment and society forecasting model to predict environmental goals and affluence. We are currently in the process of validating the dynamic predictions made in this research by creating a simulation model on emissions trading in the carbon-credit market and evaluating its contribution to improving the wealth of society as a whole.

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Long-distance RDMA-acceleration Frameworks

Hitoshi Masutani, Junki Ichikawa, Kiwami Inoue, Tomoya Hibi, Kazuaki Obana, Takeshi Kugimoto, Tsuyoshi Ogura, Koki Yube, Hirokazu Takahashi, and Koichi Takasugi

Abstract

Most datacenter networks have adopted remote direct memory access (RDMA) as the basis of the transport network to their infrastructure because modern RDMA network interface cards can provide high-performance and energy-efficient capabilities to transfer data. Standard RDMA has been developed for short-distance transmission such as internal datacenters for achieving high-performance computing. We are currently developing the Innovative Optical and Wireless Network All-Photonics Network (IOWN APN) to achieve flexible, long-distance and low-latency optical-based networking for new-generation use cases such as a cyber-physical system. By taking advantage of high-performance and low-latency data transfer in RDMA over long-distance communication such as inter-datacenter networks based on the APN, application-level networking should be accelerated over the IOWN APN. We propose two long-distance RDMA-acceleration frameworks. We first present the RDMA over Open APN framework to increase throughput of RDMA beyond 100 km by using the appropriate queue-pair configuration. This is easy to use without additional components. We then present the RDMA wide area network (WAN) accelerator to build a new long-distance RDMA-transmission framework without resource limitation of SmartNIC in the RDMA over Open APN framework. We also evaluate the performance improvement of the RDMA WAN accelerator compared with standard RDMA. For example, for data transfer of 512-byte messages, the RDMA WAN accelerator has about 35 times performance improvement compared with standard RDMA.

Keywords: IOWN, RDMA, RoCEv2

1. Introduction

Datacenter applications have required high-performance and low-latency networks in addition to low energy consumption. Although Transmission Control Protocol/Internet Protocol (TCP/IP) technologies have been developed for achieving high-performance networking, it is well-known that TCP/IP stack suffers from high central processing unit (CPU) utilization [1] especially in high-bandwidth networks for protocol processing, which leads to decreased CPU cycles for application workloads. Packet processing on one CPU core also cannot fill 100-Gbit/s or more network bandwidth [1]. InfiniBand/remote direct memory access (RDMA) was originally developed for high-speed network interconnect for high-performance computing (HPC) to connect computers [2]. Since most RDMA network interface cards (NICs) have an RDMA hardware accelerator to offload packet processing functionality into them, they can save CPU cycles for networking and achieve both low-latency and high-performance networking [3]. RDMA over Converged Ethernet version 2 (RoCEv2) is currently available in the Ethernet to achieve RDMA [2].

Today's datacenter accommodates compute- and data-intensive workloads such as artificial intelligence (AI) inferences. However, there is limitation of space to deploy commercial off-the-shelf servers in one datacenter. To run many compute- and data-intensive workloads, multiple heterogeneous computing resources deployed in geographically different datacenters are necessary. Therefore, high-performance and low-latency data transmission for datacenter interconnect (DCI) is inevitable. We are currently developing the Innovative Optical and Wireless Network All-Photonics Network (IOWN APN) [4] to achieve layer-1 transmission based on optical fiber for high-bandwidth and ultra-low latency. In addition to this infrastructure, we are aware of the necessity for network acceleration in terms of application. Though RDMA is one candidate for this, it can suffer from performance degradation caused by long fat-pipe networks. A reliable connection (RC) transport mode in RDMA is the most common transmission mechanism. However, it contains an acknowledgement (ACK) scheme without data loss. With long-distance communication such as DCI, the ACK scheme degrades performance.

This article proposes two RDMA-acceleration frameworks for long-distance transmission. We first present the RDMA over Open APN framework to increase throughput of RDMA beyond 100 km by using the appropriate DCI queue-pair (QP) configuration. This is easy to use without any additional components. We suggested this framework to the IOWN Global Forum [5, 6]. We then present the RDMA wide area network (WAN) accelerator to build a new long-distance RDMA transmission framework without resource limitation of SmartNIC in the RDMA over Open APN framework. We also evaluate the performance improvement of the RDMA WAN accelerator by comparing it to standard RDMA. For data transfer of 512-byte messages, the RDMA WAN accelerator has about 35 times performance improvement compared with standard RDMA.

2. RDMA

RDMA is a network-communication feature that allows direct memory access (DMA) to a remote server. RoCEv2 provides RDMA-capable networks on the Ethernet infrastructure. For low-latency and high-performance data transmission, the RoCEv2 function is usually offloaded into a SmartNIC, which has several acceleration hardware components for primitive processing such as RoCEv2 protocol processing and cryptographic processing.

2.1 RDMA transports and verbs

When an RDMA local host (Local) communicates with an RDMA remote host (Remote), there are three transport modes including RC, unreliable connection (UC), and unreliable datagram (UD). Since RDMA was originally developed for HPC and storage acceleration, which require reliability, RC is a common transport mode. Almost all vendors implement RC in SmartNICs as a default transport mode. In RC, QP is an essential component to establish a connection between Local and Remote and consists of send queue (SQ) and receive queue (RQ), each of which is a simple first-in-first-out queue. Since this QP is one way, bi-directional communication requires at least two QPs. Each SQ or RQ can accommodate as many requests as an application can post into a SmartNIC at once, which means sending memory data to Remote or receive memory data from Remote. Such requests are called work requests (WRs) and managed in each queue as a work queue element (WQE). If an application posts one request as a WR into the SQ, the WQE matching the WR is processed in the SmartNIC to retrieve memory data from dynamic random access memory on Local over the Peripheral Component Interconnect (PCI) Express bus and build one or more RoCEv2 packets by adding an RoCEv2 header to the memory data. After Remote receives the RoCEv2 packet, the memory data conveyed in it are transferred via the PCI Express bus to the memory area in Remote.

When Remote has successfully received the packet, an ACK message is sent to Local. After receiving the ACK message, Local releases the WQE to make room for the next WR. This is a basic operation in RC and illustrated in **Fig. 1**.

2.2 Performance degradation in long-distance communication

When a long-distance network, such as DCI, is from several dozens to hundreds of kilometers, communication latency in an optical network reaches a few milliseconds, as shown in **Table 1**. As the time taken for the ACK message to arrive at Local is much longer than the time taken for an application to post a WR into a SmartNIC, the total available queue depth (QD) is easily exhausted. Therefore, WR posting is stalled, and the overall performance of RDMA in RC may degrade. This is well-known in TCP as long fat-pipe networks [7]. In TCP/IP communication, there have been many proposals to address this issue

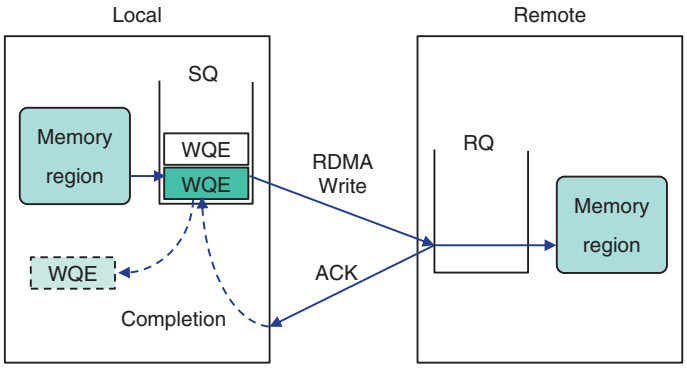


Fig. 1. The basic operation flow in RC of RDMA.

Table 1. Network latency configuration for network emulation.

Communication distance	One-way latency	Bi-directional latency (RTT)
10 km	50 µs	100 µs
100 km	500 µs	1 ms
1000 km	5 ms	10 ms

[7–11]. We evaluated this impact of RDMA as a baseline performance in our experimental system in which the maximum line speed is 100 Gbit/s, as shown in **Fig. 2**. **Figure 3** shows our evaluation results. In this evaluation, we ran the widely used benchmark tool perftest [12] to conduct basic throughput tests. For 10-km communication, network throughput dropped to 25.0 Gbit/s, and the throughput decreased to 3.0 Gbit/s at 100 km. We also observed performance degradation to 0.3 Gbit/s for 1000-km communication.

3. Related work

The performance issue inherent in RDMA is close to that of TCP. In long fat-pipe networks of TCP, the network throughput depends on network latency because a TCP client cannot send the next packet to a TCP server until the TCP client finishes receiving the ACK message. There are many types of algorithms to address this issue. In the loss-based algorithm, the amount of lost packets can start adjusting the congestion window (cwnd) to reduce network congestion and improve network throughput [8–11]. In the delay-based algorithm, round trip time (RTT) in a TCP connection is used to change the cwnd on the TCP client side to prevent network congestion. When RTT is small, the cwnd increases. However, the cwnd decreases when RTT becomes larger.

Another approach to accelerate a TCP network is to put additional accelerators on both sides between the TCP client and server. This is generally called TCP WAN acceleration. In fact, the accelerator near the TCP server monitors the status of a TCP connection, then the other accelerator on the TCP client produces a pseudo-ACK message to immediately release the TCP client waiting for the original ACK message.

4. RDMA over Open APN framework

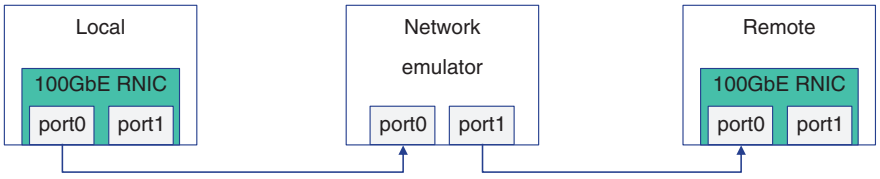
4.1 Design

In the previous section, we described that adjusting the TCP cwnd is a key factor of network performance for sending packets continuously at once. In RDMA, the amount of QD is related to the TCP cwnd. The QD is configurable in certain SmartNICs such as NVIDIA ConnectX series. To send packets without stalling packet processing, we suggest the following formula for QD configuration.

$$QD = \frac{RTT * Line\ Speed}{Total\ Frame\ Size}$$

Our experimental assumption is that the communication distance is from 10 to 1000 km, i.e., the RTT is

Server type	Hardware	Specifications
x86 server (Local, Remote)	CPU	Intel Xeon Gold 6138 CPU 2.00GHz x 20 Core
	Memory	DDR4 2666MHz 64GB (8 x 1GiB Hugepages)
	NIC (RDMA over Open APN)	NVIDIA ConnectX-5 VPI
	NIC (RDMA WAN accelerator)	NVIDIA ConnextX-6 DX
Network emulator	Chassis	Spirent Attero-100G



RNIC: RDMA network interface card

Fig. 2. The experimental setup for evaluating RDMA throughput.

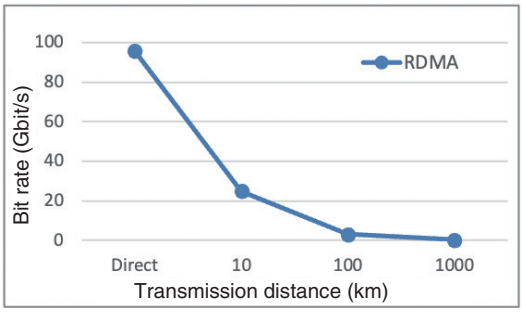


Fig. 3. Impact of RDMA throughput based on communication distance.

from 100 µs to 10 ms. The line speed of the network is 100 Gbit/s. For 100 km, an ideal QD is about 2991 when the total frame size is 4178. However, since memory resources on a SmartNIC are limited, it is assumed that there should be an upper bound in the amount of configurable QD.

4.2 Performance evaluation

With our QD's formula, we measure the network throughput of RC in RDMA with 100-Gbit/s line speed. Our experimental system in Fig. 2 has two types of NICs. One is ConnextX-5 VPI and the other is ConnectX-6 DX. In this measurement, we used ConnectX-6 NIC. The QD of ConnectX-6 DX was set to 16,384 and the Tx depth of perftest "ib_write_bw" was configured as 2048. The network emulator between Local and Remote adds 500 µs latency one way to each RoCEv2 packet. **Figure 4** shows the performance improvement in WRITE operation mode. With this QD configuration, the overall performance of RDMA for long-distance communication can be increased more than with standard RDMA. However, this framework requires a large amount of memory resources on the SmartNIC; thus, other metrics, except network bandwidth, may deteriorate.

5. RDMA WAN accelerator

5.1 Design

The RDMA over Open APN framework performs better than standard RDMA because it can consume many memory resources on SmartNICs. In addition, a large QD might cause long queuing latency or unstable behavior of network processing. Therefore, another approach is needed such as accelerating the network performance of RDMA for long-distance

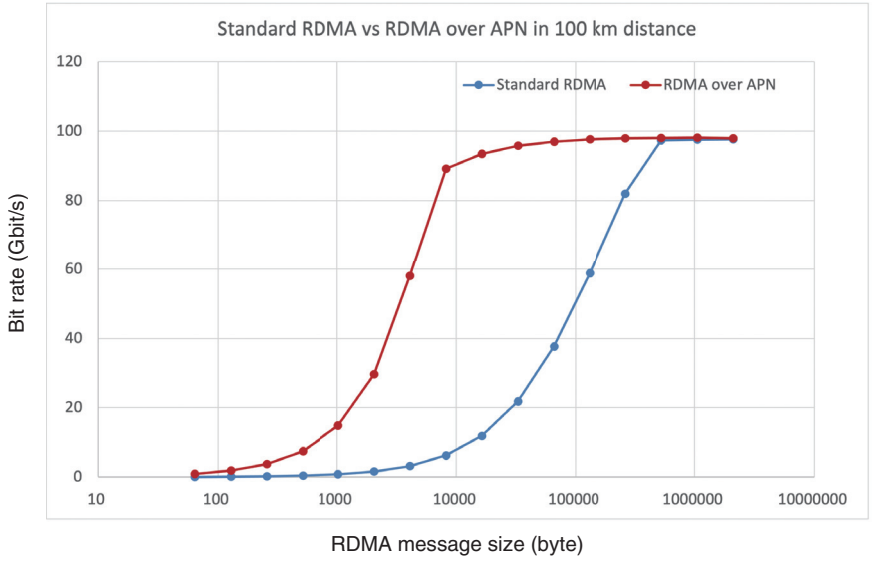


Fig. 4. RDMA throughput comparison between standard RDMA and the RDMA over APN framework.

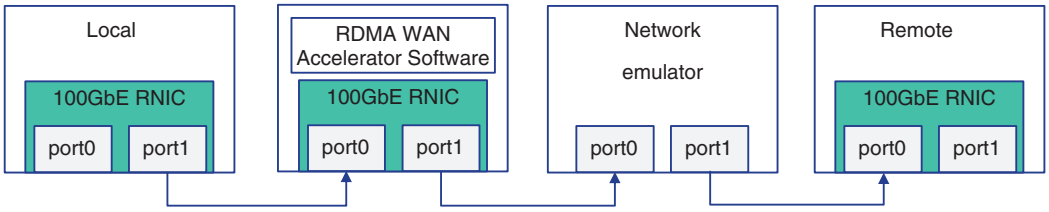


Fig. 5. The experimental setup for evaluating throughput of RDMA WAN accelerator.

communication to quickly return an ACK message to reduce its waiting time. Thus, we also developed an RDMA WAN accelerator that creates pseudo-ACK messages. Our RDMA WAN accelerator transparently works and monitors RDMA messages, which are exchanged between Local and Remote, to produce pseudo-ACK messages.

5.2 RDMA pseudo-ACK

To emulate the original ACK message, three parameters have to be accurately reproduced, i.e., packet sequence number (PSN), destination QP number (dstQPN), and message sequence number (MSN). As PSN is embedded in each RDMA message, our RDMA WAN accelerator can trace it with RoCEv2 packets. Since dstQPN and MSN are not incorporated in an RDMA message, they need to be obtained from the QP configuration in both Local and Remote. Therefore, to acquire dstQPN and MSN, our RDMA WAN accelerator traces and estimates them by analyzing the setup messages of RDMA CM (communication management) before RDMA message transmission.

5.3 Performance evaluation

We evaluated the performance of the WRITE operation in RC of RDMA using our RDMA WAN accelerator. Our experimental system is the same as that used to evaluate the RDMA over Open APN framework but without NVIDIA ConnectX5-VPI NIC and RDMA WAN accelerator, as shown in **Fig. 5**. Our RDMA WAN accelerator is a software instance and implemented using Data Plane Development Kit (DPDK) 20.11.1 [13]. **Figure 6** shows our measurement results. Compared with the RDMA over Open APN framework, the RDMA WAN accelerator starts to improve network throughput for smaller message sizes, i.e., 256 bytes, and in almost all message sizes

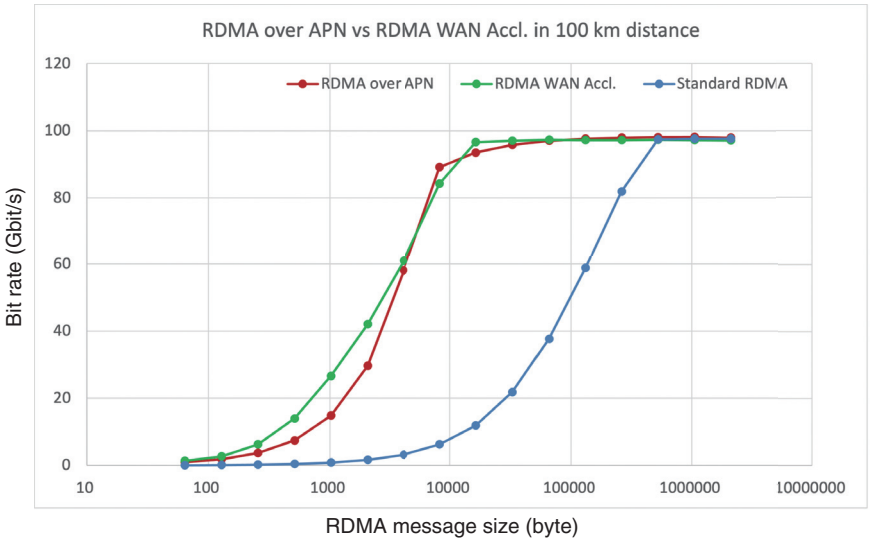


Fig. 6. RDMA throughput comparison between standard RDMA, the RDMA over APN framework, and RDMA WAN accelerator.

except 8192 bytes, the RDMA WAN accelerator performed better. In this measurement, as the QD configuration is the default setting with the RDMA WAN accelerator, we expect more stable behavior of RDMA and other network processing than with the RDMA over Open APN framework.

6. Conclusion

We proposed two long-distance RDMA-acceleration frameworks, i.e., RDMA over Open APN and RDMA WAN accelerator. For more network throughput, the RDMA WAN accelerator is more applicable than the RDMA over Open APN framework. However, the RDMA over Open APN is easy to use because no additional components are required. With these RDMA-acceleration frameworks, we can achieve high-performance data transfer over long-distance networks.

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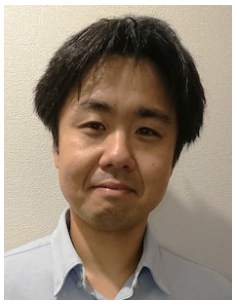

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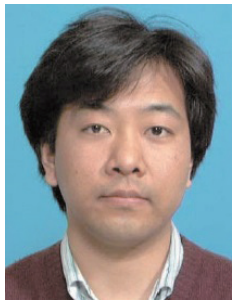

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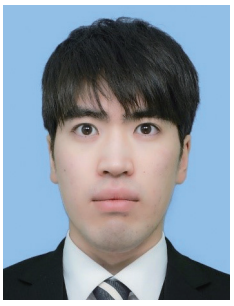

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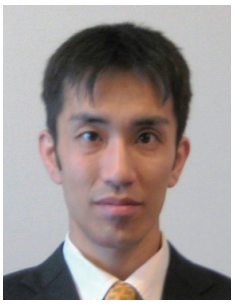

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Activity Report of TTC Bridging the Standardization Gap Working Group

Jiro Nagao

Abstract

The Bridging the Standardization Gap (BSG) Working Group of the Telecommunication Technology Committee (TTC) held a meeting in October 2023 in Tokyo and Kitakyushu, Japan. The meeting was attended by university professors and government officers from the Asia-Pacific region who work in the fields of information and communication technology (ICT) deployment and promotion of standardization. The topics of the meeting were introduction to the use of ICT in Japan (in fields such as agriculture, aquaculture, education, environment, medical care and disaster response), and discussion between the participants.

Keywords: TTC, BSG, ICT

1. What is BSG?

The Bridging the Standardization Gap (BSG) activity in general aims to support developing countries and rural areas in using information and communication technology (ICT), deploying standardized technologies, and promoting standardization. BSG is essential to maximize the benefit of global standardization and improve people's lives. BSG is also one of the five strategic objectives of International Telecommunication Union (ITU)'s standardization sector (ITU-T) [1]. Global standards show their full potential when deployed worldwide because global standards aim to connect the world with the same interfaces, give everyone the same benefit with the same look-and-feel, and reduce cost by the economy of scale. At first glance, BSG seems like a support activity only beneficial to developing countries and rural areas, but it is also beneficial to developed countries because of cost reduction, market expansion, and improvement in convenience, as described above.

2. BSG activities in TTC

The Telecommunication Technology Committee (TTC), the Japanese standards developing organization (SDO) for discussing the contributions from Japan to ITU-T, has been active in BSG in the Asia-Pacific region for over 10 years through its BSG Working Group (WG), with "SHARE" (Success & Happiness by Activating Regional Economy) as its slogan. The BSG WG has collaborated with the Asia-Pacific Telecommunity (APT), the ITU correspondent in the Asia-Pacific region, and developed trusting relations with government organizations and SDOs in the region. On the basis of such relations, it has held several workshops and training sessions every year along with the annual SHARE Meetings. Its activities in 2023 are listed in **Table 1**. NTT considers BSG activity important and has sent members to the BSG WG since its establishment. The author currently acts as the vice chair of the WG. This article reports the 19th SHARE Meeting held on 16–18 October 2023.

3. The 19th SHARE Meeting

Table 2 shows the summary of the 19th SHARE Meeting. In the morning of the first day, after the opening ceremony and summarizing report of the previous meeting, the recent activities were reported from the participants. Their recent major activities were shared, and active discussion was held. **Figure 1** shows a photo of the first day. The joint online TTC

Table 1. List of events by TTC BSG WG in FY2023.

Date	Event
19 Apr. 2023	Presentation to add the result of “Behavioural Analytics and Real-time Tracking of Patients Using IoT and RFID” to APT report at EG-BSG in 35th ASTAP
18–19 Sept. 2023	Workshop for IoT human resources development, Bangkok, Thailand
16–18 Oct. 2023	19th SHARE Meeting in Tokyo and Kitakyushu, Japan
13–17 Nov. 2023	Workshop for bridging the gender gap and training mobile solution architects for local issues, Japan
27 Nov.–1 Dec. 2023	APT Training Course: Training Experts and Foster Managements in Standardization of ASTAP and related Organizations -- Sharing trends of emerging technologies in standardization --, online

ASTAP: APT Standardization Program
EG-BSG: Expert Group BSG
RFID: radio frequency identification

Table 2. Summary of 19th SHARE Meeting.

Dates	16–18 October 2023		
Venue	Days 1, 2: Tokyo (TTC) Day 3: Kitakyushu (Hibikinada Farm, Kyushu Institute of Technology)		
Participants	TTC	Dr. Iwata, President, TTC Dr. Inoue, Advisor, TTC TTC BSG WG members	6 persons
	Philippines	Professor	1 person
	Malaysia	Professors	2 persons
	Thailand	Professor, faculty member	2 persons
	Indonesia	Professor, faculty member	2 persons
	Vietnam	Faculty member, government officers	3 persons
Schedule	16 October	Activity report from participants	
		Joint online TTC seminar with IoT Smart City WG on Recent Technology for Smart Agriculture and International Standardization Activity	
	17 October	Summary and discussion	
		Report drafting	
	18 October	Visit Hibikinada Farm	
		Visit Kyushu Institute of Technology	

Fig. 1. Discussion (first day).

Fig. 2. Site visit at Hibikinada Farm (second day).

Fig. 3. Presentation and discussion at Kyushu Institute of Technology.

seminar with TTC's Internet of Things (IoT) Smart City WG on Recent Technology for Smart Agriculture and International Standardization Activity was held in the afternoon. National activities related to smart cities in Japan, and some advanced enterprise activities in agriculture and aquaculture with ICT were reported. Activities of the ITU-T Focus Group on Artificial Intelligence (AI) and IoT for Digital Agriculture (FG-AI4A), which studies application of AI in agriculture, and activities of the ITU-T Study Group 20 (IoT and smart cities and communities (SC&C)), which studies IoT and smart cities, were also reported. The use of ICT in disaster resilience in the ASEAN (Association of Southeast Asian Nations) community was also reported by one of the SHARE members and opinions were exchanged. On the second day, the summary and report of the first day were produced in the morning, and the participants travelled to the next venue for the third day, Kitakyushu, Fukuoka Prefecture, in the afternoon.

The morning of the third day was the site visit to the large-scale high-tech farm, Hibikinada Farm, as a cutting-edge example of agriculture using ICT in Japan. **Figure 2** shows a photo of the site visit. The view of 200,000 tomato plants more than twice the human height in 8.5 ha of land was astonishing. Questioning and discussion with the staff were enthusiastic because there were participants such as professors who study the use of ICT in agriculture and aquaculture in the Asia-Pacific region. Details of ICT usage at the farm was presented after the observation. Computerized monitoring, management and control of the temperature, moisture, carbon dioxide, and culture fluid was presented. The discussion was active between the farm and the participants. For example, when the farm presented that they used coco peat as a nutriculture medium, one of the participants contributed information that coco peat is useful because it has no nutrients and low risk of diseases. The topic went beyond cultivation management to social systems to research budgeting, as the participants included university professors and government officers. It was the moment the full significance of the BSG activity was felt where common issues are shared, and solutions are discussed among people from many countries.

In the afternoon, they visited Kyushu Institute of Technology. Topics such as underwater robot control and aquafarming were presented (**Fig. 3**). Questions from the participants went deep into the research, such as why a camera was used and not sound, which is used in fish sonar.

4. Conclusions

The 19th SHARE Meeting, an activity by the BSG WG of the TTC, held in October 2023 was reported. University professors and government officers from the Asia-Pacific region who work in the field of ICT utilization participated in the Meeting. Example practices in Japan were introduced and discussions were held to support and promote deployment of ICT in developing countries and rural areas. Although it was not the focus of this Meeting, the BSG WG also holds standardization-skill-training courses (Table 1). The BSG WG will strive to bridge the standardization gap in the Asia-Pacific region by supporting and promoting deployment of ICT and standardization-skill

training.

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Report on the NTT R&D FORUM 2023 — IOWN ACCELERATION

NTT R&D Forum Secretariat

Abstract

NTT R&D FORUM 2023 — IOWN ACCELERATION was held from November 14th to 17th, 2023. The following is an overview of the Forum.

Keywords: R&D Forum, IOWN, latest technology

1. NTT R&D FORUM 2023 Overview

The Innovative Optical and Wireless Network (IOWN), which began service in March 2023, is steadily advancing. The NTT R&D FORUM 2023, with the title, "IOWN ACCELERATION," introduced some of the latest developments in IOWN, such as NTT's large-language model (LLM), called "tsuzumi" (announced in November 2023), which has been attracting attention in various domains.

On the preview day, November 13, only press-related guests were invited, so that various TV programs and other media could broadcast an overview of the event. This resulted in several articles posted in newspapers and on the web. The main event from November 14 to November 17 was also a great success, with approximately 12,000 visitors invited from Japan and overseas attending at the physical venue, the NTT Musashino R&D Center. The online venue was also a great success, receiving approximately 19,000 visitors from around the world.

A total of nine speeches were presented at the physical venue, namely Keynote Speeches with NTT management speaking about NTT business and technology strategies, followed by Special Sessions with NTT and external experts introducing hot global technology themes, and MIRAI Seminars (Outlook) in which other well-known presenters from various domains discussing their future vision for the world. These same lectures were also presented online at the virtual venue.

2. Keynote Speeches

Three keynote speeches were given. The first was by Akira Shimada, NTT President and CEO, on NTT's approach contributing to society and a vision for the future involving the new research themes of IOWN and NTT's LLM tsuzumi. The second was by Sachiko Oonishi, NTT Executive Vice President, Head of Research and Development and Market Strategy, on NTT's research and development (R&D) efforts from both "product-out" and "market-in" approaches, and the third was by Shingo Kinoshita, NTT Senior Vice President and Head of Research and Development Planning, providing technical descriptions of IOWN and NTT's LLM, and interoperations between these technologies.

2.1 Keynote Speech 1: Innovating a Sustainable Future for People and Planet NTT R&D Initiatives

NTT President and CEO Akira Shimada opened his speech by introducing NTT's new R&D theme of "Innovation for a sustainable future for people and planet," with the major goals of resolving issues faced by society and enhancing the well-being of people in society. He then went on to describe IOWN and tsuzumi, NTT's LLM, as key technologies for achieving these goals. He then discussed how IOWN

Photo 1. Keynote Speech 1: Akira Shimada.

Photo 2. Keynote Speech 2: Sachiko Oonishi.

and tsuzumi can solve difficult issues faced by societies around the world, such as labor shortages, environment and energy issues, aging populations and increasing medical costs. He introduced some concrete examples of how NTT technologies have solved issues to improve well-being in society and a vision for the future that NTT and its partners have created together (**Photo 1**).

He introduced "IOWN1.0" as the All-Photonics Network (APN) that was launched commercially in March 2023 and described plans for "IOWN2.0" and beyond, with a roadmap to advance optical technologies from the network into the computing environment. He also drew attention to a pavilion planned for Expo 2025 in Osaka, which will enable visitors to experience services using IOWN technologies.

He also discussed efforts making steady progress toward the commercial release of tsuzumi that is causing a stir in the field of generative artificial intelligence (AI) and has been attracting attention around the world. He then stressed the great potential of having these two technologies, to solve social issues and make great contributions to realizing well-being in society.

He concluded the speech with a message of "innovating a sustainable future for people and planet," stating that NTT will continue working and creating innovation for people and the planet.

2.2 Keynote Speech 2: IOWN ACCELERATION —Imagination and Creation—

NTT Executive Vice President, Head of Research and Development Market Strategy Sachiko Oonishi spoke about IOWN, with concrete examples of commercial application for full implementation in society. With the theme and title, "IOWN ACCELERATION —Imagination and Creation—," she presented a new vision for the future created through the accelerating plan and implementation of IOWN, from both "product-out" and "market-in" R&D perspectives (**Photo 2**).

In her opening she said, "I hope that you can now feel this idea (of IOWN) coming to life," and presented a roadmap to telecommunications breakthroughs for IOWN2.0, brought by progress in elemental technologies in various fields such as optoelectric integration. With key points in the speech, she also identified historical milestones developed by NTT in the form of a quiz, giving background on how NTT was able to achieve those breakthroughs.

She also introduced solutions to issues that NTT has promoted in a wide range of fields; touching on areas considered basic to human life such as clothing, food, and shelter and presenting a new "market-in" R&D perspective that NTT is adopting, which focuses on technologies and solutions needed to improve people's well-being in society.

Finally, she described NTT's goal of creating value for the social well-being of people and the planet, toward an exciting future realized by NTT.

2.3 Keynote Speech 3: LLM+×IOWN —The advancement of IOWN, the launch of NTT's LLM, and their synergy—

NTT Senior Vice President and Head of Research and Development Planning Shingo Kinoshita spoke

Photo 3. Keynote Speech 3: Shingo Kinoshita.

about progress regarding NTT's LLM tsuzumi, which was announced in November 2023, and also IOWN and the synergies between these two technologies. Using "LLM+×IOWN" as a theme and providing much technical explanation, he described the far-reaching potential of combining these technologies in various ways (**Photo 3**).

LLM tsuzumi, which is bringing new perspectives to the LLM field, has four major features: (1) It is lightweight and has low power consumption, (2) It has strong linguistic capability (especially Japanese), (3) It is flexible for customization, and (4) It is multimodal. These were each introduced in detail, including the underlying technologies that make them possible, and showing the resulting high-performance.

Regarding synergies with IOWN, he described practical experiments related to the dramatic developments in LLMs. This included experiments that overcame physical distance, combining computing resources to perform LLM training and inference efficiently, using graphics processing units (GPUs) in a datacenter roughly 100 km away to process training data held locally, and treating datacenters that are far apart as though they were a single datacenter. He also described plans to expand experiments in the field globally in the future.

He also announced a joint R&D initiative with Sakana AI, a Tokyo-based startup that is attracting attention globally. He suggested that cooperation between these companies in the field of AI, for which they both have great affinity, will have great influence on how generative AI should advance and how architectures are considered in the future.

Finally, he also reflected on the "fountain of knowledge" mindset inherited from NTT R&D. He described three elements comprising this mindset, which are to promote R&D, to implement research results practically, and to implement them in society together with partner enterprises.

3. Special Sessions

The Special Sessions were speeches given by NTT and external experts on the key topics for the R&D FORUM 2023, IOWN and NTT's LLM tsuzumi, examining future prospects along three trending themes in society.

3.1 Special Session 1: IOWN opens up a data-driven era

Hiroaki Nagashii, VP, Strategic Client Group, Oracle Corporation Japan, and Yoshisato Fukatsu, Enterprise Architect, Industry, Value and Architecture, Oracle Corporation Japan, were invited to give a lecture on the roles IOWN and Oracle play in realizing a data-driven society and their vision for that society (**Photos 4**, **5**).

Mr. Nagashii introduced his vision for the future, based on the vision of the founder of Oracle Corporation. He expressed his desire for Oracle to contribute to realizing a data-driven society and how that desire is reflected in their efforts and achievements utilizing data in various domains, including fields that require critical elements such as renewable energy.

He also indicated they have high expectations for the paradigm shift in implementing a data-driven society due to the IOWN features of high-security, high-capacity, and low latency. Mr. Fukatsu then introduced some concrete "IOWN × Oracle" solutions from the perspectives of potential and feasibility. He described concepts for future solutions created utilizing the high-capacity, low-latency communications infrastructure implemented by NTT with IOWN, together with the best data-management technology in the world from Oracle Corp. He expressed particularly high expectations for NTT regarding the high security technology in IOWN.

Finally, Mr. Nagashii talked about his strong desire to create a society in which "no one is left behind" in the future, after further collaboration between NTT and Oracle results in dramatic progress in technology. It was a captivating speech regarding co-creation by NTT and Oracle in the future.

Photo 4. Special Session 1: Hiroaki Nagashii.

Photo 6. Special Session 2: Kyosuke Nishida.

Photo 5. Special Session 1: Yoshisato Fukatsu.

3.2 Special Session 2: Does AGI dream of living with Humans? —R&D of LLM "tsuzumi"—

In the first part of Special Session 2, NTT Human Informatics Laboratories' Senior Distinguished Researcher Kyosuke Nishida presented a detailed introduction to R&D on NTT's LLM tsuzumi, and its features (**Photo 6**).

Mr. Nishida, who drove R&D on tsuzumi, included a conversation with tsuzumi as the first section of his speech, showing the astonishing achievement and high performance of tsuzumi from the beginning.

He then presented his research vision of creating an artificial general intelligence (AGI) thinking engine that can naturally coexist with people and support their well-being in any environment. In the speech he demonstrated a conversation with tsuzumi using concrete questions. LLM tsuzumi even answered questions that are unavoidable when discussing AI, such as "How can AI be trained to follow rules?"

The session gave an impression of the high performance of tsuzumi through the responses and sense of the issues it presented, toward a world in which the tsuzumi AI and people can coexist.

3.3 Special Session 2: Natured Inspired Intelligence and a New Paradigm for LLM

For the second half of Special Session 2, we invited David Ha, Co-Founder CEO, Sakana AI, and Llion Jones, Co-Founder CTO, Sakana AI (**Photo 7**).

David Ha and Llion Jones spoke about future directions for language models, focusing on LLMs. David Ha surprised the audience by indicating that, although he is among a minority in the current LLM community, he thinks that "even if the extremely large models become even larger, they will not be possible to handle the complexity of the real world." He went on to say that based on ideas from nature, "human intelligence is largely a collective intelligence," and from that perspective, rather than having a single, gigantic LLM, LLMs must evolve to cooperate and adapt dynamically to conditions, so that multiple LLMs with various features cooperate to produce intelligence.

He also talked about his expectations for the potential of Japan itself. He believes that Japan can make its presence known globally in AI, and spoke passionately about this as one of the reasons Sakana AI

Photo 7. Special Session 2: David Ha (left) and Llion Jones (right).

Photo 8. Special Session 3: Timothy McKenna (left), Bob Byer (right).

established its base in Japan.

Llion Jones, also from Sakana AI, then described "character-level modeling" in detail as one of the strengths of tsuzumi. He explained that current LLMs, which mainly focus on English, use both character-level and word-level models, but he emphasized that they would need to transition to character-level models. He also pointed out the surprising fact that there is redundancy in AI learning between different languages, so there is still potential yet to be identified in AI.

In their speeches, both speakers showed the affinity of both NTT and Sakana AI for the forms and ideal architectures of LLMs in the future, so the session raised expectations for the commercialization and later development of tsuzumi, with its particular strengths in the Japanese language.

3.4 Special Session 3: Lithium Niobate Photonics In The Era of AI

In this session, Bob Byer, the William R. Kenan, Jr. Professor Emeritus of Applied Physics, Stanford University, and Timothy McKenna, Principal Scientist, Physics & Informatics Laboratories, NTT Research, expanded on the topic, including episodes involving breakthroughs from their long history and tradition (**Photo 8**).

This session introduced the history and background of photonics using lithium niobate (LN), which is one of the most widely used functional optical materials. Bob Byer, an LN pioneer, described the "1st-generation" history in the 1960s and 1970s, and Timothy

McKenna, who led an NTT Research team in recent years driving technical innovation and commercialization, described the "2nd-generation" since the 1980s, and the following "3rd-generation."

A surprising revelation was that during his research Mr. Byer once dropped and damaged a photonic crystal, but this later led to a technical breakthrough. His answer to what to do with the damaged crystal is related to recent rapid advances in fabrication technologies. Now that fabrication of LN devices with nanometer precision has been achieved, LN is expected to play an important role in implementing high-speed, efficient communication in datacenters. The importance of thin-film LN (TFLN) photonics is also predicted to increase even more due to the rapidly increasing size and bandwidth requirements of AI clusters, an expanding photonics market, and the expanding scale and requirements of datacenters. Incredibly, the size of the TFLN market has exceeded two billion dollars in 2023, just five years since it appeared as a market. Overall, the session was very entertaining from two individuals who have been instrumental in the field of LN.

Finally, Timothy McKenna and Bob Byer expressed their hopes to make further great contributions to solving hardware issues, unlocking the fascination and hidden potential of TFLN, and building excitement for a bright future.

4. MIRAI Seminars (Outlook)

Well-known experts from various fields were invited to discuss visions for the future from their own perspectives. These future visions were given substance by discussing them in light of NTT's technologies and initiatives. A common theme in the three seminars could be stated as "Bringing to light what could not be seen before."

4.1 MIRAI Seminar 1: How the Technology Innovation Brings "Space within Your Reach"

President & CEO of Axelspace Corporation Yuya Nakamura spoke about technical innovation in satellite development and use, the importance of observations from space, and the relationship between humans and space in the future (**Photo 9**).

Space business is seen as a rapidly maturing industry around the world, with a market expected to exceed one trillion dollars by 2040. Mr. Nakamura spoke about how "observations from space" are an important element resulting from use of satellites. He emphasized that satellite imagery is used for more than just smart agriculture; that conditions on earth and in space observed from satellites are important data for understanding the world accurately and making improvements in all fields, and can also be used as evidence.

Photo 9. MIRAI Seminar 1: Yuya Nakamura.

He also introduced a new, small satellite business that provides one-stop satellite use in a short period of time, incorporating setting objectives, development, manufacturing, launch and operations, and he discussed how this initiative expands the potential for satellite use in fields and industries more removed from conventional space business and "brings democracy to space."

Mr. Nakamura also expressed strong expectations for the impact of optical communications being advanced by NTT's IOWN initiative, as a game changer for space business. Space Compass Corp. and Axel Space Corp. are already collaborating with NTT and SKY Perfect JSAT Corporation to expand optical communications into space. Mr. Nakamura concluded his speech by emphasizing that he will contribute to the next-generation communications infrastructure to be built by Space Compass and further expand cooperation.

4.2 MIRAI Seminar 2: Future Health with Digital Technology —Autonomic Nervous System and Intestinal Environment

Hiroyuki Kobayashi, Professor, Department of Research and Development for Elderly Physical Function, Juntendo University Graduate School of Medicine, was invited and gave an eye-opening speech on solutions to various issues in medicine and

Photo 10. MIRAI Seminar 2: Hiroyuki Kobayashi.

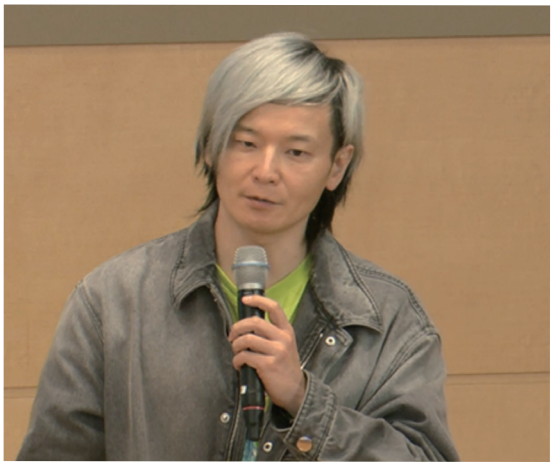

Photo 11. MIRAI Seminar 3: Hiroaki Miyata.

new solutions available through advances in technology (**Photo 10**).

Prof. Kobayashi spoke about how we assume that data science basically "makes the invisible visible" by luck, but actually these facts are established by science. He described to a surprised audience how this does not just apply to illness and infection, but that sports are also explained by science using a golf example. From the perspective of "reproducibility," which is an important element of medicine and sports science, the level of R&D and technology that NTT is advancing is highly regarded, such as the "motor-skill transfer technology" which brings potential to the world of medicine for applications such as remote surgery. He gave the impression that we have reached an age where even surgical skills can be transferred from experienced doctors to trainees.

He then expanded his topic to "What is health?", talking about how our intestinal environment is an important element for living a healthy lifestyle, and why yoghurt has a positive effect on this environment. He explained the importance of the intestinal environment for a healthy lifestyle, adding a humorous metaphor of yogurt being a "transfer student" in that yogurt stimulates its environment like a transfer student stimulates unfamiliar students.

To end the seminar, he explained how various obstacles to a healthy lifestyle can lead to a negative spiral in behavior and thinking, while also taking questions from the audience.

4.3 MIRAI Seminar 3: The Vision of a Future Society Beyond DX (Digital Transformation)

Hiroaki Miyata, Professor and Chair, Department of Health Policy Management, School of Medicine, Keio University, spoke mainly on the theme of what kind of future can be created in a world focused on digital transformation (DX) and after the IOWN concept is implemented (**Photo 11**).

Prof. Miyata reflected on how work-life has changed greatly as application of IT has progressed and information gathering with technologies like search engines has spread, and the large impact that generative AI, which is now poised to permeate society, is having on a wide range of fields. He talked about how generative AI is organizing issues, but what people need is to look at the future and to position technology accordingly. He said that a perspective of realizing our ideals rather than optimizing our current work with technologies like generative AI and DX is important and has not been achieved yet.

He also emphasized the value in the ability to "connect"—overcoming physical distances and recognize and sympathize with each other—by consolidating communication infrastructure and expanding social networking services, and expressed hope that such connections will be strengthened by NTT's IOWN initiatives.

On the other hand, he also spoke of the "Great reset" being advocated by the World Economic Forum (WEF) and further changes coming to values and the positioning of the economy. From that important aspect, he closed his speech by indicating the importance of an approach that emphasizes "maximum

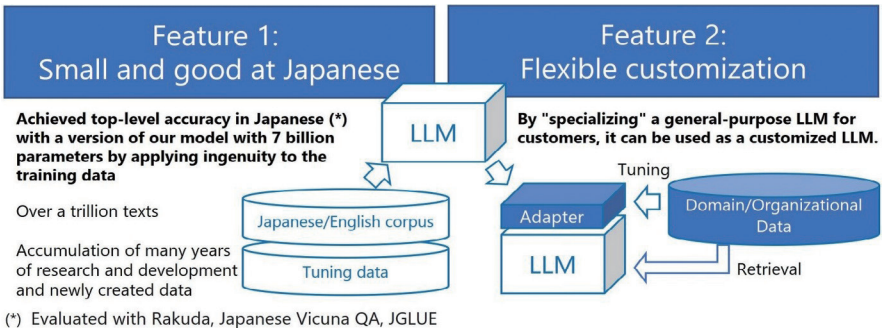

Fig. 1. The "tsuzumi" Large Language Model.

well-being with maximum diversity," rather than the traditional values of "maximizing happiness for the many," and "creating a future living together" with IOWN-based data sharing.

5. Technical Exhibits

The "IOWN Pick UP" technical exhibits presented NTT's LLM tsuzumi as a key technology and also introduced the latest developments and presented demonstrations of IOWN related technologies divided into three timelines, according to level of maturity, as "IOWN Now," "IOWN Evolution," and "IOWN Future." There were also exhibits on 18 other wide-ranging themes categorized on timelines, such as next-generation computing infrastructure, sustainable technology, APN, and next-generation wireless technology. These showed how progress in various domains is related to the implementation of IOWN.

5.1 IOWN Pick Up

The spotlight was placed on NTT's LLM tsuzumi, which was announced in November 2023. It brings together R&D results that NTT has been cultivating in natural language processing and other technologies, and has demonstrated a range of communication possibilities with language and beyond.

(1) The "tsuzumi" Large Language Model

The '"tsuzumi" Large Language Model' exhibit presented to the world NTT's long-awaited tsuzumi technology, which has been attracting much attention. It described the technology and introduced its main features as "lightweight and proficient in Japanese," and "flexible customization." Worth noting was that tsuzumi is lightweight enough to operate on a single GPU in a local environment. By increasing the quality and quantity of language-training data, it has achieved the highest performance in Japan while also greatly reducing power consumption and operating costs. The exhibit also showed that tsuzumi was able to derive correct responses by having smaller, specialized LLMs cooperate rather than having a single large LLM, as with earlier LLMs. Another major feature is that tsuzumi has a generalized LLM as a base, and "adapters" can be applied to it, enabling flexible customization for a customer's requirements or characteristics of an industry. We can anticipate these features being utilized in a wide range of applications (**Fig. 1**).

(2) "tsuzumi" for understanding graphic documents

LLM tsuzumi has also been expanded to communication beyond language. In "tsuzumi for understanding graphic documents," tsuzumi demonstrated abilities as though the LLM could actually "see." In contrast to earlier LLMs based on text data, tsuzumi is able to understand a wide range of graphical and hand-written materials and derive correct responses. A world in which LLM's can communicate with people using language, even in non-digital environments and conditions, is within sight (**Fig. 2**).

(3) "tsuzumi" with hearing and speaking abilities

LLM tsuzumi has also been expanded to utilize communication with sound. In "tsuzumi with hearing and speaking abilities," it is able to obtain information by "hearing" voices and other sounds (**Fig. 3**). By capturing non-linguistic information that is not represented in text, such as tone, physical condition, or emotion, it demonstrated the ability to communicate more intimately with people. It introduced how tsuzumi is not limited to vision and has expanded to communication using the five senses and to other means beyond language as shown in other exhibits as well.

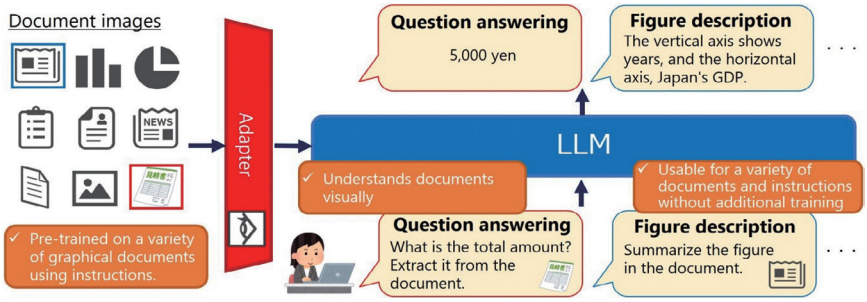

Fig. 2. "tsuzumi" for understanding graphic documents.

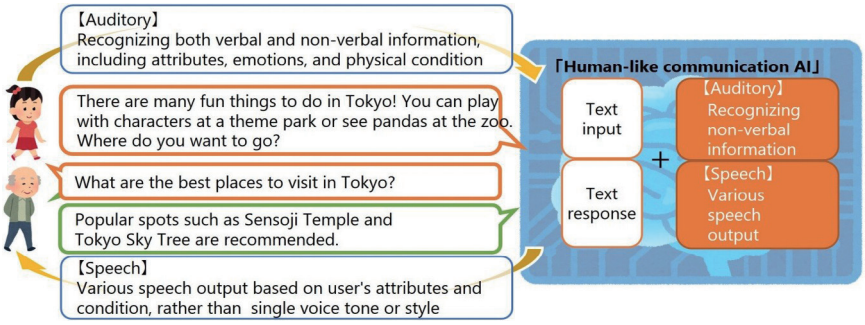

Fig. 3. "tsuzumi" with hearing and speaking abilities.

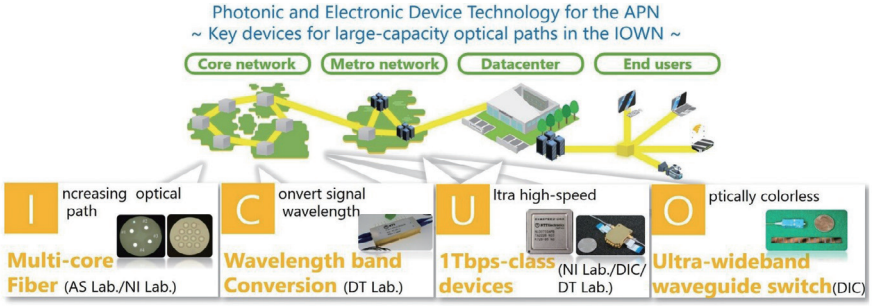

Fig. 4. Photonic and electronic device technology for All-Photonics Networks.

5.2 IOWN Now

In "IOWN Now," the current state of IOWN was exhibited, as it advances from networks into computing. NTT research results and elemental technologies that are starting to be used in various fields were described, showing the major impacts they are having on society.

(1) Photonic and electronic device technology for All-Photonics Networks

"Photonic and electronic device technology for All-Photonics Networks," presented various advanced devices that support APN and IOWN 2.0. Various NTT Laboratories technologies were gathered, such as multi-core fiber, wavelength modulation devices, 1-Tbps-class devices, and ultra-wide-band optical switches, and these research results are behind implementation of high capacity, low latency and low-power in APN (**Fig. 4**).

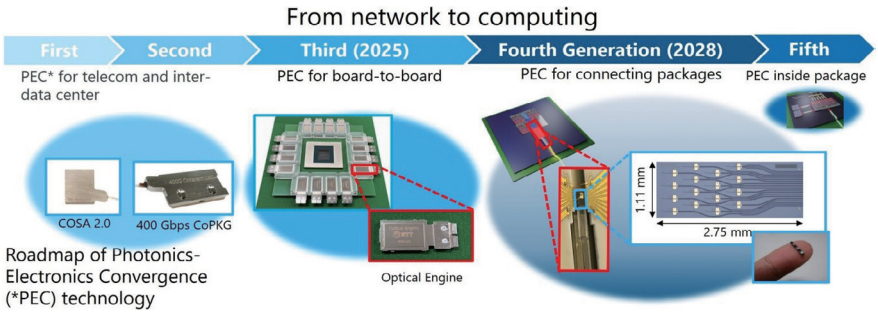

Fig. 5. Photonics-Electronics Convergence devices.

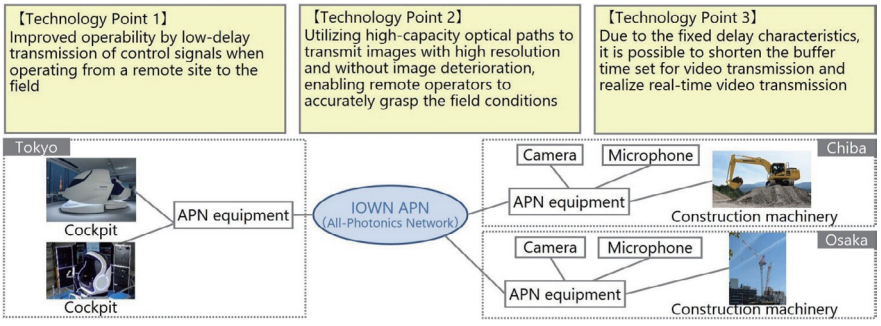

Fig. 6. IOWN APN for remote control and grasp of the on-site environment.

(2) Photonics-Electronics Convergence devices

The "Photonics-Electronics Convergence devices" exhibit presented R&D utilizing optics in even smaller components of networks, introducing compact photo-electric devices that can be placed in large-scale integrated (LSI) circuits. As IOWN progresses from networks to computing, this technology will be used to apply mechanisms for converting electrical signals to optical signals connecting progressively smaller components, from between boards to between semiconductor packages and then within semiconductor packages. It will contribute greatly to progress with IOWN high-capacity, low-latency and low power on the roadmap for the future (**Fig. 5**).

(3) IOWN APN for remote control and grasp of the on-site environment

The "IOWN APN for remote control and grasp of the on-site environment" exhibit presented and dynamically demonstrated the potential for the IOWN features of high capacity, low latency, and low power to be utilized to solve social issues in a more tangible way. Fine remote operation was made possible by using the APN to transmit high-definition video with low latency from a site, and to provide real-time control feedback from a human operator. It demonstrated the usefulness of APN in contributing to addressing various issues in the construction industry, such as personnel shortages and ensuring safe work environments for technicians (**Fig. 6**).

5.3 IOWN Evolution

"IOWN Evolution" introduced everyone to a future vision of what is close to becoming reality, opened up through advances in IOWN occurring daily. It showed NTT R&D to create solutions for various social issues and to realize well-being through application of IOWN.

(1) On-demand APN and In-network video processing

The "On-demand APN and In-network video processing" exhibit displayed implementation of a near-real-time broadcasting and distribution service and interactive video experience. This redefines video distribution utilizing two technology elements: a technology providing on-demand optical paths and a technology that can process video in its transmitted form. A video processing demo was presented at the

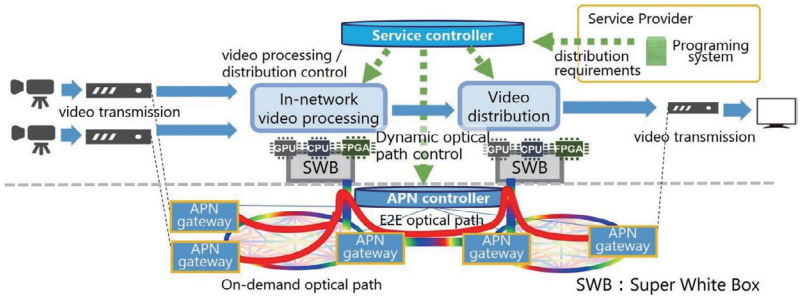

Fig. 7. On-demand APN and In-network video processing.

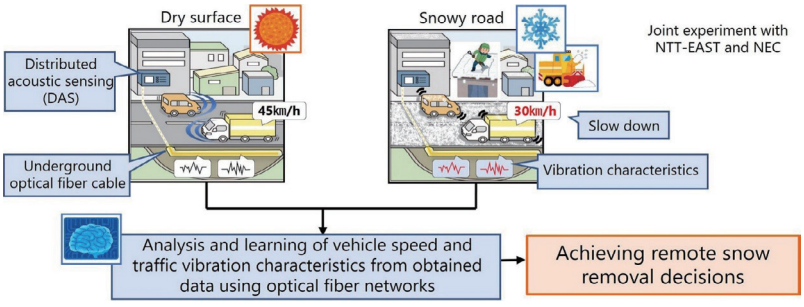

Fig. 8. Environment monitoring with optical fiber.

venue using news and video introducing cultural properties (**Fig. 7**), and showed how the camera video was delivered to the viewer without loss of time or information, but also that the viewer was now able to select which of the cameras' video to view. The fact that it can be controlled from the communications side using a Super White Box rather than a specialized broadcaster device also made a strong impression.

(2) Environment monitoring with optical fiber

IOWN is also being developed to utilize existing equipment, creating new value. The "Environment monitoring with optical fiber" exhibit introduced technology that uses optical cable installed underground as a sensor to analyze vibration. It demonstrated the world's first example of making decisions from a distant location regarding snow removal in a heavy snowfall area. It showed the prospects for using optical fiber installed in many areas around the world for more than just communication and to contribute to solutions for various regional issues by using it as infrastructure for environment maintenance (**Fig. 8**).

(3) Hyperspectral analysis technology for different views of reality

To understand the world beyond the human perception, the "Hyperspectral analysis technology for different views of reality" exhibit introduced a technology that changes coloring and makes predictions from images captured with a hyperspectral camera. The exhibit showed the potential for giving additional value to earlier images and video by visualizing information that cannot be captured by the human eye. The live demo also showed the case of using it in the entertainment field, by shining light over a wide area on the clothing at the 2023 Paris Collection to change the appearance of color in the clothing (**Fig. 9**). The neighboring exhibit, "Hyperspectral imaging with a metalens and AI," displayed an example of visualizing the sweet parts of fruit by overlaying visual information on sugar content over images of the fruit (**Fig. 10**), and introduced many application examples. By accurately visualizing various colors captured in hyperspectral images, various visual representations and communication of information should be possible using color.

(4) XR Sports space generation to reproduce the real world's experience

"XR Sports space generation to reproduce the real

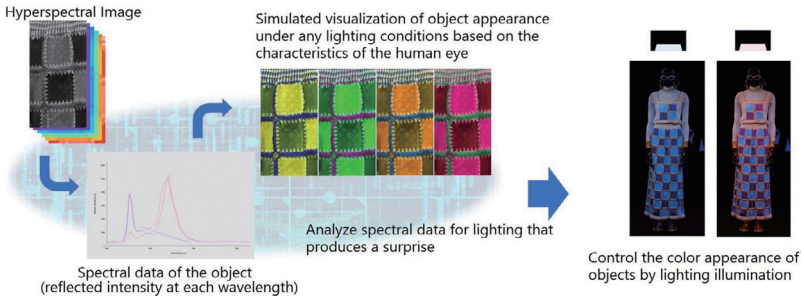

Fig. 9. Hyperspectral analysis technology for different views of reality.

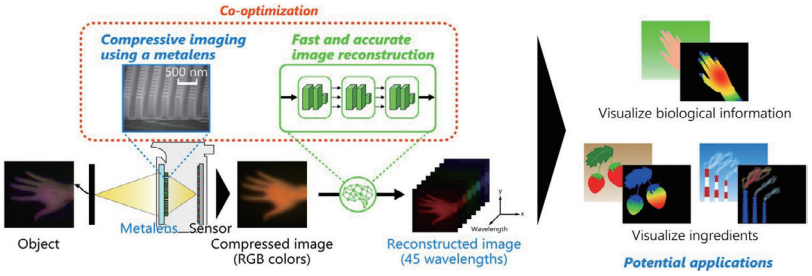

Fig. 10. Hyperspectral imaging with a metalens and AI.

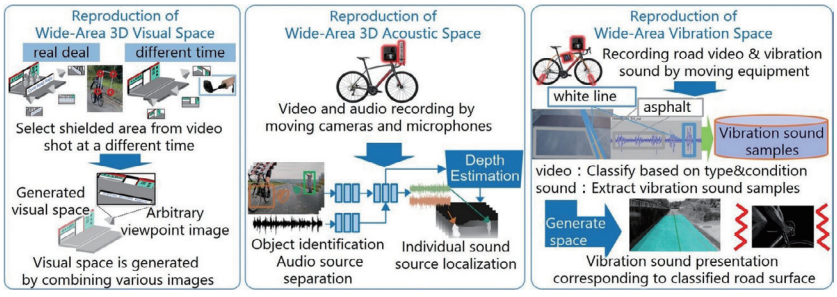

Fig. 11. XR Sports space generation to reproduce the real world's experience.

world's experience" exhibited technologies to perceive virtual space with all five senses, and not just vision. It presented "XR Sports Space" technology, which is an ultra-realistic meta-based space that provides a realistic virtual sports experience using time-change, sound, vibration, and other information (**Fig. 11**). Also presented was a dynamic demonstration that attracted much attention, introducing the feeling of participating in a bicycle race using technology that reproduces video, audio, and tactile sensation just like actually being there (**Fig. 12**). This brings us closer to a world in which viewers can participate in an international tournament being held in a far-away place and "race" with the contestants in real time.

5.4 IOWN Future

Exhibits in "IOWN Future" introduced initiatives related to improving well-being for people in society and developing new solutions to large scale social issues at a global level with NTT technologies.

(1) Artificial photosynthesis

Fig. 12. Bicycle race demo exhibit using space reproduction technology.

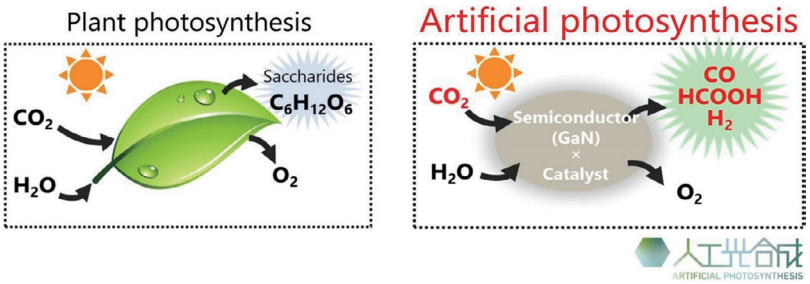

Fig. 13. Artificial photosynthesis.

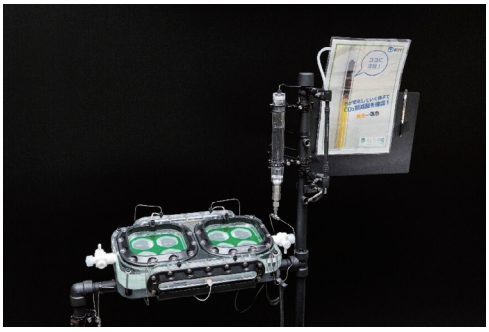

Fig. 14. Artificial photosynthesis presentation demo.

Achieving carbon neutrality has become a global issue and "Artificial Photosynthesis" exhibits some R&D focusing on the workings of plants as they grow. It exhibited a technology being developed to reduce CO_2 using "high-quality semiconductor photocatalysts," one of NTT's strengths, by adding a protective layer to suppress deterioration (**Fig. 13**). This technology has enabled NTT to achieve world-class performance, with "continuous operation of more than several hundred hours." The exhibit introduced conditions producing real photosynthesis and generated much excitement and anticipation for implementation (**Fig. 14**).

(2) IOWN and future car

There is a range of initiatives and R&D being conducted around the world on automobiles and some of this R&D is looking to the future. The "IOWN and future car" exhibit featured applications of IOWN

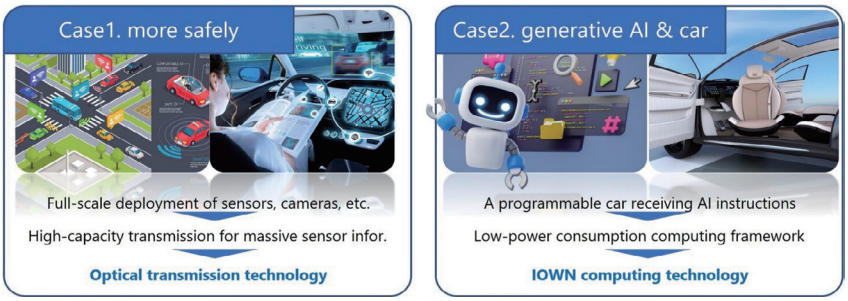

Fig. 15. IOWN and future car.

optical transmission technology, opto-electric integration technology, and computing. These will be essential in realizing "future cars" as they are being discussed at the IOWN Global Forum, to solve social issues and also to increase well-being. Of course they will realize a safer, more-enjoyable in-car space while fully utilizing information from cameras and sensors in all directions to ensure safe and secure driving, but they will also be equipped with more-advanced features using generative AI and low-energy computing, so that vehicles will evolve from being just a means of transport into a "lifestyle support partner" for a comfortable and sustainable future. This exhibit also attracted much attention (**Fig. 15**).

6. Conclusion

During this Forum, we have introduced R&D being promoted by NTT, highlighting the steady progress toward implementation of IOWN, and new potential created by technologies such as IOWN and tsuzumi, NTT's LLM. We hope that our many visitors have gained a real sense of NTT's latest technologies and future prospects, as well as the vision for the future that we are co-creating with our various partners. NTT will continue working to create a rich future for people and the planet, meeting new challenges and continuously innovating. We hope you will continue to look forward to IOWN and other NTT R&D as it accelerates in the future.

Members of NTT R&D Forum Secretariat: (from left in the back row) Atsushi Ikeda, Masakatsu Fujiwara, Tetsuya Ooishi, Hiroyuki Shiba, Kei Karasawa; (from left in the front row) Yoshifumi Shiraki, Masaki Hyodo, Shunsuke Mori, Tokinobu Mitasaki, Tomoki Baba, Hironari Yokoi, Takanori Watanabe, Keita Takahashi

External Awards

IPSJ Contribution Award
Winner: Katsumi Takahashi, NTT Social Informatics Laboratories
Date: June 1, 2023
Organization: Information Processing Society of Japan (IPSJ)

For contribution to the technology and legal system of data security and privacy.

3rd place at iPWS Cup 2023
Winners: Takayuki Miura, NTT Social Informatics Laboratories; Masanobu Kii, NTT Social Informatics Laboratories; Atsunori Ichikawa, NTT Social Informatics Laboratories; Juko Yamamoto, NTT Social Informatics Laboratories
Date: August 28, 2023
Organization: iPWS Cup Committee, International Workshop on Security (IWSEC) 2023

Won 3rd place overall at iPWS Cup 2023, a data anonymization competition held at IWSEC 2023.

Outstanding Paper Award
Winners: Naoki Azuma, Nihon University; Toshiki Onishi, Nihon University; Shunichi Kinoshita, 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: September 19, 2023
Organization: IPSJ/Multimedia, Distributed, Cooperative, and Mobile Symposium (DICOMO) 2023

For "A Study on Prediction of Listener's Various Backchannels Based on Multimodal Information."
Published as: N. Azuma, T. Onishi, S. Kinoshita, R. Ishii, A. Fukayama, T. Nakamura, and A. Miyata, "A Study on Prediction of Listener's Various Backchannels Based on Multimodal Information," Proc. of DICOMO 2023, 3A-2, Toyama, Japan, July 2023.

2nd place at PWS Cup 2023
Winners: Tomoya Matsumoto, Osaka University; Yumeki Goto, Osaka University; Hiroki Tejima, Osaka University; Takayuki Miura, NTT Social Informatics Laboratories; Issa Sugiura, Osaka University
Date: November 1, 2023
Organization: 9th Privacy Workshop (PWS 2023)

Won 2nd place overall (3rd place in anonymization and 2nd place in attribute estimation) at PWS Cup 2023, a data anonymization and attribute estimation competition held at PWS 2023.

ACC Finalist in Creative Innovation Category, ACC TOKYO CREATIVITY AWARDS
Winners: Tatsuya Kako, NTT Computer and Data Science Laboratories; Hironobu Chiba, NTT Computer and Data Science Laboratories; Akira Nakayama, NTT Computer and Data Science Laboratories; Kenichi Noguchi, NTT Computer and Data Science Laboratories; Shoichiro Saito, NTT Computer and Data Science Laboratories; Hiroshi Sakai, NTT Sonority, Inc.; Jun Iwase, NTT Sonority, Inc.; Hiroaki Sato, NTT Sonority, Inc.; Yoichiro Kakiyama, NTT Sonority, Inc.; Kenta Yamada, NTT Sonority, Inc.; Chihiro Sasaki, NTT Sonority, Inc.; Yoshiaki Kozaki, NTT Sonority, Inc.; Tsukasa Kumagai, NTT Sonority, Inc.; Koichi Sugiura, NTT Sonority, Inc.; Itaru Sugita, NTT Sonority, Inc.; Kazunori Kobayashi, NTT Sonority, Inc.; Shintaro Takeuchi, NTT Sonority, Inc.
Date: November 2, 2023
Organization: All Japan Confederation of Creativity (ACC)

For research and development of nwm MWE001 open ear earphone that reduces sound leakage.

ICETC 2023 Best Poster Award
Winner: Jumpei Hayakawa, NTT Access Network Service Systems Laboratories
Date: November 30, 2023
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE) Communications Society

For "Simple Method for Measuring Spatial Mode Dispersion in Coupled Multi-Core Fibers without Accessing Both Ends."
Published as: J. Hayakawa, A. Nakamura, M. Nakamori, and Y. Koshikiya, "Simple Method for Measuring Spatial Mode Dispersion in Coupled Multi-Core Fibers without Accessing Both Ends," International Conference on Emerging Technologies for Communications (ICETC) 2023, P1-10, Sapporo, Japan, Nov./Dec. 2023.

Fellow
Winner: Yoji Yamato, NTT Network Service Systems Laboratories
Date: December 11, 2023
Organization: IEICE

For research and practical application of the advanced open source cloud.

Honorable mention
Winner: Team NTT-EASE (Yuki Kubo, NTT Social Informatics Laboratories; Tomoya Yamashita, NTT Social Informatics Laboratories; Masanori Yamada, NTT Social Informatics Laboratories)
Date: December 23, 2023
Organization: Dialogue Robot Competition (DRC) 2023

For "Dialogue System of Team NTT-EASE for DRC2023."
Published as: Y. Kubo, T. Yamashita, and M. Yamada, "Dialogue System of Team NTT-EASE for DRC2023," arXiv:2312.13734, 2023.

OFT Young Researcher's Award
Winner: Ryota Imada, NTT Access Network Service Systems Laboratories
Date: January 11, 2024
Organization: IEICE Technical Committee on Optical Fiber Technologies (OFT)

For "A Study on Bending Loss Property of Coupled Multicore Fiber."
Published as: R. Imada, T. Sakamoto, T. Mori, Y. Yamada, and K. Nakajima, "A Study on Bending Loss Property of Coupled Multicore Fiber," OFT2022-58, 2023.

Papers Published in Technical Journals and Conference Proceedings

Catalytic Transformation from Computationally-universal to Strictly-universal Measurement-based Quantum Computation

Y. Takeuchi

arXiv:2312.16433, December 2023.

There exist two types of universality in measurement-based quantum computation (MBQC): *strict* and *computational* universalities. It is well known that the former is stronger than the latter. In this paper, we give a method of transforming from a certain type of computationally-universal MBQC to the strictly-universal one. Our method simply replaces a single qubit in a resource state with a Pauli-Y eigenstate. We apply our method to show that hypergraph states can be made strictly universal with only Pauli measurements, while only computationally-universal hypergraph states were known so far.

Blind and Spatially-regularized Online Joint Optimization of Source Separation, Dereverberation, and Noise Reduction

T. Ueda, T. Nakatani, R. Ikeshita, K. Kinoshita, S. Araki, and S. Makino

IEEE ACM Trans. Audio Speech Lang. Process., Vol. 32, pp. 1157–1172, January 2024.

This paper proposes a computationally efficient joint optimization algorithm that performs online source separation, dereverberation, and noise reduction based on blind and spatially-regularized processing. When applying such online Blind Source Separation (BSS) as online Independent Vector Extraction (IVE) to a speech application, we must focus on the trade-off between the algorithmic delay and separation accuracy, both of which depend on the analysis frame length. In addition, to separate the sources with specified source permutation, researchers introduced spatial regularization based on the Directions-of-Arrival (DOAs) of the sources into IVE. However, the scale ambiguity of IVE often makes the spatial regularization work inappropriately. To solve these problems, we first propose a blind online joint optimization algorithm of IVE and weighted prediction error dereverberation (WPE). This online algorithm can achieve accurate separation even using short analysis frames because reverberation can be reduced using WPE. We then extend the online joint optimization with robust spatial regularization. We reveal that regularizing the scale of the separated signals is very effective in making the DOA-based spatial regularization work reliably. Our experiments confirm that our blind online joint optimization algorithm can significantly improve the separation accuracy with an algorithmic delay of 8 ms. In addition, we confirm that the proposed spatially-regularized online joint optimization algorithm reduces the rate of the source permutation error to zero percent.
