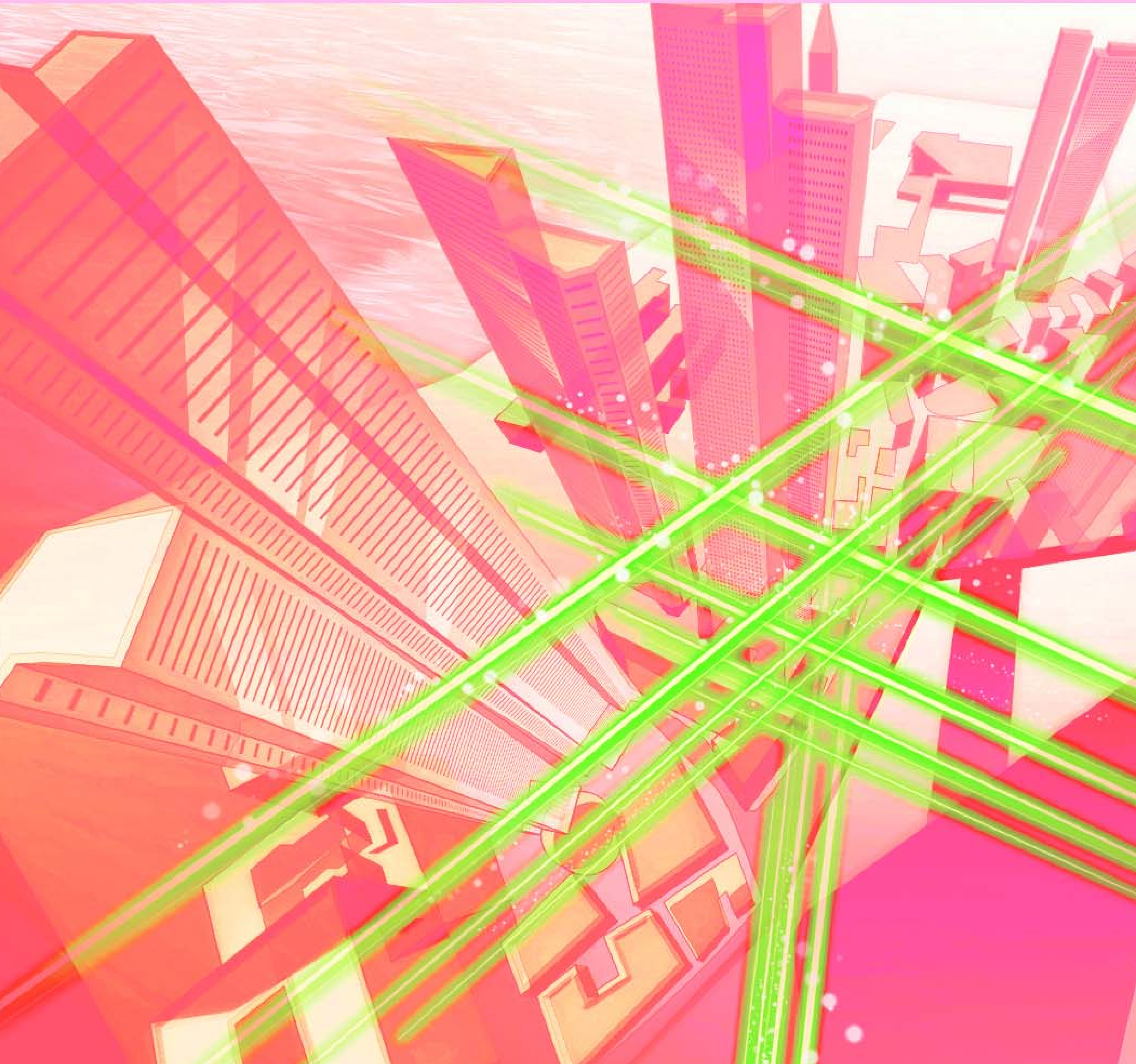
NTT Technical Review

3
2023



March 2023 Vol. 21 No. 3

NTT Technical Review

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Let's Focus on the Now Regardless of History or Background and Take on New Challenges with ICT from a Global Perspective

Masaaki Moribayashi
Representative Member of the Board, President and CEO, NTT WEST

Abstract

NTT WEST is striving to solve social issues in the region where it operates by supporting the digital transformation of regional industries and communities. The company is also taking on challenges in new areas and creating innovations by using cutting-edge information and communication technologies toward building a sustainable society of well-being. We asked Masaaki Moribayashi, CEO of NTT WEST, about his vision and attitude as top management.

Keywords: ICT, DX, co-creation

2023 will be a critical year

—It's been two years since our last interview, and this is your third time in total. The last interview was when you were in London during the COVID-19 pandemic. How does it feel to be back to Japan?

Although remote work has taken root in society after the COVID-19 pandemic, people are also returning to the office as an option, and opportunities to meet face-to-face with customers and partners are gradually increasing. Considering that trend, I feel that society has changed from what it was before the pandemic.

After returning to Japan in June 2022, I've been working in western Japan for the first time in 30 years. I was with NTT Communications from 1999, the year it was founded, until 2019. With the exception of the years from 2016 to 2018, I was consistently engaged in international business, including secondments to overseas companies. From 2019 to 2022, I was working in London for NTT Ltd. and more than half of my life at NTT has been spent involved in international business mainly related to overseas bases. For that reason, some people might be concerned about whether I am able to fit into domestic business, particularly, for a reginal company like NTT WEST, but I assure you that I'm working without any sense of discomfort or resistance.

Of course, I realize that business in the western Japan region has changed dramatically over the past 30 years, and our customers have changed as well. However, from a global perspective, Japan is one region of the world, and regarding information and communication technology (ICT), the issues faced by domestic companies such as NTT EAST and NTT WEST are almost the same as those faced globally in terms of networks, security, cloud computing, digital

transformation (DX), and so on. Therefore, I think I can make use of my experience. For example, we can collaborate directly with global partners by taking advantage of the relationships that I have formed during my time at NTT Ltd. and NTT Communications.

In 2022, with the completion of the new headquarters of NTT WEST, NTT WEST i-CAMPUS, we opened an open-innovation facility called QUINTBRIDGE, for solving social issues and creating a future society with our partner companies. Since the opening of QUINTBRIDGE, more than 50,000 people have visited and more than 240 events have been held. We have also started a future co-creation program, called "Future-Build," and received more than 100 proposals from domestic and foreign ventures in the four fields of health, lifestyle, economy, and environment and are investigating the commercialization of six of such proposals. We plan to provide the partner companies at QUINTBRIDGE business-matching opportunities with NTT WEST Group companies, NTT Group companies inside and outside of Japan, venture companies in the West Coast of the USA and Israel, and major IT companies to facilitate collaboration and co-creation.

—The knowledge you have acquired while working in the global market and your solid personal network are very reassuring. Could you tell us about the current business environment and your vision for 2023?

Social conditions have changed significantly such as semiconductor shortages and soaring energy prices. In the field of information and telecommunications, the importance of the infrastructure supporting information and telecommunications is increasing as social life is transformed in light of the COVID-19 pandemic, and the trend toward digitization and online access is accelerating and taking root in all aspects of business and daily life.

With such a business environment as a backdrop, at my presidential inaugural press conference in June 2022, I raised the slogan 伝新人輪 (*den-shin-jin-wa*), which is composed of the Japanese *kanji* characters mimicking the sound of the words 電信電話 (*den-shin den-wa*, i.e., "telegraph and telephone"). The first character, 伝 (*den*, i.e., "tradition"), represents our desire to preserve and refine NTT's traditions and technologies. The second character, 新 (*shin*, i.e., "new"), represents taking on new challenges viewed from a global perspective. The third character, 人 (*jin*, i.e., "people"), represents our connections with all types of people, including employees, customers, and the local community, and the importance we place on people. The fourth character, 輪 (*wa*, i.e., "circle"), expresses our desire to expand the circle of co-creation with partners.

The year 2023 will be a critical year for NTT WEST—as we transform from our past image as a telephone, optical, and telecommunications company to an advanced, innovative, and attractive company that leverages artificial intelligence (AI), Internet of Things, and other technologies. We are aiming to keep the information and telecommunications infrastructure—the backbone of our business—connected in a stable and high-quality manner while continuing to improve the infrastructure by increasing efficiency through DX. As a pioneer in solving social issues, we will also promote regional revitalization through connections with local communities and partners.

With those aims in mind, we will further strengthen our business in growth areas. Strengthening the businesses of our group companies, such as the infrastructure business, which capitalizes our expertise in infrastructure facilities, e-book business, and contact center business, will also be essential for our future growth. Specifically, we focus on (i) the "regional revitalization cloud" to address issues such as industrial revitalization, job creation, and aging population that local governments are facing and improve work efficiency required by local companies, which are often short of labor; (ii) the platform "L. ID" to help transform uniform education into personalized education and improve the convenience of education (including student life) for promoting educational DX for universities in accordance with the concept of "digital education"; (iii) multiple-solution packages for small and mid-size companies; (iv) new co-creation through the use of electric vehicles as a carbon-neutral initiative; and (v) the carrier-infrastructure business, which is becoming more sophisticated through the analysis and use of our data.

Pursuing well-being and solving social issues with the power of ICT

—All of the businesses in the growth areas are indispensable and important in today's society. In our daily lives, ICT is becoming more and more convenient and widely used.

As our daily lives become increasingly digitalized, we are also becoming increasingly oriented toward well-being. With that trend in mind, we are also focusing on the development of ICT-based services in the entertainment area. Have you heard of "Comic C'moA," a comprehensive e-book service that celebrated its 18th anniversary in 2022? In March 2022, as a first step to deliver this service to customers around the world, we began offering a digital manga store for overseas customers called "MangaPlaza." Entertainment service is a dynamic area in which new services are born one after another along with the evolution of information terminals, and together with our partners, we want to take on the challenge of creating a new culture.

Prevention and early detection of illness and promotion of health are important issues for all people. These issues are deeply correlated with sleep habits. We have therefore established NTT PARAVITA, a joint venture with Paramount Bed Corporation, which has the largest market share in Japan for medical and nursing care beds and mat-type sleep sensors. The purpose of this venture is to support the early detection of illness and provide information for health promotion by using ICT from the perspective of sleep. Specifically, the venture provides a service for visualizing sleep information using high-precision sensors and providing advice by experts to improve sleep and a health support service at dispensing pharmacies. We will work on early detection of diseases in the pre-disease stage by combining our

expertise in an AI engine for analyzing sleep data with the expertise of Paramount Bed on sleep.

Be comfortable with change and alteration

—What has been important to you as a top executive?

I consider "people" and "human connections" to be the most important. Although remote work has become a common practice in Japan, I want to value human connections and communication in our hybrid work environment while taking advantage of the benefits of both remote work and face-to-face work.

The relationships we have with our employees as well as our customers and partners are important. Even though I have opportunities to interact with executives and department heads on a daily basis, I don't have many opportunities to talk with other employees, so I visit branches in 30 prefectures in western Japan to communicate with employees and hold dialogue meetings over lunch. NTT WEST employs approximately 50,000 people, so it is not possible to hold a dialogue with all of them. Even so, I'm planning to communicate with as many employees as possible.

As a top executive, I value the outside perspective when making decisions. For example, one may feel that something is not quite right with the work that is being done at one's new assignment. That unease usually signifies an issue that needs to be addressed, and such perception is often correct. In that case, I ask employees, "Isn't this strange?" I understand that it is difficult for them to argue against me, the president, so I carefully observe their facial expressions and nuances during conversations and try to listen to their opinions before making decisions.

When I ask such questions, I often hear a reply saying "This is the way it is because of what we have done up to now." When I ask, "What would it be like without that background?", the answer is often, "In that case, as you say, it would appear strange." We don't have a rule that you have to carry on what was decided 10 years ago. So throw away your ties of obligation and do what you think is right and optimal on the basis of your judgment at the moment.

—Finally, what would you like to say to our partners, researchers, and employees?

I expect researchers to create something that NTT can add value to, something that does not exist in the world. As a world-leading technology, the Innovative Optical and Wireless Network (IOWN) is a major vision for the NTT Group. We will promote IOWN at Expo 2025 Osaka, Kansai, Japan in two years. I want to encourage all our bright-minded researchers to approach their research with a global mindset.

We look forward to collaborating with our partners. Our doors are open such as at QUINTBRIDGE. We want to create new business and provide services with as many people as possible, whether it be one person or one company.

To our employees. The key to solving social issues and growing as a company is people. We promote respect for human rights, diversity and inclusion, safe labor, health management, and a new work style based on remote work, and we promote a “work-in-life” style that allows employees to choose where and when they work. I’ll say it again, 2023 is a critical year for us. We have many things to do to grow businesses in growth areas in parallel. I encourage you to look at the “now” and propose what you think is best, without regard to history or background. My own positivity will never change. Let’s continue being positive.

Interviewee profile

■ Career highlights

Masaaki Moribayashi joined Nippon Telegraph and Telephone Public Corporation in 1984. He became president and managing director of NTT Europe Ltd. in 2009, senior vice president and head of the Cloud Services Department of NTT Communications in 2016, senior executive vice president of NTT Communications in 2018, and board director and senior executive vice president of NTT Ltd. in July 2019. He has been in his current position since June 2022.

Researchers Value Passion and Knowledge, and Seek to Solve Problems at Hand and Those That Have Remained Unsolved for Many Years

Tatsuaki Okamoto
NTT Fellow, NTT Social Informatics Laboratories

Abstract

One of the most fundamental problems in science is quantitatively defining the complexity of organized things. Over the past several decades, many quantitative definitions of complexity have been proposed, but a single definition has not been agreed upon. Tatsuaki Okamoto, an NTT Fellow at NTT Social Informatics Laboratories proposed a quantitative definition that simultaneously captures all three key features of complexity for the first time. We interviewed him about the progress of his research activities and the research environment in Japan and the United States.

Keywords: organized complexity, probability distribution, deterministic strings

The world's first quantitative definition that simultaneously captures all three key features of complexity

—It has been two years since our last interview. I heard that you have returned to Japan from Silicon Valley.

Yes, the previous interview took place in 2020. At that time, I was in Silicon Valley as the director of Cryptography and Information Security Laboratories (CIS Lab) of NTT Research, and I talked about the research themes in cryptography and blockchains pursued at the CIS Lab and what kind of research institute NTT Research is. After returning to Japan in July 2022, I have been researching cryptography theory at NTT Social Informatics Laboratories. While at NTT Research in the summer of 2021, I managed the CIS Lab while also providing research guidance for internship students on the topic of adaptor signatures, a cipher used in blockchain transactions.

The research I'll discuss today is related to cryptography in a broad sense, but it is more specifically about the field of *complexity*. If we follow the microscopic world, such as the cells that make up organisms such as animals and plants, we will see they have extremely complicated structures. We also know that the universe has evolved from its simple form immediately after the Big Bang to a more complex form. When we look around us in this way, we see that we are in fact surrounded by an abundance of complex things. Complexity is the topic of scientific study through which the complexity of those things that are said to be complex in the world is defined and quantified from a unified viewpoint. The research field of complex systems has been around for more than 30 years, and many excellent research results have been reported; however, not much progress has been made in regard to the study of the underlying complexity of those systems. I have been thinking about this research field while researching cryptography and recently published a paper on a quantitative definition of complexity in the journal *Complexity* [1]. It is the world's first definition that simultaneously captures all three key features of complexity (described later).

The ideas and concepts behind cryptography have also been helpful for me to study complexity; for example, the concept of *knowledge complexity* introduced in connection with the theory of zero-knowledge proof used in cryptography provided one clue in deriving this definition.

—You have proposed a world's first in research that could be considered your life work. Would you tell us more about it?

First, let me explain the essence of the problem of complexity. Warren Weaver, an American scientist, classified scientific problems into three categories: problems of *simplicity*, problems of *disorganized complexity*, and problems of *organized complexity (OC)*. A typical problem of simplicity is one in which the motion of a few balls on a billiard table is accurately analyzed and predicted using dynamics. A typical problem of disorganized complexity is one in which millions of balls are rolling around on a giant billiard table and randomly colliding with one another and the cushions of the table, and their average motions are analyzed and predicted using statistical mechanics. A problem of OC is defined as one involving organized and complex things such as living organisms and ecosystems in which many cells are interrelated and form a single living organism as well as artificial objects. Problems of complexity are thus categorized as "organized" or "disorganized."

In problems of complexity, the most fundamental and important notion—from a scientific perspective—is the quantitative definition of complexity. The quantitative definition of disorganized complexity (randomness) of physical systems was established to be entropy, which appears in thermodynamics and statistical mechanics. Moreover, the quantitative definition of the disorganized complexity (randomness) of information sources (a probability distribution) was established as Shannon entropy. These two entropies are essentially the same except for a constant.

Despite many attempts to give a quantitative definition of OC, there is no definition that is widely agreed upon. The difficulty with this definition lies in the fact that OC depends heavily on our senses—or can be perceived by intelligent creatures like humans—and is very different from the randomness of objects. Those previous attempts have covered either deterministic strings or probability distributions, and there was no definition that covered both simultaneously.

Capture all three key features of complexity (descriptive, computational, and distributional) simultaneously

—So, it is necessary to establish a definition that covers both deterministic strings and probability distributions at the same time.

I considered what should be the object of the definition of OC. The object of complexity is everything around us, which includes the stars and galaxies in the universe, living organisms, ecosystems, artificial things, and even human societies. The only way for us to recognize those things is observation via telescopes, microscopes, various instruments, and electronic devices. We directly recognize the existence of an object by actually holding it in our hands; however, this recognition is also a result of observation; that is, our brain processes the observed data obtained through our five senses (sensors) to interpret and recognize the existence of the object. In other words, we perceive everything on the basis of observed data.

In general, the source (information source) of observed data (i.e., a deterministic string) of physical phenomena is a probability distribution, and the observed data are values randomly selected in accordance with that distribution. It is therefore natural to assume that the object of OC is not the observed data (i.e., deterministic values) selected by chance from the source but the source itself (i.e., probability distribution). Accordingly, I considered that the object of OC should be a probability distribution (i.e., the source). Since a deterministic string may be a special case of a probability distribution (in which only one value occurs with probability of 1), it is also an eligible object.

—What were the problems with the existing quantitative definitions of OC?

Let's take two cases as an example. First, we give a chimpanzee a computer keyboard and allow it to press keys freely and generate a character string of 1000 letters of the alphabet. Second, we take a character string of 1000 letters of the alphabet from one of Shakespeare's plays. Both cases are deterministic strings; however, comparing the two sources of information clearly reveals the difference in complexity of the two strings.

The information source of the chimpanzee's string is almost a uniform distribution (i.e., a simple distribution) of 1000 random letters, so its OC is at the lowest level. On the contrary, the information source of Shakespeare's string is the probability distribution of several candidate expressions in Shakespeare's mind. Regardless of whether Shakespeare chooses from several expressions that come to mind (i.e., a complex probability distribution of several candidate expressions) or he chooses one expression without hesitation (i.e., a probability distribution of one complex string occurring with probability of 1), both distributions are complex, so their level of OC is very high.

If we consider OC in Shakespeare's strings, we notice that complexity has several different features. Since the object (information source) of OC is a probability distribution, one feature of complexity is the complexity of the pattern of probability distribution (distributional feature). Another feature of complexity is the complexity of the amount of description (descriptive feature) such as the knowledge required to write a play (language, history, culture, etc.) and the play's story. Moreover, when Shakespeare decided what he wanted to write, he would have thought deeply to choose the appropriate literary expressions to express that decision. Choosing such linguistic expressions can be regarded as a graph problem, and choosing an appropriate expression has a computational complexity (computational feature) that is equivalent to solving a graph problem. Therefore, OC has three features: distributional, descriptive, and computational, and to define it, all of these features must be captured simultaneously. Of course, values of complexity should be computable, and the complexity of problems of disorganized complexity (as in the above-mentioned example of a chimpanzee) or problems of simplicity should be low.

The problem with the existing definitions is fourfold: first, they capture only one of these three features of complexity (distributional, descriptive, and computational); second, they target either deterministic strings or probability distributions and cannot seamlessly target both at the same time; third, the complexity of some definitions is incomputable; fourth, some definitions are not rigorously specified (**Table 1**).

Accordingly, I set out to and successfully established a new quantitative definition of OC that would solve all four of those problems.

You need to have enough energy and passion to keep pursuing your research—whether you are asleep or awake

—You have overcome a longstanding issue. Please tell us about your definition of OC.

The basic idea of my quantitative definition of OC is that OC is defined by using the smallest stochastic automaton-form of a circuit (*oc-circuit*) that simulates an object, i.e., information source (probability distribution). (Making the oc-circuit the "smallest" means my definition accords with the principle called Occam's razor.) While some computational models must be used to capture the descriptive and computational features of complexity, the existing definitions use a Turing machine (a computer). Instead, my definition uses a circuit (oc-circuit). The reason for using a circuit is that the three features of OC can be obtained simultaneously. Moreover, a definition using a circuit is computable, whereas a definition using a Turing machine is incomputable.

Therefore, my quantitative definition of OC satisfies all the requirements and overcomes all the problems of existing definitions: (i) the three features of complexity (distributional, descriptive, and computational) can be obtained simultaneously, (ii) probability distributions and deterministic strings can be seamlessly covered as objects, (iii) the definition is computable and (iv) rigorously specified, and (v) the complexity of problems of disorganized complexity and problems of simplicity is low (Table 1).

My definition can be applied to theoretical

Table 1. Comparison with existing definitions.

Definition	Object (probabilistic and deterministic)	Simply regular	Simply random	OC			Computable
				Descriptive	Computational	Distributional	
Kolmogorov complexity	×	✓	×	✓	×	×	×
Effective complexity	×	✓	✓	✓	×	×	×
Logical depth	×	✓	✓	×	✓	×	×
Effective measure complexity	×	✓	✓	×	×	✓	✓
Statistical complexity	×	✓	✓	×	×	✓	✓
My definition of OC	✓	✓	✓	✓	✓	✓	✓

<table>
<tr><th>Definition</th><th>Approach</th><th>Rigorously specified</th><th>Computational models</th><th>Computable</th><th>Features</th></tr>
<tr><td>Kolmogorov complexity</td><td rowspan="5">Occam’s razor</td><td rowspan="6">✓</td><td rowspan="3">Turing machine</td><td rowspan="3">×</td><td rowspan="2">Descriptive</td></tr>
<tr><td>Effective complexity</td></tr>
<tr><td>Logical depth</td><td>Computational</td></tr>
<tr><td>Statistical complexity</td><td>Stochastic finite-state automata (∊-machine)</td><td rowspan="3">✓</td><td>Distributional</td></tr>
<tr><td>My definition of OC</td><td>Stochastic automaton form of circuit (oc-circuit)</td><td>All</td></tr>
<tr><td>Effective measure complexity</td><td>Information theoretic</td><td rowspan="3">None</td><td>Distributional</td></tr>
<tr><td>Natural complexity</td><td rowspan="2">Framework</td><td rowspan="2">×</td><td rowspan="2">—</td><td>—</td></tr>
<tr><td>Thermodynamics depth</td><td>—</td></tr>
</table>

—: Difficult to evaluate

foundations for machine learning and artificial intelligence, algorithms with OC, networks, analysis of amounts of computational and communication limits and averages, and semantic information theory. I believe that, for example, in contrast to Shannon’s information theory, which treats entropy (disorganized complexity) as the amount of information for the problem of signal transmission (syntactics), a semantic information theory that deals with the problem of conveying meaning (semantics) can be constructed using my definition of OC as the amount of (semantic) information (**Fig. 1**).

—The impact you have academically and socially is immeasurable. Finally, please tell us what you value as a researcher and what you would like to say to Japanese researchers who are aiming to work abroad.

I believe that a researcher is someone who values passion and knowledge, and attempts to solve problems at hand and problems that have remained unsolved for many years. With the spread of the Internet, the world has become borderless. It is thus important for researchers to approach their research with a global perspective.

As I mentioned, I have worked with some of the best and brightest researchers at the CIS Lab, NTT Research in Silicon Valley. The CIS Lab is full of energy since the world’s best and brightest researchers are stimulating and competing with each other. Some of the researchers are enrolled in doctoral programs and are quite enthusiastic. I believe it is important for young Japanese researchers and graduate students who aspire to become researchers to possess such enthusiasm for research. If you want to compete with powerful researchers around the world and accomplish research that will have an impact on the world, you will need to have enough energy and passion to keep pursuing your research—whether you are asleep or awake.

If we want to produce world-class researchers from Japan, we may have to reform our research system and structure that supports them. For example, in the U.S., PhD researchers usually start as postdoctoral fellows. A postdoctoral fellow is not positioned as an assistant researcher, but rather as an independent researcher with their own research theme. When their tenure is up, if their results are good, they will continue to research as a researcher in an upgraded

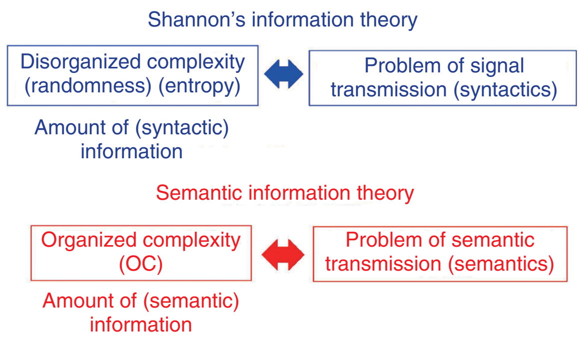


Fig. 1. Application to semantic information theory.

position (obtained through competition). (Although this is the case for theoretical research, it seems to differ in the case of experimental research.) As an independent researcher, you are more likely to develop yourself through competition with your peers than by learning from your professors. I therefore think it is necessary to create an environment in which outstanding researchers from around the world can gather so that young researchers can develop their career as researchers without depending on where they do their research.

Nevertheless, it is important for researchers and those who aspire to become researchers to choose where they can conduct research and where they can engage in competition—without blaming the environment if they make the wrong choice. One choice is to work at a research institute abroad. In that case, living abroad can be stressful owing to differences in language and culture. Such a situation could be a disadvantage, although time may solve that problem to some extent as they get used to life in another country. I hope that when they determine to research abroad, they will bring enough enthusiasm that overcomes such stress.

Reference

[1] T. Okamoto, "A New Quantitative Definition of the Complexity of Organized Matters," Complexity, Vol. 2022, Article ID 1889348. https://doi.org/10.1155/2022/1889348

■ Interviewee profile

Tatsuaki Okamoto received a B.E., M.E., and Ph.D. from the University of Tokyo in 1976, 1978, and 1988. He has been working for NTT since 1978 and is an NTT Fellow. He is engaged in research on cryptography and information security at NTT Social Informatics Laboratories. He served as the director of Cryptography and Information Security (CIS) Laboratories at NTT Research in USA from 2019 to 2022. He also served as president of the Japan Society for Industrial and Applied Mathematics (JSIAM), director of International Association of Cryptology Research (IACR), and a program chair of many international conferences. He received the best and life-time achievement awards from the Institute of Electronics, Information and Communication Engineers (IEICE), the distinguished lecturer award from the IACR, the Purple Ribbon Award from the Japanese government, the RSA Conference Award, and the Asahi Prize.

Spatial-mode Optical Measurement Technology to Support Diverse Global Services in the Future

Atsushi Nakamura
Distinguished Researcher, NTT Access Network Service Systems Laboratories

Abstract

Communication traffic continues to increase each year and to continue to support this demand in the future, it will be necessary to shift from conventional single-mode fiber to next-generation optical fiber lines, utilizing multi-core and multi-mode fiber. However, to implement high-quality next-generation optical fiber lines requires consideration of different physical phenomena than those considered in the past. We spoke with Distinguished Researcher Atsushi Nakamura about his spatial-mode optical measurement technology, which can visualize and grasp such phenomena.

Keywords: optical measurement technology, spatial modes, optical-fiber transmission line

Spatial-mode optical measurement technology is essential for high-quality, next-generation optical-fiber transmission lines

—Can you tell us what "next-generation optical-fiber transmission lines" are?

Communication traffic has continued to increase in recent years, and society's demand for more capacity on optical fiber networks is increasing. Transmission methods on conventional optical fiber networks have used single-mode fiber, meaning a single optical fiber carried only one optical signal. However, we are approaching the limits of per-fiber transmission capacity for single-mode fiber, which will make it difficult to increase transmission capacity in the future. As such, new transmission methods that overlap multiple signals spatially will be needed in order to continue to meet the increasing demand for communication capacity in the future.

The simplest method for spatially overlap signals is to build multiple conventional single-mode fiber transmission systems in parallel. However, with this method, increasing the transmission capacity by a factor of N would also increase the cost by a factor of N, which would not be practical or economically feasible. Thus, to continue increasing transmission capacity, methods incorporating multiple cores within a single optical fiber, and methods that create multiple optical signal paths (spatial modes) within a single core (space-division multiplexing) are being studied (**Fig. 1**).

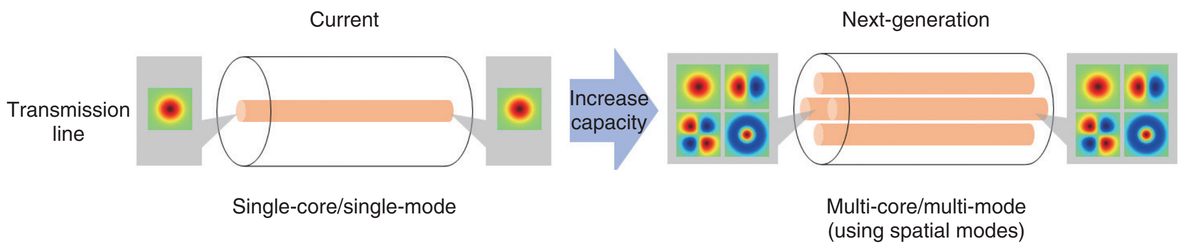


Fig. 1. Next-generation optical fiber technology using spatial modes.

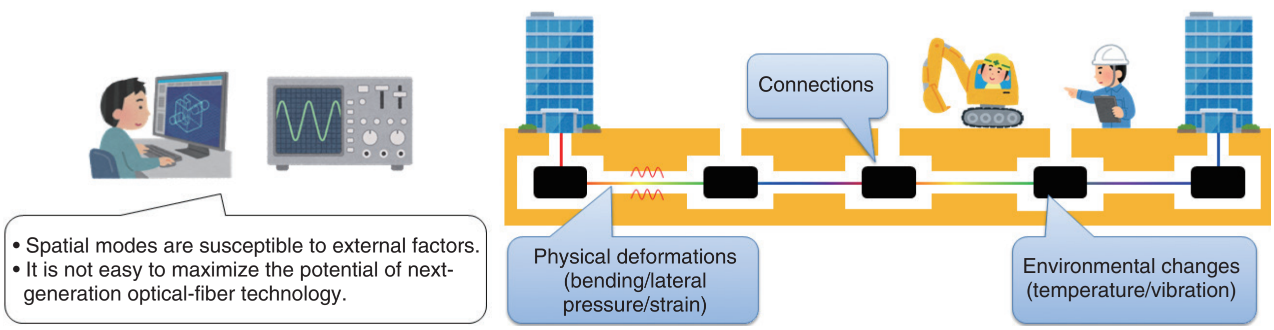


Fig. 2. External factors when constructing optical-fiber transmission lines in real environments.

—Can you tell us about any difficulties encountered in implementing next-generation optical-fiber transmission lines?

Next-generation optical fiber is a promising technology for dramatically increasing the transmission capacity of a single optical fiber, but it is not easy to implement transmission lines that can maximize this potential. With conventional single-mode fiber, communication uses only a single spatial mode, so when creating a transmission line with single-mode fiber, quality could be ensured mainly by evaluating losses in the optical signal. However, multiple spatial modes are used for communication in next-generation optical fiber, so in addition to optical signal losses, it is necessary to consider complex optical characteristics such as interference and loss differences between the spatial modes. These characteristics are susceptible to external factors, so even the smallest changes can alter their behavior. To maximize the potential of next-generation optical-fiber technology, it is important to evaluate how these complex optical characteristics change due to external factors, and to create optical-fiber transmission lines that minimize the effects of such changes. For these reasons, it is extremely important to have optical measurement technology that can visualize the quality of transmission lines.

Additionally, creating optical-fiber transmission lines in real environments introduces various external factors, including physical deformation due to bending, lateral pressure, and strain; optical fiber connections; and environmental factors such as temperature and vibration (**Fig. 2**). For example, when the two communication buildings on the left and right in Fig. 2 are connected, an optical-fiber transmission line is created by installing several kilometers of optical cable through conduits, with successive connections between them. If there are any quality issues with connections or other factors when building this transmission line, it will need to be rebuilt to ensure communication quality. If any issues are detected after the entire transmission line has been built, manual work to re-connect, or to remove and reinstall optical cables will be required. To avoid the additional effort of redoing this work requires testing the quality every time a connection is made.

The difficulty here is the need to evaluate characteristics at any point along the transmission line from one end of an optical fiber cable, while the transmission line is being built. This is because optical cables and connection points are on outdoor and underground segments when building a transmission line and it is not operationally practical to transport measurement equipment to each location. As such, we require measurement equipment that can be placed within the communication facility buildings and can evaluate the quality of the line being built at any distance from the building. Establishing this sort of optical measurement technology will enable us to build and operate next-generation optical-fiber transmission lines with a thorough understanding of spatial-mode characteristics and will contribute to taking the lead globally in implementing next-generation ultra-high-capacity optical communication services.

—Specifically what sort of research are you conducting to implement these next-generation optical-fiber transmission lines?

A specific area of research has involved devising and verifying testing methods to be used when building optical-fiber transmission lines with multi-core fiber, which has multiple cores within a single optical fiber. If the spacing between cores becomes too narrow, optical signals can leak between the cores (causing "crosstalk") and can degrade communication quality when creating multi-core fiber transmission lines. The effects of such crosstalk on communication quality can vary greatly depending on the quality of work when performing construction in real environments, so it is necessary to evaluate such effects at every stage of transmission line construction. If such tests are not done and poor quality is identified only after construction is completed, the line may have to be rebuilt, as mentioned earlier, incurring great additional time and expense. However, directly measuring crosstalk requires very expensive equipment, which is a major obstacle for businesses. Existing single-mode fiber will continue to be used even after multi-core fiber is introduced, so new equipment will also need to be compatible with single-mode fiber. For these reasons, we also devised and verified a method to evaluate changes in crosstalk characteristics based on loss values that can be measured using an ordinary optical-pulse tester, which is also used for testing single-mode fiber. This enables us to use existing equipment to ensure construction quality when building next-generation optical-fiber transmission lines using multi-core fiber in real environments.

Explaining spatial-mode characteristics, establishing methods to evaluate transmission-line quality, and creating new added value

—Could you tell us about your research objectives and vision for the future?

Next-generation optical-fiber transmission line technology is an important technology for achieving "125x transmission capacity," which is one of the performance objectives for the All-Photonics Networks (APN), as part of the Innovative Optical and Wireless Network (IOWN) plan. The optical measurement technology that I am currently researching to visualize spatial-mode characteristics and behavior will contribute to building and operating next-generation optical-fiber transmission lines with high capacity and stable communication quality. In future research, we hope to realize a world in which next-generation optical-fiber transmission lines are used continuously as indispensable social infrastructure to support all kinds of services around the world.

In a future initiative, I would like to be able to fully control spatial modes so that they can be used for optical measurements. I do not have concrete ideas for this technology yet, but I think we should be able to create new optical measurement technologies using the characteristic of spatial modes that they are sensitive to minute changes. For example, no changes can be observed before an earthquake using existing optical measurement technologies, but it may be possible to use spatial modes to take measurements and visualize phenomena that could not be observed earlier. Using spatial-mode characteristics could contribute to early detection of disasters in this way, or to solving other societal issues (**Fig. 3**).

—What are some important aspects of research for you?

I conduct research with the idea that technology does not produce any value until it is used by someone. Research is the first step, and I am careful to consider where what I am researching will ultimately be used, what it will be useful for, what approach will achieve it, and what impact all of these will have on my final objectives. Research also involves competition with other institutions, so a sense of momentum and urgency is important. Of course, we want to take the time needed to produce good technology, but there is always the chance of being second to the market, which reduces the value of the technology. To

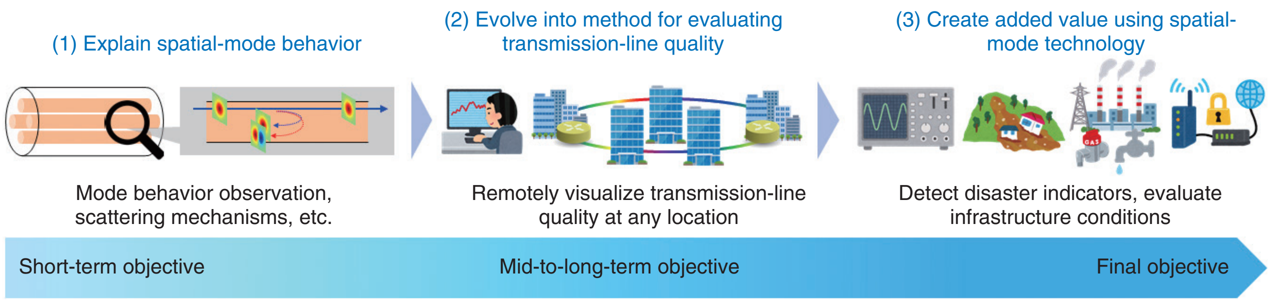


Fig. 3. Initiatives and objectives in spatial-mode optical measurement technology.

avoid such an outcome, I set objectives and priorities to be the first to achieve them. I also approach research with the intention of always producing a result in the form of a patent or published paper on the subject being studied. Including other group companies, NTT is a large corporation, so what we research can be made into something that is actually put to use within the group. This makes it possible to accumulate results that have been implemented, which gives me a sense of the value of my efforts and experience.

The ability to produce good results is not something we are born with, but is determined by our knowledge and experience. Especially now, technology and conditions in society are changing quickly, and what is needed changes accordingly. Under such conditions, insufficient preparation and effort can result in missed opportunities, so I try to maintain steady effort in my studies. Even for business or events that initially seem unrelated to my research, I always try to find something that I can get from them, because changing my perspective can provide a chance to gain a new way of thinking or new experience.

—Dr. Nakamura, please leave us with a message for other researchers, students, and business partners.

NTT Access Network Service Systems Laboratories, where I work, has wide ranging initiatives from basic research to applications, mainly in communications infrastructure technology. There are many excellent researchers, each with different knowledge and experience, so I have strong connections in many fields, and by conducting research as a team in such an environment, I can achieve things I could not do as an individual. I feel this is a real strength of NTT. As I continue my research, I always feel that it would be difficult for me to produce major results by myself, and my social connections are extremely important for the smooth progress of my research. As an example, for research it is important to collaborate with people in many fields, but if I have no relationship with someone and suddenly try to ask them to do something new, they basically would not listen to me. For starting new research, it is very important to build a broad network. When someone has a network in another laboratory within or outside of NTT, it can also help to make connections through them. Having people with many connections around me in this way also helps me to steadily advance my research.

When research advances to a completed product or technology, no matter how good it is, the result will be meaningless if we cannot describe it to users in a way that makes them want to use it. Someone with experience in business will have better skills in this area than a researcher like me. I am also very thankful that I can collaborate with people around me who are skilled at tasks that I cannot do myself.

I suppose there may be young researchers reading this who would like to stay inside their own world doing their research. When I was a student, I don't think I was very courteous with people that seemed unrelated to my research either. However, after entering the work-force, we sometimes meet people that do not seem to have anything to do with our research, or even have to work with them on research, and this can lead to new and different opportunities. I hope that you will always value the connections you have with the people you meet, to find as many opportunities as possible and not miss any.

■ **Interviewee profile**

Atsushi Nakamura completed a master's degree at Osaka Prefecture University in 2012 and joined NTT the same year. He completed a Ph.D. at Osaka Prefecture University in 2018. He has been a distinguished researcher at NTT Access Network Service Systems Laboratories since 2022, conducting research on optical measurement technology and contributing to realizing next-generation optical-fiber transmission lines. He has received awards including a 2018 IEICE Young Researcher's Award.

IOWN1.0—Start of IOWN Service

Akira Shimada
President and Chief Executive Officer, NTT Corporation

Abstract

This article introduces the Innovative Optical and Wireless Network (IOWN) service that is due to launch in March 2023. 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—Road to IOWN 2022" held from November 16th to 18th, 2022.

Keywords: IOWN, APN, Digital Twin Computing

1. The future is a data-driven society

With the spread of Internet of Things (IoT) and new digital services, we are rapidly transforming into a data-driven society, where analysis and actions are based on data. In addition to the vast increase in volumes of data handled in this data-driven society, it is anticipated that the power consumption required for data processing will increase significantly.

In terms of data volume, to watch a video in full high definition, for example, requires broadband speeds of 1.5 Gbit/s, but to watch the same video in 16K requires speeds approximately 750 times faster. It is anticipated that the extended reality of the metaverse will grow rapidly, and the move from two-dimensional (2D) to 3D data will necessitate an approximately 30-fold increase in data volume. More and more aspects of our lives will also be networked as part of IoT. It is projected that the number of IoT devices in use will increase 5-fold, from approximately 27 billion in 2017 to 125 billion by 2030 (**Fig. 1**).

Let's take a look at the expected increase in energy consumption. Datacenter energy consumption in 2018 stood at 14 TWh in Japan and 190 TWh globally. However, as more data migrates to the cloud, by 2030 it is anticipated that energy consumption will increase significantly, increasing 6-fold in Japan to 90 TWh and 13-fold globally. When we factor in the various new services that will begin to appear, along with the existing services such as large-volume storage and video streaming which today can be used without problems on current high-speed communication networks, extremely lower latency will be essential to enable, for example, the adoption of virtual reality and augmented reality (VR/AR) robots and autonomously driven drones. In VR, unless latency of less than 20 ms is achieved, images appear slower than human movement, causing VR motion sickness. Looking at all the statistical data it is clear that data volumes and energy consumption are anticipated to increase significantly (**Fig. 2**).

The Innovative Optical and Wireless Network (IOWN) will resolve the challenges relating to data volume, energy-consumption increases, and network latency. Specific performance targets for IOWN are 100 times more energy efficiency and have 125 times more transmission capacity and 1/200 end-to-end latency.

2. All-Photonics Network services (low latency and high capacity)

In the first phase of IOWN services (i.e., IOWN1.0), we will launch All-Photonics Network (APN) services in March 2023. They will be 100-Gbit/s leased line services that will provide users with exclusive end-to-end access to optical wavelengths. The service

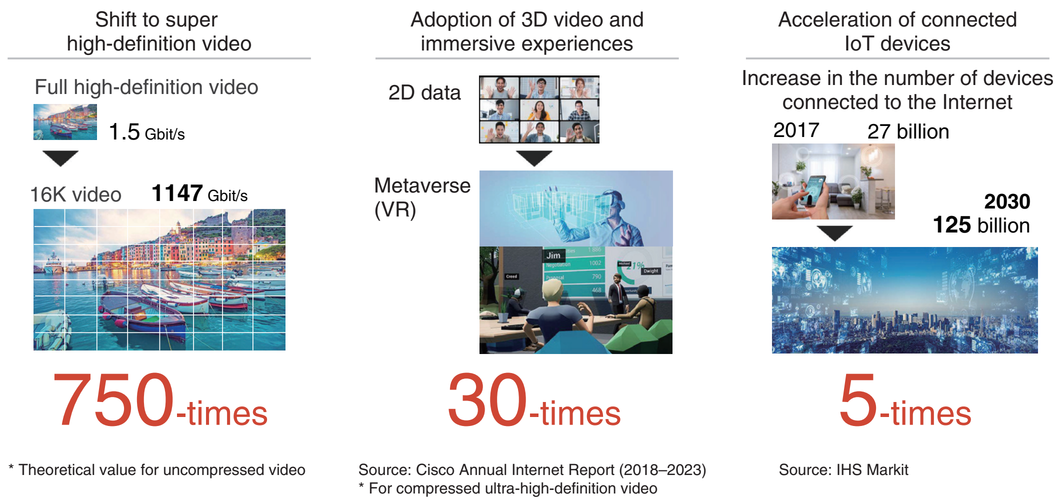


Fig. 1. Why will data volume increase?

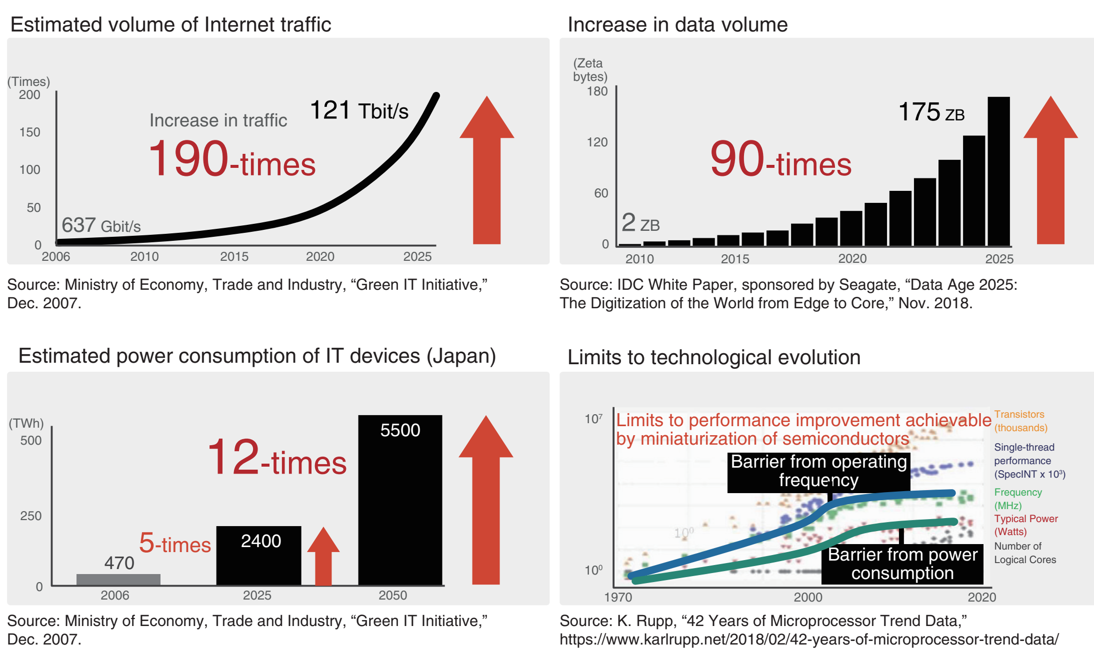
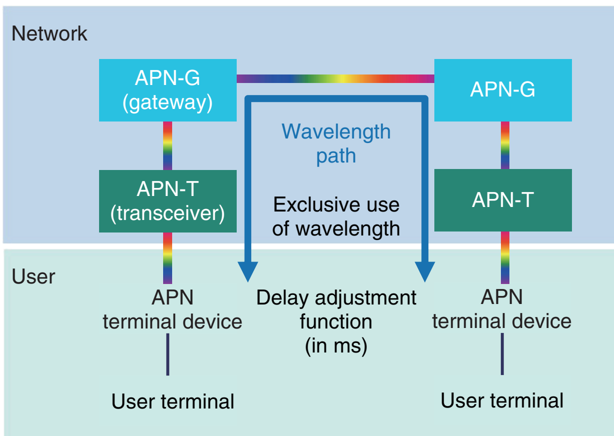


Fig. 2. Statistical data.

specifications are shown in **Fig. 3**. The key features of IOWN1.0 APN services are low latency and high capacity. In terms of capacity, a 1.2-fold increase will be provided. Because of transmission as optical wavelengths, latency can be reduced to just 1/200th of current services. In other words, IOWN1.0 will achieve the performance targets initially set for IOWN. Latency fluctuations will also be eliminated. With Internet protocol (IP) and Ethernet service latency fluctuations, it is difficult to predict latency with any certainty, which in turn presents challenges for conducting detailed and complex operations remotely. With IOWN1.0 APN services, latency fluctuations will be eliminated, making it possible to predict a consistent level of latency, and this predictability can be applied to many different services. The

- 100-Gbit/s leased line
- Users exclusively use an optical wavelength end-to-end.
- APN terminal devices enable visualization and adjustment of delay.



Provider		NTT EAST, NTT WEST
Communication mode		Point-to-point (to be expanded to point-to-multipoint*1)
Unit of service area		Within prefecture (to be expanded to cover areas spanning prefectures*1)
Interface		OTU4 (100 Gbit/s) (to be expanded to other interfaces*1)
Basic functionality	Bandwidth quality	Guaranteed (exclusive use of wavelength)
	Frame transparent transfer	Unlimited
	Link disconnection transfer	Available
	Delay adjustment*2	Available
Operation and maintenance	Fault report reception and monitoring	24/7
	Fault notification	Available (by e-mail)

*1 The required devices are installed on the basis of service applications.
*2 Provided by terminal device

Fig. 3.   IOWN1.0 APN services start in March 2023.

capability to visualize and adjust latency means that even when connecting between remote locations it is possible to synchronize timing.

I would now like to give four examples of the ways APN services can be used. First is the field of remote medicine. Low and unfluctuating latency enables the stable operation of precision robots. We believe that this will significantly expand opportunities for remote surgery. We are currently engaged in joint experiments with Medicaroid Corporation, which manufactures and sells the hinotori™ surgical robot system, and together we plan to contribute to the development of community medicine.

Let's take a look at another example involving the use of robots, i.e., a smart factory. We are looking into the possibilities for operating chemical plants remotely. Chemical plants are enormous and maintenance is very demanding in terms of staffing requirements. It is in these plants that we are planning to use APN services to conduct detailed operations remotely, such as checking equipment and fine-tuning valves in elevated locations and explosion-proof areas.

The third example is in e-sports. In e-sports games, where split seconds make the difference between winning and losing, using the low and unfluctuating latency of APN services will make it possible for players in remote locations to enjoy stress-free and fair play.

The fourth example is connectivity between datacenters. Using APN services to connect regional datacenters and hyperscale datacenters with high-capacity and low-latency connectivity will make it possible for all locations to be handled as if they were a single datacenter.

3. Photonics-electronics convergence devices (low power consumption of the APN and servers)

Next, let me explain the status of the development of a photonics-electronics convergence device that will help achieve low energy consumption. Our APN services will ensure low latency, but perhaps the most significant point about IOWN is improvement in energy efficiency. The key element behind this efficiency boost is the photonics-electronics convergence device. Photonics-electronics convergence is the fusion of optical and electrical circuits to improve performance in various ways, including miniaturization and efficiency as well as boosting speed and lowering energy consumption. By applying photonics-electronics convergence to networks as well as

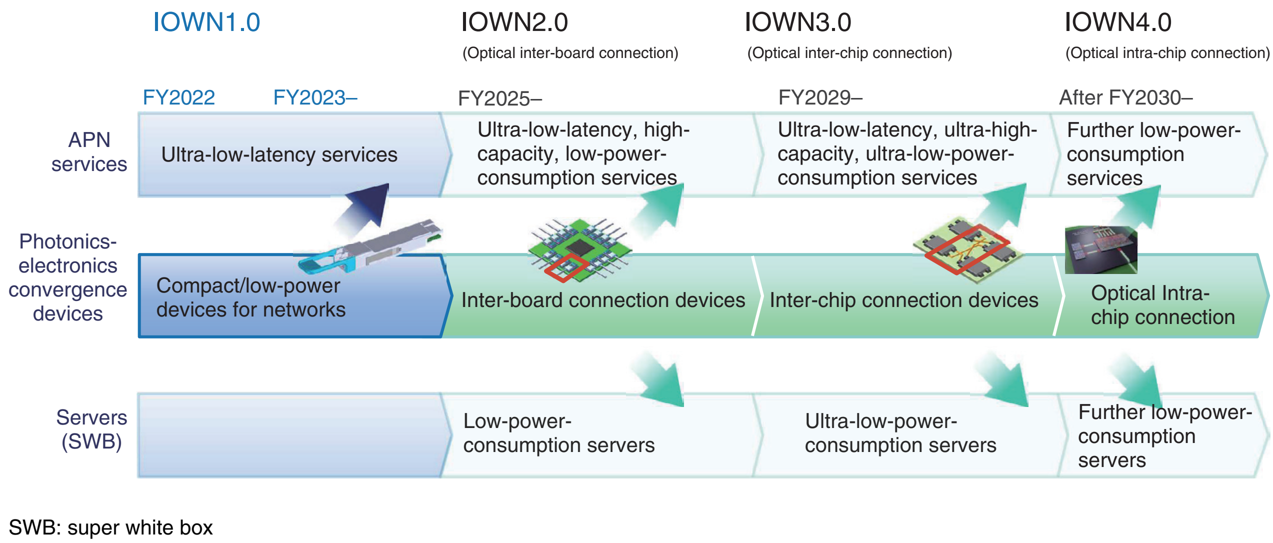


Fig. 4. Services for photonics-electronics convergence devices.

the world of computing, we are seeking to achieve major reductions in energy use.

In our roadmap to the implementation of photonics-electronics convergence devices, by FY2023 we aim to have a miniaturized, low-power-consumption device for networks ready for commercial use. We are seeking to reduce power consumption by incorporating what used to be multiple devices into a single, significantly miniaturized package. Specifically, we are planning to have a commercial 400-GB device ready in FY2023 and 800-GB device available in FY2025. Additionally, as devices become smaller, this will enable the miniaturization of network devices, such as transmission equipment, which will lead to simplified operations.

In FY2025, we plan to commercialize board-connecting devices that will enable the use of optics for board-to-board and board-to-external interface connections. These advances will make it possible to use photonics-electronics convergence in computing. By FY2029, we aim to use photonics-electronics convergence technology to connect chips within boards, and from FY2030 onwards achieve in-chip connectivity. By applying such photonics-electronics convergence devices to APN services and servers, we will further refine and improve IOWN. In FY2023, we will launch a miniaturized and low-power-usage networked device in our APN services, further helping to boost their energy efficiency (**Fig. 4**).

As part of IOWN2.0, from FY2025 we plan to expand the scope of application of board connection devices to include not just APN services but also servers. Under our current schedule, by FY2026 the plan is to develop a commercially feasible low-energy-consumption server using such a photonics-electronics convergence device. As part of IOWN3.0, by FY2029 the aim is to have developed chip-to-chip devices, and from FY2030 or thereafter, as part of IOWN4.0, to achieve optical intra-chip connection, thus significantly reducing power consumption.

In addition to these photonics-electronics convergence devices, and taking into account anticipated improvements in wavelength and optical fiber technologies, for IOWN2.0 from FY2025, we plan to achieve a 13-fold increase in energy efficiency in the APN sector, an 8-fold increase in efficiency in the server sector, as well as a 6-fold increase in capacity. From FY2029, with IOWN3.0 we anticipate further performance improvements and predict that we will be able to achieve a 125-fold increase in capacity. Although energy efficiency depends on the rollout of technology to devices, from IOWN2.0 we expect to be able to improve performance, achieving a 20-fold increase in the server sector compared with current levels. What is more, from FY2030 and beyond, with IOWN4.0 we are seeking to boost energy efficiency 100 times overall, enhance capacity 125 times, and achieve our target for latency of 1/200th of current levels.

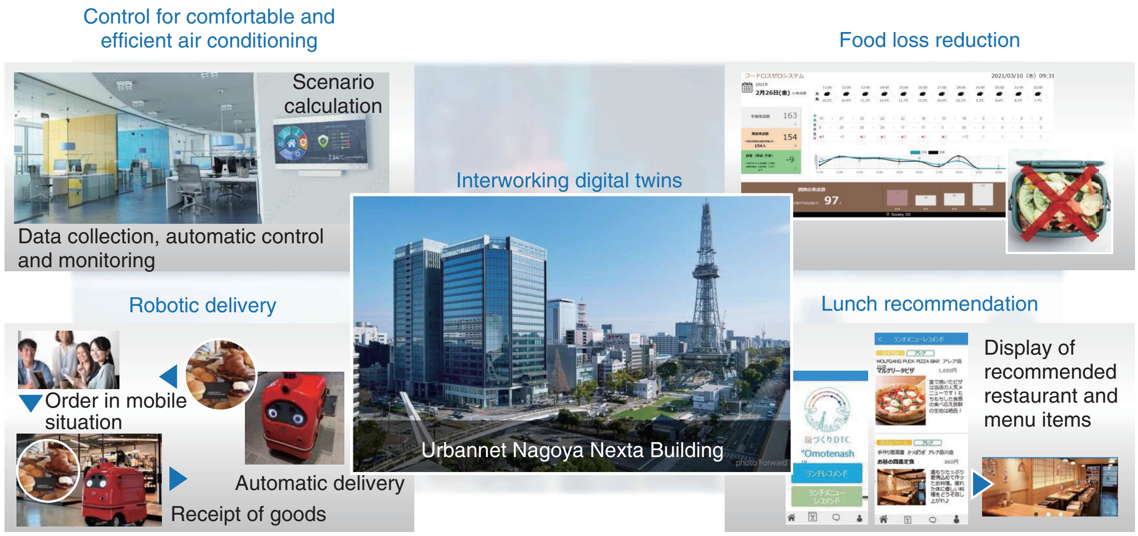


Fig. 5. Urban development using Digital Twin Computing.

4. Digital Twin Computing

Next, let me say a few words about Digital Twin Computing, which is another IOWN technology. The IOWN framework consists of the APN and server infrastructure, of which photonics-electronics convergence devices are a component, as well as Cognitive Foundation and Digital Twin Computing technologies. Cognitive Foundation means the optimization of all information and communication technology resources and their operation and control. Digital Twin Computing is the ability to predict the future and optimize by combining digital twins in the real and digital worlds. Digital Twin Computing is the process of taking various digital copies of people, objects, and things in real space and expressing these digital copies in cyberspace, using them to perform data analysis and simulations such as predictions about the future. On the basis of the results, the optimal methods and actions are then fed back to the real world to help improve processes and decisions to address challenges in real situations. For example, by linking data on people flows and traffic volumes with basic data on the urban environment, it will become possible to create conditions for controlling an optimal transportation environment.

Let me introduce a real example of how Digital Twin Computing is being put to use in urban development. Since FY2022, we have been conducting an urban development pilot project at Urbannet Nagoya Nexta Building using Digital Twin Computing (**Fig. 5**). At Urbannet Nagoya Nexta Building, we are testing a new initiative to link four services, i.e., air-conditioning control, food loss reduction, robotic delivery, and lunch recommendation, and optimize them on the basis of predictions using Digital Twin Computing.

As you can see, urban development using Digital Twin Computing has already begun. Although currently still in the pilot stages, we plan to commercialize solutions for air-conditioning control and food loss reduction by the end of FY2022. By further expanding our services and deploying them in various urban environments, we aim to contribute to urban development that benefits both people and the global environment.

5. Concluding remarks

Finally, let me share with you that at Expo 2025 Osaka Kansai, Japan, NTT plans to present a real-world pavilion and virtual platform to be called “Floating Yumeshima” where every life shines. We hope to be able to announce the launch of IOWN2.0 services at the Expo, so please keep following our progress.

Road to IOWN – Light Up –

Atsuko Oka
Executive Vice President,
Head of Research and Development Planning Department,
NTT Corporation

Abstract

This article introduces research and development efforts and the latest results on the Innovative Optical and Wireless Network (IOWN). It is based on the keynote speech given by Atsuko Oka, executive vice president, head of the Research and Development Planning Department of NTT Corporation, at the "NTT R&D Forum—Road to IOWN 2022" held from November 16th to 18th, 2022.

Keywords: IOWN, APN, photonics-electronics convergence

1. Welcome to NTT R&D Forum

At this NTT R&D Forum titled "Road to IOWN 2022," more than 90 exhibits and 5 lectures were streamed. The exhibits were divided into three categories: "IOWN Now," "IOWN Evolution," and "IOWN Future." The respective exhibits introduced the Innovative Optical and Wireless Network (IOWN) available now, the world and related technologies envisioned by 2030, and the technologies beyond that.

We again held the exhibits virtually as part of our measures against COVID-19. However, some exhibits were shown in-person by reservation and invitation only. This was our third year holding the forum online. Many participants from previous forums commented that the long list of exhibits made it difficult to find those of interest to them. Many people also asked us to summarize the key points of the technologies. Therefore, we asked someone who is not in the research and development (R&D) field to create illustrations that will help to visualize and understand the content. Therefore, participants were able to find exhibits close to their interests more quickly.

Before I discuss the highlights of this forum, I would like to recap the IOWN initiative. The key element is optical technology. The concept is to create a smart world that promotes well-being through Digital Twin Computing (DTC). DTC adopts a new network and computing infrastructure using high-speed and low-power-consuming optical devices to process, analyze, and use massive data.

Let me explain the All-Photonics Network (APN) that uses optical technology. You may be asking, aren't we already using optical fiber for communications? The answer is 'yes,' but it requires many electro-optical conversions along the communication path. It is like changing trains (**Fig. 1**). We are changing this to a direct optical path. It will be like taking a direct train. This will enable the creation of a higher capacity, lower latency, and more secure network than what currently exists.

By changing the wavelength, i.e., the color, of light, separate networks can also be created within a single fiber. One network may be for traditional Internet protocol, another for medical protocol. Therefore, function- and role-specific networks can be created.

Optical communications go inside the computer. By connecting the card level with optical waveguides, we can get rid of the server chassis. Optical lines have extremely low distance attenuation,

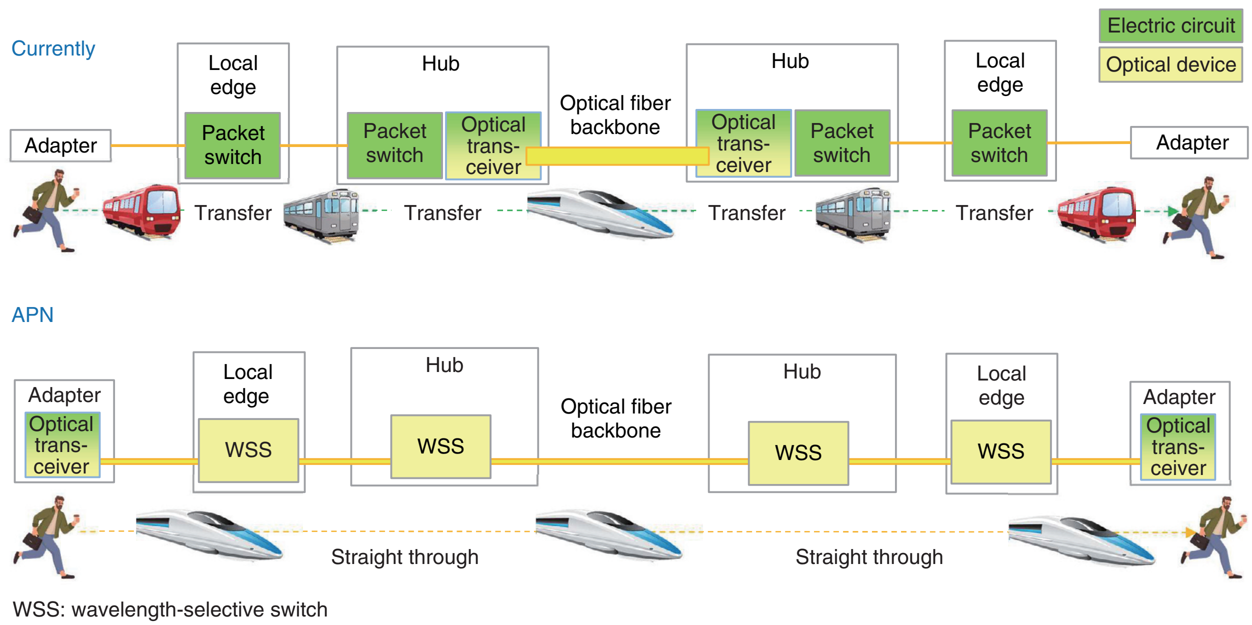


Fig. 1. All-Photonics Network (APN).

allowing for greater parallel computing and memory sharing than before. By creating intra-board optical waveguides, we can also eliminate the board walls and achieve a powerful computing system. We call this *photonic disaggregated computing*.

2. Where did IOWN actually originate from?

I am often asked, "When did NTT consider the IOWN initiative?" It was prompted by NTT's development of an optical transistor, announced in April 2019. This instantly sped up the discussion on IOWN and led to its announcement. However, the idea of light impacting not only communications but even computing is not a new one. Believing in its feasibility, NTT has continued to research light since the 1960s. When I was reviewing this history, I found an interesting article from 1988, more than 30 years ago, the year I joined the company. It was included to a journal of the Institute of Electrical Engineers of Japan (IEEJ) for their 100th anniversary issue by our researchers at the time. Chapter 3.1 of the article is titled "Optical interconnection," which refers to board-to-board and chip-to-chip connections by light, and embodies the very idea of photonic disaggregated computing. Chapter 3.2, "Computing with coherent optics," is about building a physical machine. This led to the IOWN initiative's LASOLV™ coherent Ising machine for solving optimization problems. Chapter 3.3, "Parallel digital optical computing," is about fabricating optical processors. The development of the optical transistor was a part of this. Chapter 3.4, "Optical neurocomputing," is about constructing neural networks using light. Therefore, the idea had been around even when no one knew about the significant social impact that neural network-based artificial intelligence (AI) would have. When the IOWN initiative was announced in 2019, I imagine many people wondered if NTT had lost its senses and if it was even possible. However, NTT researchers had long predicted the heralding of such an era and proceeded with their research. We have now finally reached the stage when the research findings can be shared.

3. Development plan for photonics-electronics convergence devices

I will explain our development plan for photonics-electronics convergence devices, which will be central to the actualization of the IOWN initiative. Our R&D classifies devices into five generations (**Fig. 2**).

The first generation is current networks with higher performance. The second generation is devices focused on easy handling for inter-datacenter transmission. In the third generation, light enters the

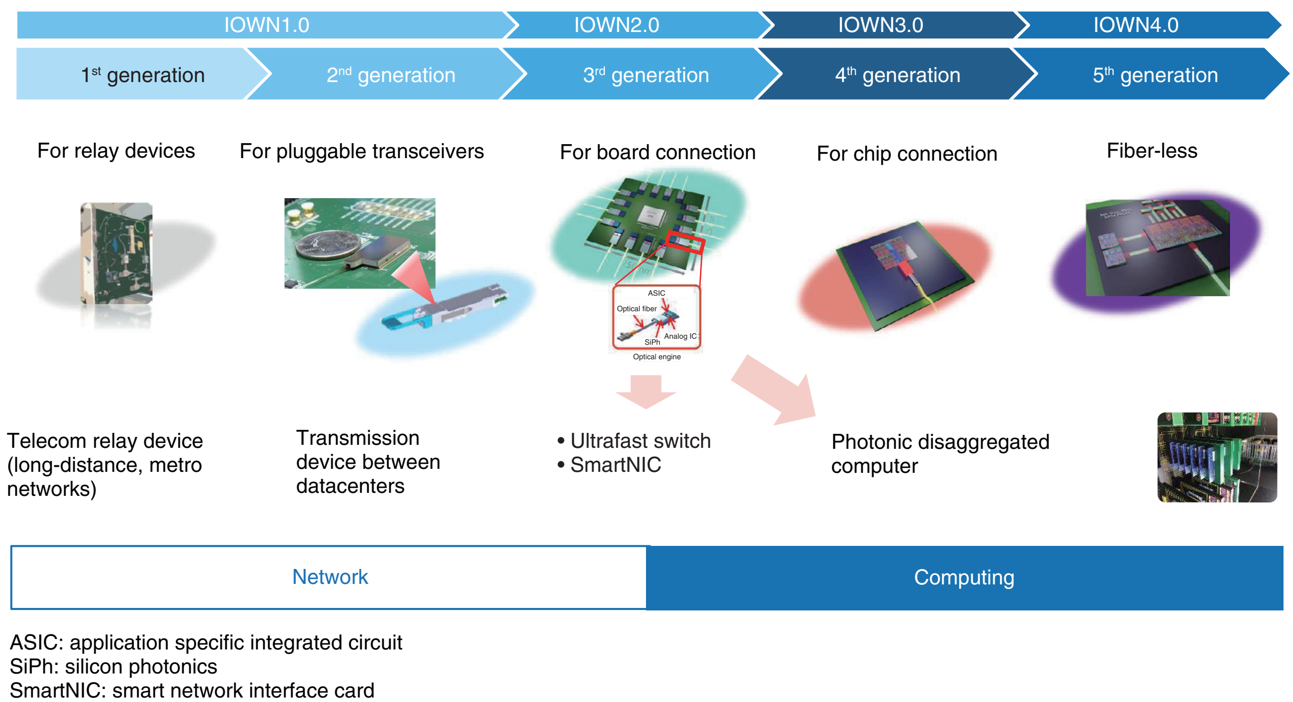


Fig. 2. Evolution of photonics-electronics convergence devices and application areas.

computing domain. Rather than computer-to-computer connections, the devices are designed for connecting their parts, board-to-board, using light. The fourth and fifth generations are respectively inter-chip and intra-chip devices where light penetrates deep into the computer. While there are still technical hurdles to overcome, we are working hard to develop these devices.

4. Light Up

I would like to move on to the progress of our research. The APN will be available as a service at the end of FY2022 (March 2023). Since the announcement of the IOWN initiative to today, we have been studying use cases and discussing necessary technical requirements with IOWN Global Forum members and other partners. Equipment compliant with the IOWN method have already been launched by member companies. The ideas that we have been brainstorming with IOWN Global Forum members have been translated into tangible form, and we are entering the phase of full-scale demonstration. The subtitle of this lecture is "Light Up." I chose this subtitle envisioning the light of IOWN being lit up and its infrastructure becoming available to you.

4.1 IOWN "Datacenter × APN"

First, I will explain IOWN "Datacenter × APN." The APN will connect NTT's laboratories in Japan and NTT Group companies' datacenters, among other facilities. Datacenters will be installed with photonic disaggregated computing, data hubs that enable data sharing, the latest security technologies, and other IOWN capabilities, in a stepwise manner. We will be conducting testing in this large, practical environment and developing services at an accelerated pace.

One of the goals of connecting datacenters with the APN is decentralization of datacenters. Datacenters are becoming increasingly larger. For large datacenters, securing land and power is a major challenge. Looking ahead to the future, a key question will be how to meet the large power requirements with renewable energy alone. To address this issue, we aim to decentralize datacenters. By connecting small and medium-scale datacenters with the APN, we aim to make computers run as if the datacenters are a single datacenter. It is inefficient to transmit valuable power over long distances. Decentralizing datacenters will be essential for the local production and local consumption of energy.

The core infrastructure for decentralizing datacenters is high-speed, high-capacity, low-latency

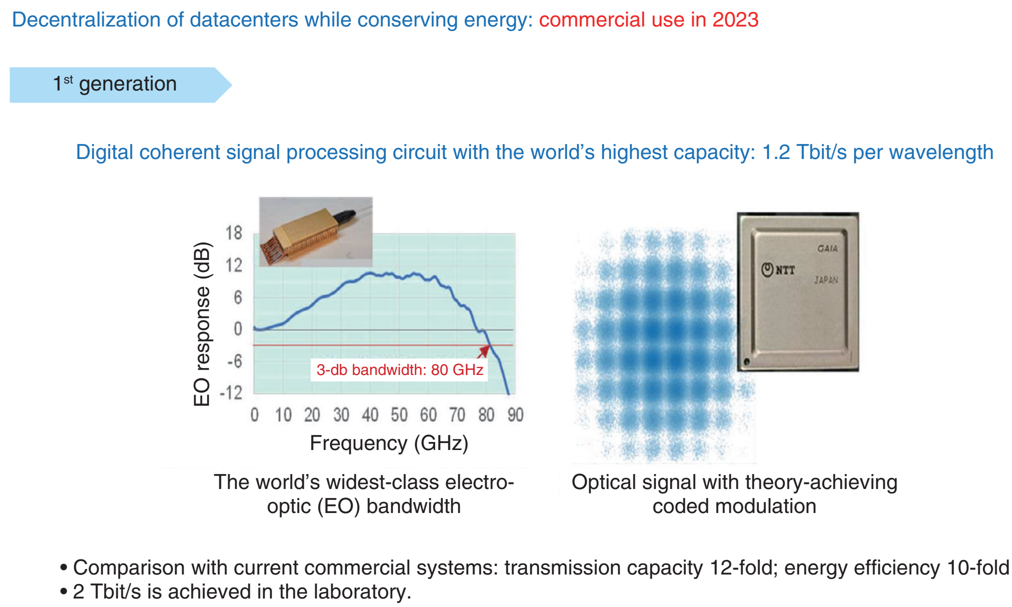


Fig. 3. Digital coherent signal processing circuit capable of optical fiber transmission at 1.2 Tbit/s per wavelength.

communications, or the APN. Let me mention two APN-related achievements.

The first is the successful development of a digital coherent signal processing circuit capable of optical fiber transmission at 1.2 Tbit/s per wavelength (**Fig. 3**). The mainstream commercial capacity is currently 100 Gbit/s. Therefore, our circuit instantly increases capacity by 12 times and improves energy efficiency per bit by 10 times. This system will be commercially available in 2023. As we announced in our press release in September 2022, we have achieved 2 Tbit/s in the laboratory. There is still much room for improvement. We will continue our research of this platform technology, which will support next-generation ultra-high-capacity communications.

Our other achievement is the successful creation of a 400-Gbit/s co-packaged optics prototype for transceivers (**Fig. 4**). This is a small, low-power-consumption device that integrates everything from signal processing circuits to optical transmission and reception functions. It is currently under development and is expected to be commercially available in 2023. We are also conducting R&D to deliver an 800-Gbit/s version, which will contribute to further energy savings in datacenters. Connecting the high-speed APN to datacenters will significantly change the way customers design future services. You have probably seen many times the picture of "AI and Internet of Things," where only mechanical and other devices are at the sites and the AI part is cloud-based. However, is this really the case? With the exception of smartphone apps, the edge is also often equipped with GPGPUs (general-purpose computing on graphics processing units) or other fairly large computing units. This is because there were many problems on the network side. We will address this issue by using the APN to connect datacenters as well as the sites and create a genuine industrial infrastructure environment. We will demonstrate that it is truly possible to make advances in AI and foster an environment that can continue to provide high-value services.

4.2 The APN transfers reality & skills

The APN is more than just an infrastructure platform for datacenters. One of the main benefits of the APN is high transmission capacity for conveying reality. For a person to perform an activity in a simulated reality, that person must be able to demonstrate their skills, which are transmitted through the APN. Information is needed to reproduce reality. This may be visual or acoustic information, or in some cases, verbal or tactile information or their combination. To reproduce reality, high-capacity communications and ultra-low latency are extremely important, which are supported by the APN next-generation network. If people can fully demonstrate their skills and these skills can be transmitted, new ways of working and engaging with society will emerge, creating new

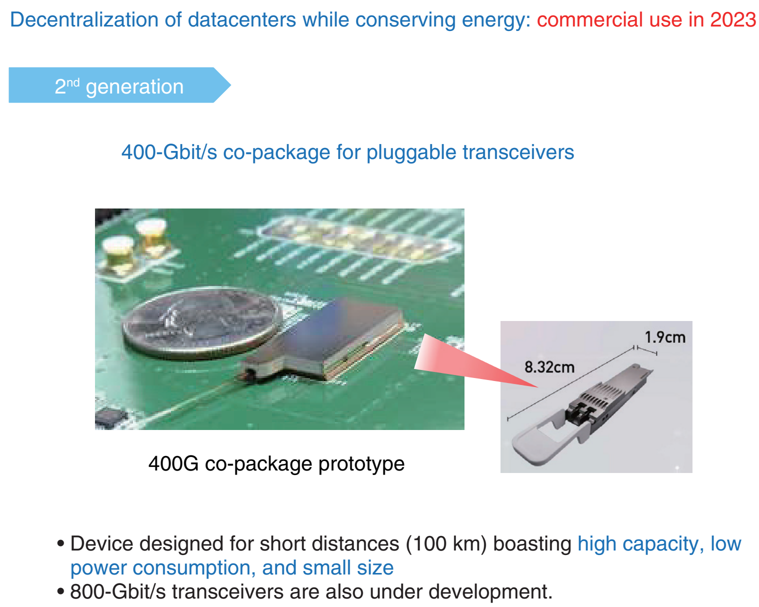


Fig. 4. 400-Gbit/s co-packaged optics prototype for transceivers.

value. We will proactively implement such initiatives to create services as quickly as possible.

The most typical use case is remote surgery, which was presented at this forum. The remote operator of the machine needs real information about the patient. In remote medicine, there are physicians, both on the side operating the machine and with the patient. Even if they are separated physically, they need to be able to communicate smoothly as one team. Whether it is transmission of clear voices or panoramic images, two-way transmission is critical to realistically convey the situation of the entire operating room, i.e., the onsite environment. The APN's high-capacity communications and low latency make it possible for people in different locations to work together as if they are in the same place.

4.3 Perspectives on the "Now" exhibits

I mentioned that the exhibits of this forum were divided into three categories and that "IOWN Now" introduced technologies that are available now. They were centered around the decentralized datacenters as well as technologies that support the APN and use cases that I have discussed. If you viewed the exhibits from this holistic perspective, I believe you gained a deeper understanding of our initiatives. In this forum, we announced that IOWN will be taking off. These are services that we have been discussing together with the members of IOWN Global Forum. The members discussed the activities of the Global Forum in a panel discussion, which was streamed during this forum. The title was "Have your ticket ready. – IOWN is taking off NOW!" As the title suggests, the members presented IOWN's initiatives that are about to get off to a flying start.

4.4 Other notable exhibits

Next, I would like to introduce other noteworthy exhibits. Since announcing IOWN, light has been the keyword of our various announcements. However, sound is another area NTT has long researched. Some people may still think of us as a telephone company. Delivering clear sound has value even now. NTT has an advantage in acoustics and voice technologies, both in conference presentations and intellectual property. I would like to mention two applications, as well as one basic research project that looks ahead to the future.

The first is acoustic communication technology. Did you know that there are drones that can maneuver underwater? There are no means of communication capable of high-capacity, long-distance transmissions underwater. Therefore, most underwater drones needed to be connected to a cable to control remotely. Sometimes they get entangled or harm organisms and the environment. We applied acoustic technology to communications and achieved 1-Mbit/s communication at a 300-m distance (**Fig. 5**). Underwater drones

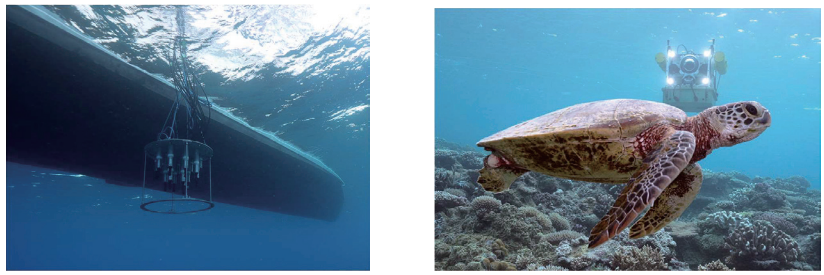


Fig. 5. Acoustic communication technology.

can now be controlled wirelessly over long distances. Technically, the shallower the water, the harder communication becomes due to sound waves bouncing off the seafloor and due to marine life. However, high-speed communications are now possible even in shallow water. At 1 Mbit/s, standard definition (SD)-quality movies can be transmitted. Since clear images can be produced, underwater drones are expected to have a variety of uses, such as inspecting underwater equipment and checking shellfish and fish being cultured.

Next is Personalized Sound Zone (PSZ) technology. Our goal is to create a sound space that lets you hear only the sounds you want to hear and not the sounds you do not want to hear. The PSZ technology exhibit presented two achievements. The first is a technology to contain the reproduced sound in a small area. Using this technology, we have created a new type of earphones. Open-ear earphones that are not placed inside the ear usually leak sound into the surroundings. With our earphones, leakage is kept to a minimum. Such earphones have been commercialized by NTT Sonority. I understand they have received very positive reviews. I use them for my online meetings. They are lightweight, so your ears do not get tired even after long use. Because they are open-ear type, you can also hear surrounding sounds, which is great. PSZ has also succeeded in cancelling out ambient noise. This technology is the active noise cancellation feature, which is available with many earphones inserted into the ear. At this forum, we showed speakers with this feature.

I would like to mention a study by NTT Research, Inc., which is based out of the West Coast of the U.S. It has been published in the scientific journal, Nature. The AI boom is supported by deep learning technology. Its many layers of neural networks learn from a vast amount of data and make outstanding predictions. Although this is usually done by computation inside a computer, the study showed that various physical systems can become multi-layered neural networks. This exhibit introduced some systems, including an interesting system that uses a microphone and speaker to create a neural network which can recognize handwritten numbers. The research findings are extremely interesting. I urge you to take a look at them.

5. Closing remarks

Today, in my presentation entitled, “Road to IOWN – Light Up –,” I discussed IOWN’s broad applications. The IOWN initiative may have been just a concept to you. This concept is becoming tangible in the current phase. We are now ready to put the ideas into action. We are committed to deepening collaboration with our partners to create concrete products and services. I invite people from the telecommunications and many other industries, academia, and government agencies to join us in creating a new future together. Stay tuned to what the future holds for IOWN.

Over 100-Tbit/s Ultra-wideband Wavelength Division Multiplexed Transmission Technologies for Future Optical Transport Network Systems

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Abstract

This article reviews trends in ultra-wideband wavelength-division multiplexing (WDM) transmission techniques for expanding the capacity of optical transmission systems. It also presents NTT's recent research and development results on ultra-wideband WDM transmission for over 100-Tbit/s transmission capacities in a triple-band (S, C, and L bands) WDM configuration.

Keywords: digital coherent, wavelength division multiplexing, digital signal processing

1. Introduction

To cope with the rapid increase in communication traffic, it is necessary to increase the transmission capacity per optical fiber while reducing the cost per bit of optical transmission systems. Innovative technologies, such as wavelength-division multiplexing (WDM) transmission with optical amplifiers and digital coherent technology with digital signal processing (DSP) [1], have continuously been expanding the system capacities for optical transmission. DSP application-specific integrated circuits (ASICs) for digital coherent technology support multi-rate and multi-modulation formats to meet the demand for multiple applications: long-haul, metro, and short-reach (particularly datacenter interconnects) networks. For example, a DSP-ASIC can execute ~32-GBaud polarization-division multiplexed (PDM) quadrature amplitude modulation (QAM) formats with modulation orders from 4 to 16 for from 100 to 200 Gbit/s/carrier [2]. Up to 600-Gbit/s/carrier with 64QAM transmission experiments have also been reported with a real-time transponder including a 64-GBaud-class DSP-ASIC [3]. NTT has recently developed a cutting-edge DSP and an optical device supporting 1.2 Tbit/s/carrier with 140-GBuad-class coded 64QAM for digital coherent systems [4].

To further increase system capacity, expanding the WDM bandwidth is effective along with high spectral efficiency (SE) signals with digital coherent technology using high-order QAM formats. A transmission of 102.3-Tbit/s with PDM-64QAM signals has been demonstrated under the 11.2-THz dual-band (C and L bands) WDM condition with an SE of 9.1 bit/s/Hz [5]. NTT has also successfully demonstrated the first ever greater than 150-Tbit/s transmission with 272-channel PDM-128QAM signals under the 13.6-THz triple-band (S, C, and L bands) WDM condition with an SE of 11.05 bit/s/Hz [6]. Both experiments were conducted using the offline evaluation technique in which DSP is carried out on workstations for transmitted and captured received signals. The offline evaluation enables detailed signal analysis of DSP methods toward ASIC implementation.

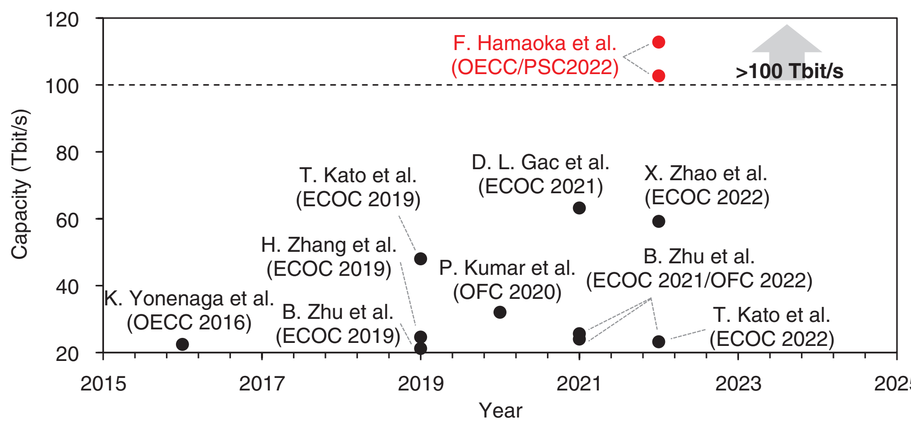

Fig. 1. Trends in capacity growth in digital coherent experiments for real-time transmission with DSP-ASIC-integrated optical transponders.

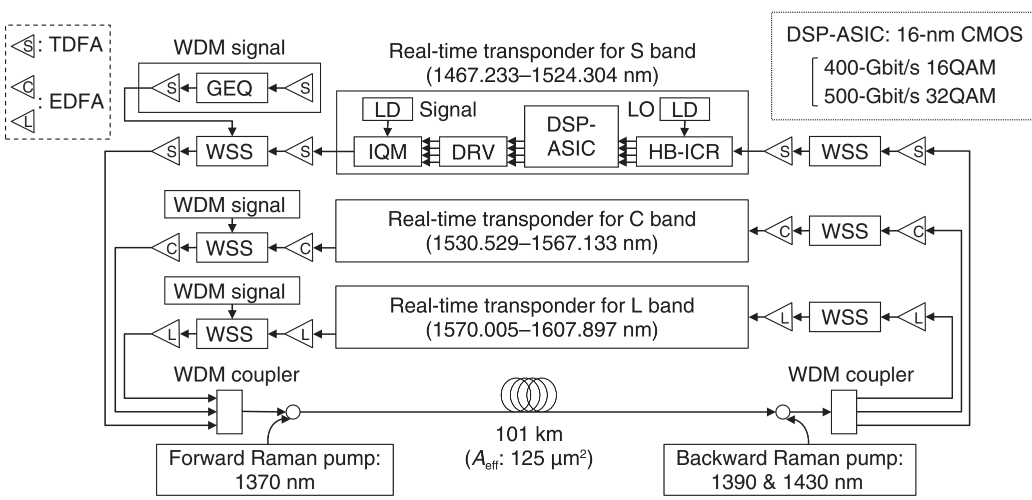

Fig. 2. Experimental setup for triple-band WDM transmission with DSP-ASIC-integrated real-time optical transponders.

In this article, we present real-time triple-band transmission with a WDM bandwidth of 16.95 THz using DSP-ASIC-integrated optical transponders. We transmitted total capacities of 102.7 and 112.8 Tbit/s using 226-channel WDM signals with 400-Gbit/s PDM-16QAM and 500-Gbit/s PDM-32QAM [7]. As can be seen in **Fig. 1**, we achieved, for the first time, over 100-Tbit/s capacity in real-time transmission experiments.

2. Experimental setup for ultra-wideband WDM transmission using DSP-ASIC-integrated optical transponders

Figure 2 shows the setup for triple-band WDM transmission experiments with real-time optical transponders. We used three real-time optical transponders having DSP-ASICs based on 16-nm complementary metal oxide semiconductor (CMOS) technology [3, 8]. The transponders were also implemented driver (DRV) amplifiers, a lithium niobate in-phase and quadrature modulator (LN-IQM), and a high-bandwidth intradyne coherent receiver (HB-ICR). Signal and local oscillator (LO) laser diodes

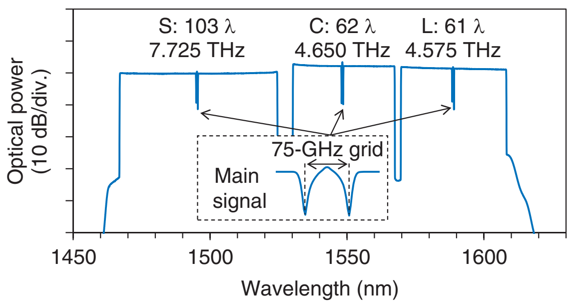

Fig. 3. WDM signal spectra of 16.95-THz bandwidth.

(LD) sources were external cavity lasers for the S band and integrable tunable laser assemblies for the C and L bands. The modulation formats of the main signal were 67-GBaud PDM-16QAM with a net rate of 400 Gbit/s and 66-GBaud PDM-32QAM with a net rate of 500 Gbit/s, which were generated in the optical transponder for each WDM band. The carrier frequency of the main signal was set to 1467.233–1524.304 nm in the S band, 1530.529–1567.133 nm in the C band, and 1570.005–1607.897 nm in the L band.

The WDM signals in the S, C, and L bands were generated using amplified spontaneous emissions from the thulium-doped fiber amplifiers (TDFAs) and erbium-doped fiber amplifiers (EDFAs). The power level of the WDM signal was equaled using a gain equalizer (GEQ) on the basis of flexible-grid wavelength selective switches (WSSs) with liquid crystal on silicon (LCOS). TDFAs for the S band and EDFAs for the C and L bands were used in this experiment. The main signal from the real-time optical transponder and WDM signal for each band were multiplexed in a LCOS-based flexible-grid WSS. The WDM grid in this experiment was set to 75 GHz. The WDM signals in the S, C, and L bands were then multiplexed in a WDM coupler with a total bandwidth of 16.95 THz (7.725, 4.650, 4.575 in the S, C, and L bands, respectively), as shown in **Fig. 3**. The total number of WDM signals was 226 channels (103, 62, and 61 channels in the S, C, and L bands, respectively). The triple-band WDM signal was transmitted through the transmission line of a 101-km large-core low-loss fiber, which is compliant with ITU-T (International Telecommunication Union - Telecommunication Standardization Sector) G.654.E, with an effective area (A_{eff}) of 125 μm^2. We used a forward (FW)-pumped distributed Raman amplifier (DRA) at a wavelength of 1370 nm and a backward (BW)-pumped DRA at 1390 and 1430 nm.

The triple-band WDM signal was divided into each S-, C-, and L-band WDM signal after 101-km optical fiber transmission. The WDM signals were then amplified using a TDFA for the S band and EDFAs for the C and L bands at the receiver side to compensate for the transmission losses. After filtering the main signal for each S, C, and L band using a LCOS-based flexible grid WSS, the signal was coherently detected with the HB-ICR with the optical LO. Finally, the received signal was equalized, demodulated, and decoded in the DSP-ASIC [3].

3. Experimental results of over 100-Tbit/s real-time transmission

In the ultra-wideband WDM configuration, inter-band stimulated Raman scattering (SRS) affects the WDM signals. A nonlinear interaction is caused by inter-band SRS in bands with a gap of around 100 nm for ultra-wideband transmission systems; inter-band SRS causes a signal power transition from S- to L-band signals in triple-band transmissions [6]. Therefore, we evaluated the effect of inter-band SRS with the 16.95-THz triple-band WDM configuration. The fiber loss at 101 km and transmission loss with inter-band SRS are shown in **Fig. 4**. The signal-power transition was mainly observed from the S band to the L band.

Figure 5 shows the experimental results in 101-km real-time triple-band WDM transmission. The FW- and BW-pumped DRA were applied for the transmission line to compensate for the excess power loss in the S band caused by the inter-band SRS. As Fig. 5(a) shows, the WDM signal power in the S band was drastically increased by the Raman amplifiers with sufficient Raman amplification gain. To evaluate the signal performance, we used the pre-forward error collection (FEC) quality (Q) margin, which is defined by the difference between the measured pre-FEC Q factor in the experiments and the required pre-FEC Q factor to achieve an error-free post-FEC bit error rate (BER). We observed that the pre-FEC Q margins of all measured 226-channel WDM signals showed more than zero, as shown in Fig. 5(b). We also confirmed that the post-FEC BER of all signals were error-free in this case. That is, in this setup, we achieved 112.8-Tbit/s (= 500 Gbit/s × 224 λ + 400 Gbit/s × 2 λ) transmission using real-time optical transponders.

The long-term signal performance under the 16.95-THz triple-band WDM condition was evaluated

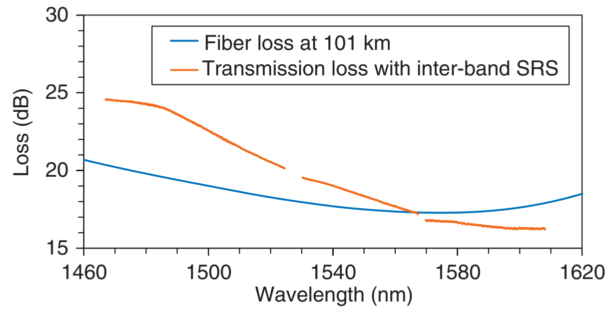

Fig. 4. 101-km fiber loss and transmission loss with inter-band SRS.

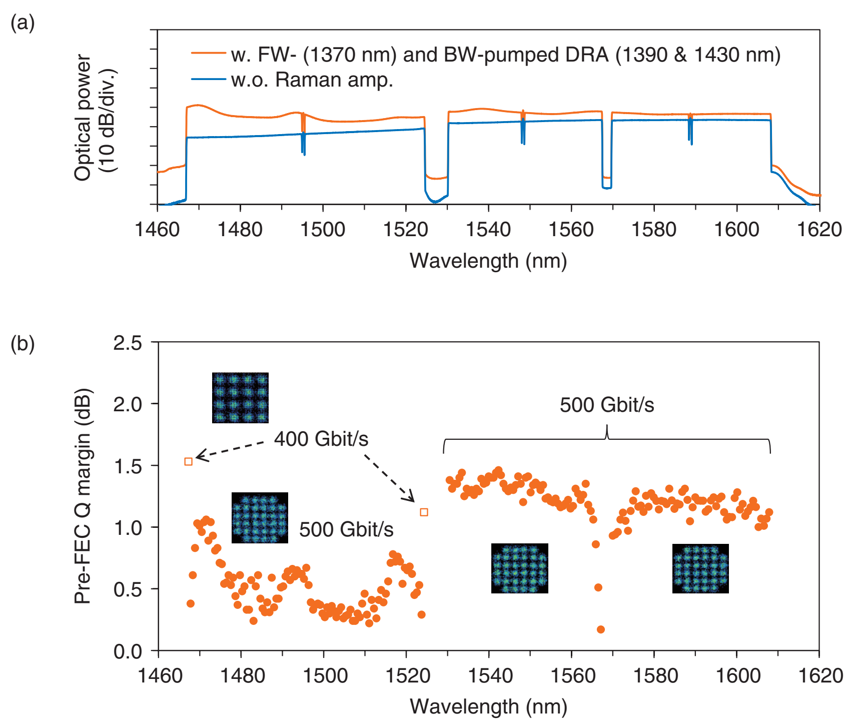

Fig. 5. Experimental results: (a) WDM optical spectra with and without FW- and BW-pumped DRA and (b) pre-FEC Q margin after 226-channel triple-band WDM transmission through 101-km fiber transmission with FW- and BW-pumped DRA.

during transmission in 101-km fiber when applying the FW- and BW-pumped DRA. As shown in **Fig. 6**, we obtained stable signal-transmission performance at the center channels of S-, C-, and L-band signals with small pre-FEC Q-factor fluctuations of less than or equal to 0.036, 0.025, and 0.037 dB, respectively, within continuous measurements for 60 min. During the stability test, we also confirmed error-free operation after FEC decoding.

4. Conclusion

We reviewed trends in ultra-wideband WDM transmission techniques to expand the capacity of optical transmission systems and NTT's latest R&D in the field. With the combination of ultra-wideband WDM transmission and digital coherent technology using the state-of-the-art DSP-ASIC, we successfully demonstrated the first ever over 100-Tbit/s real-time transmission. This technology is promising for use in

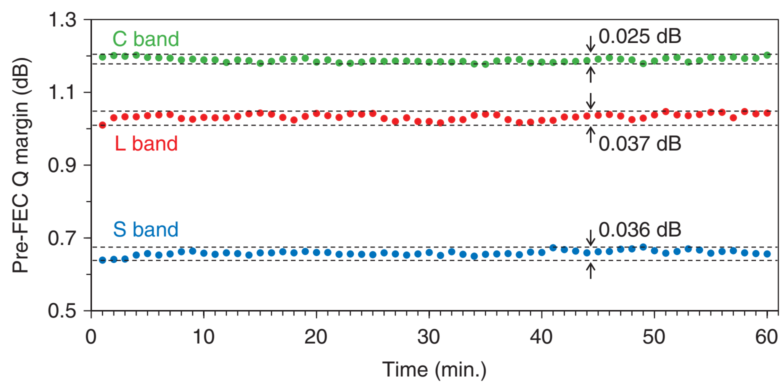

Fig. 6. Stability test for signal performance at center channels of S-, C-, and L-band signals with FW- and BW-pumped DRA during 101-km fiber transmission under 16.95-THz triple-band WDM condition within continuous measurements for 60 min.

future optical transport network systems.

Acknowledgments

This work was supported by the Ministry of Internal Affairs and Communications, "The research and development project for the Tera-bit optical network technologies towards big data era" and "Research and Development of innovative optical network technology that bears new social infrastructure (Technological Theme I) (JP MI00316)."

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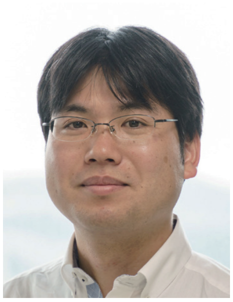

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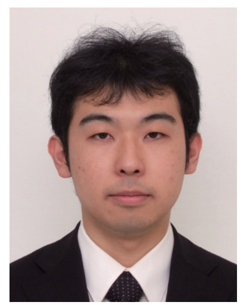

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Report of the ITU Plenipotentiary Conference 2022 (PP-22)

Memiko Otsuki and Noriyuki Araki

Abstract

The Plenipotentiary Conference 2022 (PP-22) of the International Telecommunication Union (ITU) was held in Bucharest, Romania, from 26 September to 14 October 2022. This article gives an overview of the conference and its major deliberations.

Keywords: ITU, PP, election, ICT, development

1. Introduction

The Plenipotentiary Conference 2022 (PP-22) of the International Telecommunication Union (ITU) was held in Bucharest, Romania, from 26 September to 14 October 2022. About 2500 people from 193 countries participated in the conference, and the Japanese delegation consisted of about 90 people from the government and private sectors, led by Mr. Yoshifumi Tsuge, State Minister for Internal Affairs and Communications, and Mr. Hiroshi Yoshida, Vice Minister for Policy Coordination (International Affairs) of the Ministry of Internal Affairs and Communications.

2. Overview of PP-22

The PP is the highest decision-making body of ITU, which meets once every four years. Representatives of all member countries (Member States) participate in the conference for the elections of senior officials and the Member States of the ITU Council (Council Member States) for the next period and for the discussion of important documents such as PP resolutions. The PP-22 established six committees (COMs) and a Working Group of the Plenary (WG-PL) under the Plenary. COM1 was a Steering Committee, COM2 dealt with credentials, COM3 with budget control, COM4 with editing, COM5 with policy and legal matters, COM6 with administration and management, and WG-PL with the reports and proposals and recommend appropriate actions with regard to issues related to public policies, including Internet, and other general matters. Mr. Sabin Sărmaș, a member of the Romanian Parliament and a Chairman of the IT&C Commission within the Chamber of Deputies, was appointed the Chair of the conference.

3. Results of the elections of senior officials and Council Member States

The PP-22 held elections of ITU senior officials and Council Member States for the period 2023–2026. The Japanese candidate Seizo Onoe (Chief Standardization Strategy Officer, NTT) was elected as the next Director of the Telecommunication Standardization Bureau (TSB). He will serve one term of four years, with a maximum of two terms. In addition to Mr. Onoe, there were two other candidates running for the post of the TSB Director: Dr. Thomas Zielke (Germany) and Dr. Bilel Jamoussi (Tunisia), a current TSB staff member. Mr. Onoe was elected on the first ballot with a majority of the votes cast by the PP-22 participating Member States entitled to vote. This is the first time a Japanese national has been elected as the Director of TSB, and he is expected to be responsible for the standardization of next-generation telecommunications networks.

In addition to the next TSB Director, the PP-22 also saw the election of the next Secretary-General, the next Deputy Secretary-General, the next Director of Radiocommunication Bureau, the next Director of the Telecommunications Development Bureau, the next member of the Radio Regulations Board, and the next Council Member States, with Ms. Doreen Bogdan-Martin (USA) elected as the Secretary-General and Mr. Tomas Lamanauskas (Lithuania) as the Deputy Secretary-General. Mr. Mario Maniewicz (Uruguay) was re-elected for his second term as the Director of Radiocommunication Bureau, and Dr. Cosmas Zavazava (Zimbabwe) was elected as the Director of Telecommunications Development Bureau.

In the election for the next Council Member States, Japan also stood for Region E (Asia and the Pacific) (13 seats) and was elected with 146 votes (180 valid votes). This is the 13th consecutive time since 1959 that Japan has served on the Council. For more information on the election results, see Election Results [1] on the ITU PP-22 website.

4. Major resolutions discussed at PP-22

Fifty-seven resolutions and two decisions were revised, one resolution was deleted, and six new resolutions were approved at the PP-22. The following is a summary of the main discussions and outcomes.

4.1 Policy and legal matters

(1) Resolution 208: Appointment and maximum term of office for chairmen and vice-chairmen of sector advisory groups, study groups, and other groups

Based on the Japanese proposal, it was agreed to report the attendance rate of the chairmen and vice-chairmen to the relevant assemblies or conferences. The Russian region proposed that the candidates agreed upon by each region for the appointment of the chairmen and vice-chairmen be approved at the assembly level meeting, but this proposal was not reflected due to the opposition from the U.S., European countries, and Japan. The author of this article, Ms. Memiko Otsuki, chaired the ad hoc meeting including this resolution.

(2) Proposed resolution: Encouraging the participation of industry in the work of the Union

Concerned about the declining participation of industry in ITU, a new resolution to enhance the engagement of industry in the work of ITU had been proposed by the Europe and Americas regions and Australia. However, since China, Africa and Arab countries insisted on limiting the definition of “industry,” the conflict could not be resolved, and it was agreed to insert a recommendation to continue to encourage the enhanced participation of entities and organizations in the activities of ITU in the plenary report.

(3) New resolution: Use of frequency assignments by military radio installations for national defense services

A new resolution includes the following points: a frequency assignment for which Article 48 of the ITU Constitution has been invoked is used only for military radio installations, and the Secretariat may seek clarification from the Member State regarding possible misuse of this article.

4.2 Administrative and operational matters

(1) Resolution 71: Strategic plan for the Union for 2024–2027

New strategic goals and priorities were set under the vision and mission for the 2024–27 strategic plan. After discussion on whether cybersecurity should be a stand-alone priority, it was agreed to merge it with another priority.

(2) Decision 5: Revenue and expenses for the Union for the period 2024–2027

Although the contributions from Member States increased by 12 1/4 units from the previous period, the financial plan for 2024–2027 was agreed to be about 652 million Swiss francs (CHF). It was decided to maintain the contributory unit for ITU’s annual budget at 318,000 CHF per year for the period 2024–2027.

4.3 Matters related to public policies

(1) Resolution 130: Cybersecurity

The African, Arab, and Russian regions proposed to expand the activities of ITU, including enhancing its role in the United Nations (UN)-wide cybersecurity discussions, while the Western countries argued that ITU’s activities should be limited to sharing best practices and capacity building. In the latter half of the negotiations, the review and revision of the ITU Global Cybersecurity Agenda (GCA) became the most contentious issue. It was finally agreed to delete the reference to the GCA in the resolution, but a recommendation that “the ITU Council will consider proposals from Member States on the GCA and its possible future elaboration” will be included in the plenary report.

(2) Resolution 139 and proposed new resolution: Open Radio Access Network (RAN)

Brazil proposed a new resolution including the standardization of Open RAN, and the Arab region proposed to include a reference to Open RAN in several resolutions. However, due to the opposition from

Europe, the U.S., Canada, and other countries, it was agreed to include a reference to the promotion and information sharing of Open RAN and other activities in Resolution 139, which aims at bridging the digital divide.

(3) Resolution 206: Over the top (OTT)

The Americas region proposed "no change" and the African region proposed a new text to encourage OTT companies to contribute financially to infrastructure development and instruct the Secretary General to support the establishment of regulatory frameworks for OTTs in developing countries. Although Europe and the U.S. compromised on the change during the ad hoc discussions, the text was not revised as a result of the lack of agreement on the content of the revised text until the end of the meeting.

(4) New resolution: Artificial intelligence (AI)

Two proposals had been submitted for the adoption of a new resolution on AI, which was rejected by the last PP (PP-18). The African region emphasized the need to introduce AI in developing countries to achieve the Sustainable Development Goals, but after discussion, the European region's proposal, which included the continuation of existing work on AI within the mandate and core competence of ITU and continued collaboration with other UN bodies, was reflected. It was agreed that the title of the resolution would be "AI technologies and telecommunications/information and communication technologies (ICTs)" to reflect this.

(5) New resolution: Role of telecommunications/ICTs in mitigating global pandemics

Several regions proposed a new resolution on the role of ICTs and ITU in pandemic preparedness, which included working with the World Health Organization and other agencies and organizations within the mandate of ITU, and support projects and other activities that enable the deployment and use of telecommunications/ICTs.

4.4 Other topics

The candidacy of India for the 2024 World Telecommunication Standardization Assembly (WTSA-24), Thailand for the 2025 World Telecommunication Development Conference (WTDC-25), and Qatar for the 2026 Plenipotentiary Conference (PP-26) were approved as the host countries for the next major conferences. Rwanda has also announced its intention to host the 2027 Radiocommunication Assembly and World Radiocommunication Conference (RA/WRC-27). The exact location and dates will be decided at a future Council meeting.

5. Conclusion

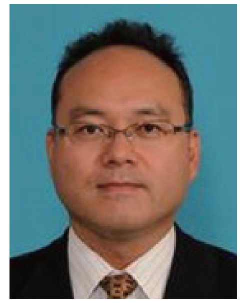
The PP-22 was held with a sense of tension due to COVID-19 and Russia's invasion of Ukraine. However, the meeting proceeded very efficiently and fruitfully, thanks to the scheduled preparatory meetings in each region and inter-regional coordination, including online, as well as the fact that several resolution proposals were packaged for discussion in the ad hoc meetings during the conference. In the election, Japan was elected as a Council Member State for the 13th consecutive time since 1959, and Mr. Seizo Onoe, the candidate for the TSB Director, was elected with a majority of the first ballots cast. The NTT Group will continue to make efforts to enhance its presence in the ITU and actively engage in activities related to the development of telecommunications and ICTs and their deployment around the world.

Reference

[1] ITU PP-22, Election Results, https://pp22.itu.int/en/elections/elections-results/

Memiko Otsuki
Manager, Tariff and Regulatory Affairs Office/Spectrum Planning Office, NTT DOCOMO, INC.

She received an MPP from the Australian National University (Canberra, Australia), and B.A. in business management from the International Christian University (Tokyo, Japan). She is currently serving as a manager of the Tariff and Regulatory Affairs Office and the Spectrum Planning Office at NTT DOCOMO, where she has been actively involved in policy and standardization work at ITU and Asia-Pacific Telecommunity (APT). Most recently, she was appointed as the Vice-Chair of the ITU Telecommunication Development Sector Study Group (SG) 1 and the rapporteur of Question 12 of ITU Telecommunication Standardization Sector (ITU-T) SG3. Prior to her current position, she was the assistant director of the Global Strategy Division at the Ministry of Internal Affairs and Communications, Japan. In her role, she had been contributing to a number of ITU activities including the Council, the Council Working Group, the Expert Group on the International Telecommunication Regulations, the Informal Experts Group on World Telecommunication/ICT Policy Forum (WTPF-21), the World Summit on the Information Society (WSIS) Forum, the ITU Telecom, the Broadband Commission, and preparatory meetings for WTSA-20, WTDC-22, and PP-22. She has over 15 years of professional experience in the telecommunications/ICT field and has expertise in policy and regulatory issues. She received the ITU-AJ Encouragement Award from the ITU Association of Japan in 2017 for her contributions over the years. She is a member of the Japan Society of Information and Communication Research (JSICR).



Noriyuki Araki
Director, Standardization Office, Research and Development Planning Department, NTT Corporation.

He received a B.E. and M.E. in electrical and electronic engineering from Sophia University, Tokyo, in 1993 and 1995. He joined NTT Access Network Service Systems Laboratories in 1995, where he researched and developed operation and maintenance systems for optical fiber cable networks. He has been contributing to standardization efforts in ITU-T SG6 since 2006. He was the rapporteur of Question 6 of ITU-T SG6 from 2006 to 2008 and rapporteur of Question 17 of ITU-T SG15 from 2008 to 2012. He also served as the chairman of the ITU-T Focus Group on Disaster Relief Systems and Network Resilience and Recovery. He was the vice-chairman of ITU-T SG15 from 2013 to 2022. He also contributes to the activities of International Electrotechnical Commission (IEC) Technical Committee 86 (fiber optic systems). He received the ITU-AJ award from the ITU Association of Japan in 2017. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE).

Report on NTT R&D Forum—Road to IOWN 2022

NTT R&D Forum Secretariat

Abstract

NTT R&D Forum—Road to IOWN 2022 was held from November 16th to 18th, 2022. The following is an introductory overview of the Forum.

Keywords: R&D Forum, IOWN, latest technology

1. Forum overview

With the commercialization of Innovative Optical and Wireless Network (IOWN)1.0 services close at hand, NTT R&D Forum 2022 introduced the latest achievements of NTT research and development (R&D) toward the further evolution of large-capacity, low-latency, and low-power communication technologies. It featured keynote speeches by Akira Shimada, president and chief executive officer (CEO) of NTT Corporation, and Atsuko Oka, executive vice president, head of the Research and Development Planning Department of NTT Corporation, and three special sessions by members of the IOWN Global Forum as well as more than 90 research exhibits. The technology roadmap that has been under consideration is finally taking shape and the light of IOWN is about to shine. We report on this NTT R&D Forum successfully held online under the theme of “Road to IOWN 2022.”

2. Keynote speeches/special sessions

2.1 Keynote Speech 1

Under the theme of “IOWN1.0—Start of IOWN Service,” Akira Shimada, president and CEO of NTT Corporation, delivered a keynote speech centered on IOWN services scheduled for launch at the end of FY2022 (**Photo 1**).

President Shimada first touched upon key issues that arise in a “data-driven society” in which actions are taken on the basis of data generated by a wide variety of devices making up the Internet of Things (IoT). These include a significant increase in data capacity and power consumption as well as communication delays. He announced the commercialization of All-Photonics Network (APN) services by March 2023 as the first round of IOWN services (i.e., IOWN1.0) to address these issues. He then went on to describe how APN services could be applied to a variety of services such as remote medicine, smart factories, and e-sports among remote players by achieving communications that satisfy IOWN performance targets, i.e., a delay 1/200 the current level with no flicker. He also presented the possibility of treating multiple datacenters as a single datacenter by interconnecting them with high-capacity, low-latency circuits.

Next, President Shimada talked about “photonics-electronics convergence devices” that merge optical and electronic circuits as key power-efficient devices that represent the most outstanding feature of IOWN. The plan is to apply these devices not only to networking but also to computing to achieve a drastic reduction in power consumption. He also announced a detailed plan for service development that, while applying and expanding these photonics-electronics convergence devices to APN services and servers, IOWN would increase communication capacity by 125 times in IOWN3.0 in 2029 and increase power

Photo 1. Keynote Speech 1 delivered by NTT President and CEO Akira Shimada.

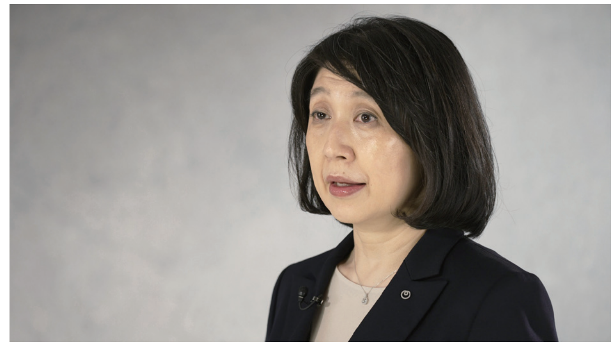


Photo 2. Keynote Speech 2 delivered by NTT Executive Vice President and Head of Research and Development Planning Department Atsuko Oka.

efficiency by 100 times in IOWN4.0 and beyond as performance targets.

Finally, President Shimada introduced the urban development of Urbannet Nagoya nexta Building as an example of Digital Twin Computing that represents diverse digital copies of real space in cyber space to conduct data analysis and simulations for predicting the future. He described how services for air conditioning control and reduction of food waste would be commercialized and implemented in FY2023 and how such a development would "contribute to people-friendly and earth-friendly urban development" while promoting service enhancement and expansion. With a view to Expo 2025 Osaka, Kansai, Japan, President Shimada also declared that NTT would be announcing pavilion exhibits and the commercialization of IOWN2.0 services. For details, please see the article titled "IOWN1.0—Start of IOWN Service" in this issue.

2.2 Keynote Speech 2

Atsuko Oka, executive vice president, head of Research and Development Planning Department of NTT Corporation, also delivered a keynote speech under the theme of "Road to IOWN – Light Up –." She described how the actual provision of IOWN services would begin at the end of FY2022 and that IOWN would finally shine its light on users (**Photo 2**).

Though currently at the conceptual level, IOWN is about to enter a practical phase, and with this in mind, Executive Vice President Oka announced a variety of research findings as the first round of research results of the IOWN initiative.

In the first topic of her speech, "IOWN Datacenter × APN," Executive Vice President Oka described the need for interconnecting NTT datacenters by the APN and accelerating service development in a large-scale and practical environment. To deal with the trend toward increasingly larger datacenters, she explained a plan to make operations more efficient through the APN while decentralizing datacenters. This approach has the potential of solving the problem of securing land and power. She also introduced two examples of APN-related achievements. One is the development of a digital coherent signal processing circuit that can achieve an optical-fiber transmission capacity of 1.2 Tbit/s per wavelength. The other is the creation of a 400-Gbit/s co-package prototype for transceivers. She revealed that these technologies should be commercialized in 2023 and that research would continue on basic technologies for supporting next-generation ultra-high-capacity communications.

Executive Vice President Oka also pointed out that "the current environment that combines AI [artificial intelligence] and IoT has a network problem," and that NTT would solve this problem by interconnecting datacenters by the APN to create a "true industrial infrastructure."

Given that "high transmission performance for conveying reality" is an intrinsic property of the APN, Executive Vice President Oka presented remote surgery as a use case of the APN that supports the transmission of visual, acoustic, verbal, and even tactile information essential to reproducing reality. Then, from among a variety of acoustic and voice technologies that NTT has long been researching, she announced the development of advanced acoustic technology for wirelessly controlling underwater drones. She also introduced the world's first earphones and speakers using Personalized Sound Zone (PSZ) technology that generates only the sound that

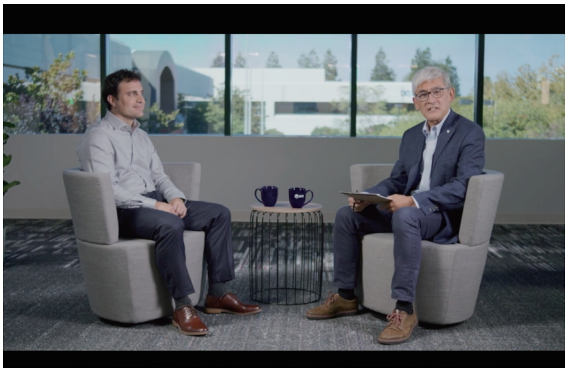


Photo 3. Special Session 1: (from left) Dr. Brent Waters and NTT Research CEO Kazuhiro Gomi.

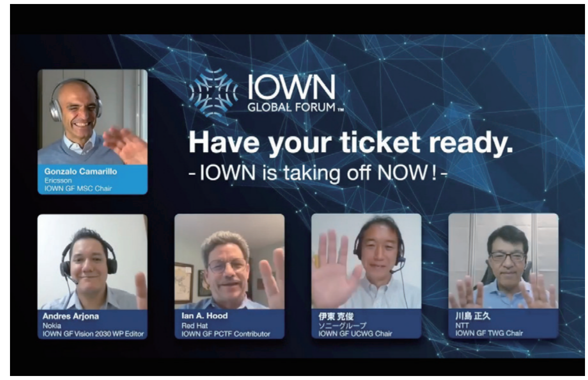


Photo 4. Special Session 2: (Top) Gonzalo Camarillo; (from bottom left) Andres Arjona, Ian A. Hood, Katsutoshi Itoh, and Masahisa Kawashima.

you want to hear and cancels out unwanted ambient noise. For details, please see the article titled “Road to IOWN – Light Up –” in this issue.

2.3 Special Session 1

In Special Session 1, “Protocols for Post Quantum Cryptography,” Dr. Brent Waters, director of Cryptography & Information Security Laboratories (CIS Lab), NTT Research, Inc., spoke with Kazuhiro Gomi, president and CEO of NTT Research, about the current research in this field (**Photo 3**).

Dr. Waters began the discussion by talking about the problem of using quantum computing to break public-key encryption, one of the encryption systems now in use. Learning with error, which adds error during inner-product computation, is a lattice-based encryption scheme that can withstand even calculations by a quantum computer, and Dr. Waters explained that this function has various benefits apart from post-quantum cryptography.

Next, in response to the question: “Can public-key encryption be protected against malicious acts?” Dr. Waters replied “Definitely yes!” In support of his answer, he touched upon a method that can avoid the risk of security breaches, citing fully homomorphic encryption technology proposed by Craig Gentry in 2009. This method “enables computations to be performed on received data despite knowing nothing about that data.” Additionally, as a deeply interesting encryption technology, Dr. Waters talked about attribute-based encryption, which he invented, as a scheme that executes “encrypting toward an access policy,” and gave examples of advanced versions of this function developed in succession by fellow researchers. In the second half of the session, the NTT Belgium team introduced a method using attribute-based encryption to protect portions of images that include highly confidential information.

Finally, with respect to risks in post-quantum cryptography, Dr. Waters said “While we don’t know how many years it will take for large-scale quantum computers to appear, we must devise countermeasures in advance,” and emphasized the importance of being cautious about those risks.

2.4 Special Session 2

Special Session 2 titled “Have your ticket ready. IOWN is taking off NOW!” brought together five members of the IOWN Global Forum to discuss proof of concept (PoC) activities (**Photo 4**). Moderator Gonzalo Camarillo, chair of the Marketing Steering Committee, talked with panelists Andres Arjona, editor of IOWN GF Vision 2030 White Paper, Ian A. Hood of Red Hat, Katsutoshi Itoh, chair of the Use Case Working Group, and Masahisa Kawashima, head of IOWN Development Office and chair of the Technology Working Group.

Mr. Arjona began the session by sharing his vision. Mr. Itoh then introduced use cases implemented in 2022 while Mr. Kawashima introduced the APN and Data Centric Infrastructure (DCI) as key IOWN technologies along with their role in PoC activities. Mr. Camarillo then opened the discussion by sharing his view of the “importance of reiterations in developing and further evolving paper specifications and use cases based on PoC implementations.”

Starting with the topic of “study items in PoC activities and activities now being focused on,” each panelist reported on specific PoC activities that

IOWN Global Forum commenced in 2022, indicating technical specifications that had been discussed since 2021 are finally breaking through into an implementation phase.

First, Mr. Hood introduced PoC activities for achieving use cases on Red Hat's platform and demonstrating the advantages of the APN. He described how technologies such as remote direct memory access and remote information management security could be used to eliminate some of the technology gaps that are needed to implement those use cases. He also presented a plan for demonstrating the advantages of the APN in the mobile field and accelerating the introduction of new services. Next, Mr. Arjona described a plan to develop a PoC regarding use of the APN in the mobile fronthaul. Continuing on, Mr. Itoh reported on activities using sensing and robotic solutions in the entertainment and industry-management fields. Finally, Mr. Kawashima reported on the building of an IOWN testbed that will use the APN to connect current NTT datacenters in major cities and on the development of use cases, the feasibility and viability of which will be tested in 2023.

Turning to the second topic of "what comes next after PoC," Mr. Arjona shared his idea of promoting global alliances and collaborative activities with other standards bodies to open up new horizons in optical communications. Mr. Hood then announced a plan for achieving targets at standards bodies and within open source projects and Mr. Itoh reported on activities for bringing service providers into an open ecosystem. Finally, Mr. Camarillo concluded the session by sharing his outlook for the future, saying "I would like to make it a tradition of NTT R&D Forum to explain our work on realizing and popularizing IOWN and what advances we were able to make each year."

2.5 Special Session 3

In Special Session 3, "The Era of Space Voyages: A Compass for Carving a Path to the Future," celebrity Harry Sugiyama served as Master of Ceremonies in welcoming Koichiro Matsufuji and Shigehiro Hori, representative directors and Co-CEOs of Space Compass Corporation, to talk about the future of the space industry (**Photo 5**).

Photo 5. Special Session 3: (from left) Harry Sugiyama, Shigehiro Hori, and Koichiro Matsufuji.

The Space Integrated Computing Network concept promoted by Space Compass Corporation is a plan for "connecting all people and things on the ground, on the sea, in the air, and in outer space by optical communication at high speeds." To achieve the Beyond fifth-generation (5G)/6G mobile network envisioned by NTT, this plan aims to construct new high altitude platform stations (HAPS) to cover terrestrial communication bands throughout Japan from the stratosphere and low Earth orbits in space and to observe Earth in real time. Mr. Matsufuji explained that the benefit of this plan is "the ability to objectively capture the true conditions and appearance of Earth by observing it from space."

Next, Mr. Hori and Mr. Matsufuji talked about the three business pillars of the Space Integrated Computing Network concept: space sensing, space datacenter, and space radio access network. They explained that the Space Integrated Computing Network will make possible what heretofore has been impossible, such as the "reliable implementation of disaster-prevention measures, transmission of economic information, and ensuring of national security" by collecting data through observations of what cannot be seen with the human eye. Among these developments, they introduced experiments currently being conducted on eagerly anticipated non-terrestrial infrastructure HAPS with a view to achieving practical communications by 2025.

Finally, as visions of the future, Mr. Hori talked about the need for people to undertake "business and challenges that will pave the way to the new era of space voyages," while Mr. Matsufuji stressed the need for "constructing a network that can support technologies such as robots, drones, and self-driving for the coming aging society."

3. Research exhibits

NTT's latest technologies and research achievements were introduced through virtual exhibit booths

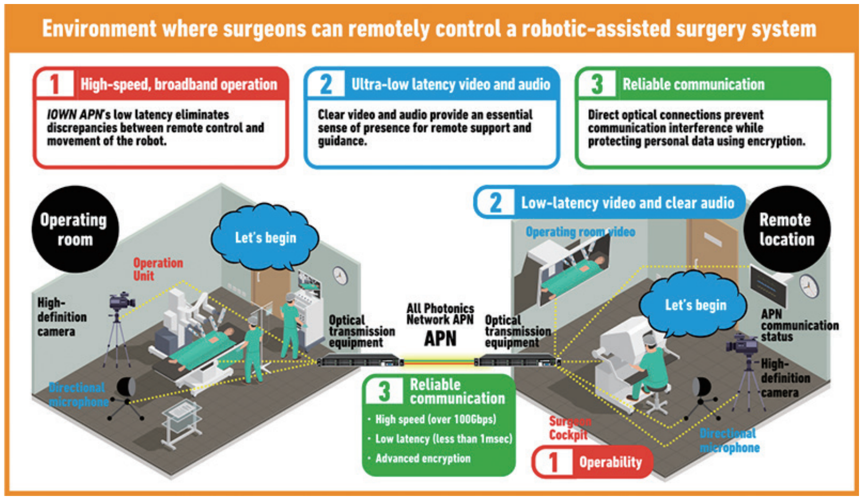


Fig. 1.   Use case of surgical robot using IOWN APN.

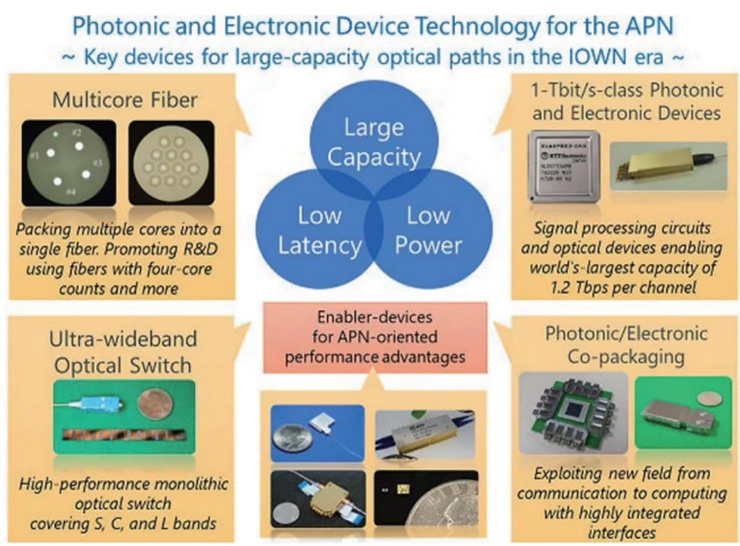


Fig. 2.   Photonic and electronic device technology for the APN.

divided into six categories. We report on research that attracted particular attention.

3.1 Network

In the "Network" category, we introduced a variety of optical/wireless network technologies centered on IOWN APN services to be provided from March 2023.

In "Use case of surgical robot using IOWN APN," we introduced technology for supporting surgical robots as an example of applying the APN (**Fig. 1**). A service using this technology will be provided from 2023. We anticipate that medical treatment from even more remote locations will become possible by achieving robot operations and video transmission with low latency and no flicker through the APN and implementing a high-security surgery environment by adding encryption technology.

In "Photonic and electronic device technology for APN," we introduced a variety of advanced functional devices for supporting high-speed and large-capacity optical paths in the APN (**Fig. 2**). These

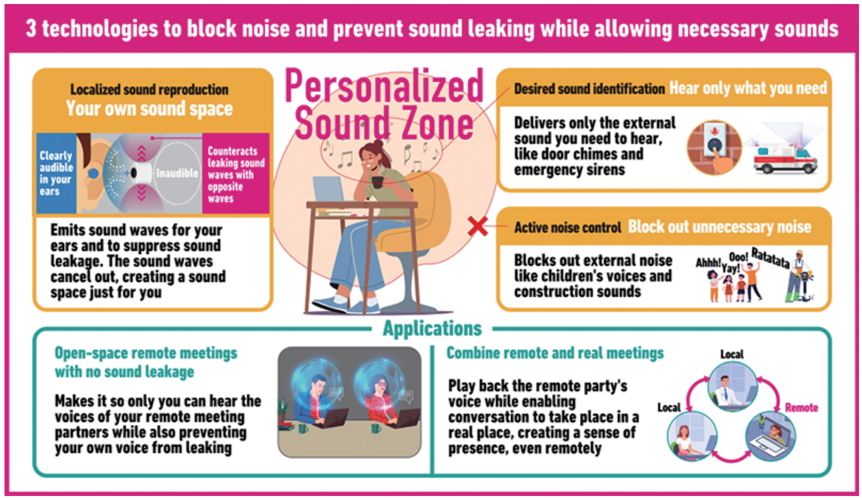


Fig. 3. Personalized Sound Zone (PSZ).

Fig. 4. Metaverse in the IOWN era.

include an optical device that achieves the world's largest capacity of 1.2 Tbit/s and a next-generation high-density interface, both of which contribute to meeting the IOWN performance targets of large capacity, low latency, and low power consumption.

3.2 XR (UI/UX)

In the "XR (UI/UX)" category, we exhibited technologies for supporting the convergence of the real world and cyber world and for supporting a remote world that enables experiences that transcend the real-world environment.

In "Personalized Sound Zone (PSZ)," we introduced research on controlling the ambient sound space and creating a sound space appropriate for the user (**Fig. 3**). Using technology for blocking ambient sound and technology for hearing the sounds desired by the user, we exhibited a comfortable-and-safe sound space inside a vehicle and the world's first open-ear earphones.

In "Metaverse in IOWN era," we held a demonstration of future communication in which the real and virtual are intermixed using "3D [three-dimensional] spatial media processing technology" to achieve real space and "Another Me technology" to enable an avatar having a real identity to behave in an autonomous manner in cyber space (**Fig. 4**). The aim is to heighten connections between people and society and

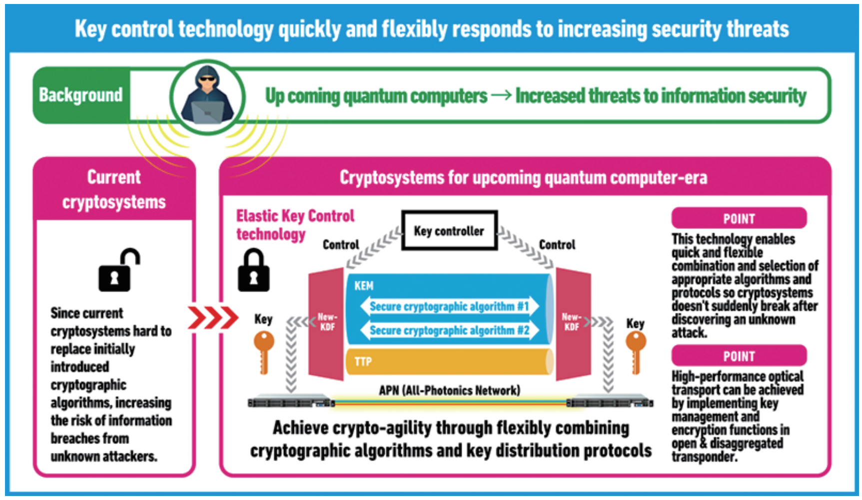
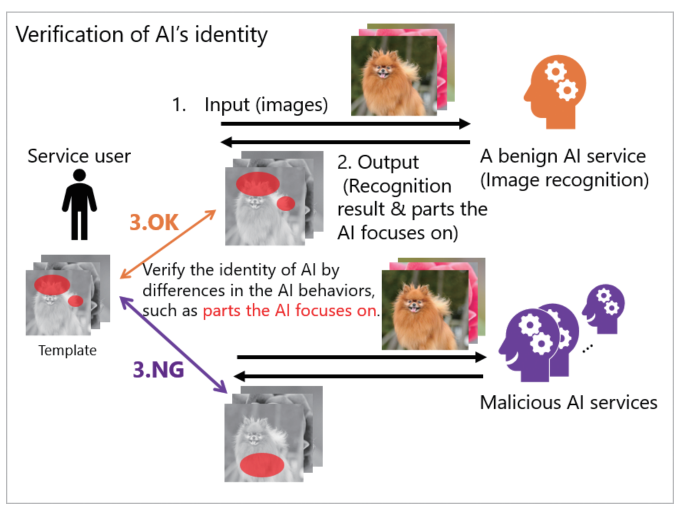


Fig. 5. Secure optical transport network for quantum computer age.



NG: not good

Fig. 6. Verification of AI's identity by its profile.

create a sustainable society receptive to diversity.

3.3 Security

In the "Security" category, we presented technologies for achieving safe and secure communications using encryption technology.

In "Secure optical transport network for quantum computer age," we introduced secure cryptographic technologies in anticipation of quantum computers that are expected to become a reality from 2030 on (**Fig. 5**). For example, "elastic key control technology" that combines multiple algorithms and key-sharing protocols will eliminate security breaches in encrypted communications, digital signatures, authentication and approval, etc.

In "Verification of AI's identity by its profile," we introduced technology for preventing damage caused by impersonating AI as AI comes to be widely used (**Fig. 6**). It will be possible to identify inappropriate AI by paying attention to those locations focused on by AI and examining output results. The aim is to promote the safe use of AI in business and enable

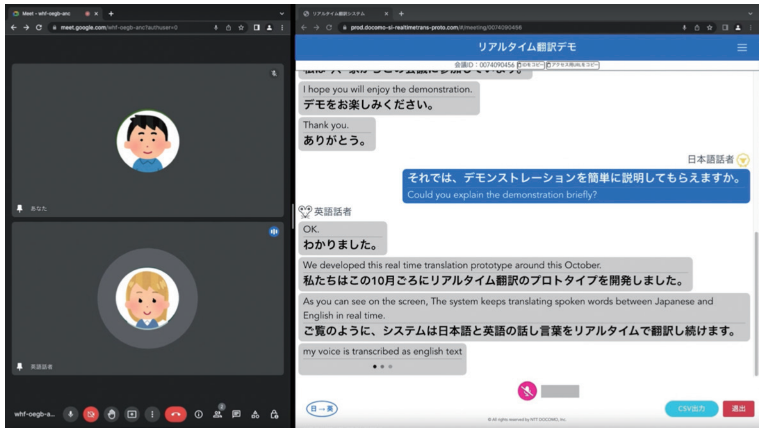


Fig. 7. Real-time translation technology to break the language barrier for business.

Fig. 8. Signal-free mobility: distributed traffic coordination without traffic signals.

people and AI to coexist and prosper together.

3.4 AI/Computing

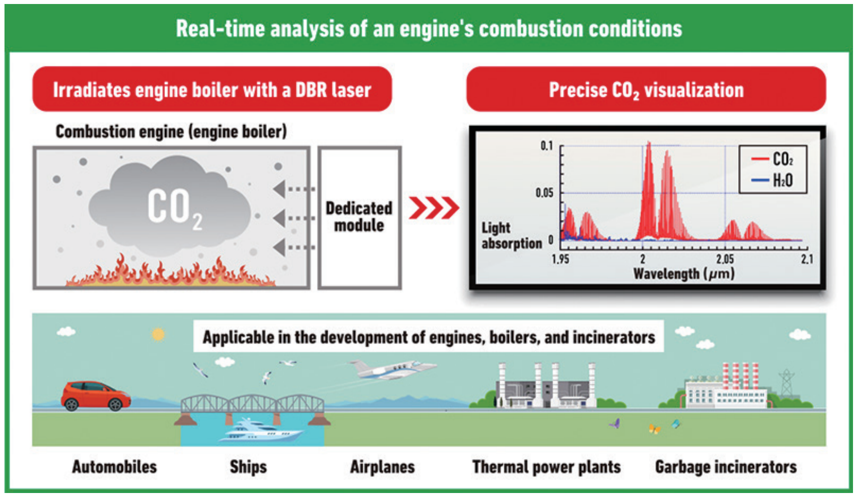
In the “AI/Computing” category, we introduced services using AI in diverse fields and presented exhibits using AI.

In “Real-time translation technology to break the language barrier for business,” we introduced high-accuracy Japanese-English simultaneous translation technology as an alternative to interpretation (**Fig. 7**). This technology achieves natural translation of conversations in real time by combining technology for automatically removing words, pauses, etc. deemed unnecessary for conveying the meaning of a sentence, technology for automatically inferring the position of sentence delimiters, and a machine-translation engine.

In “Signal-free mobility: distributed traffic coordination without traffic signals,” we demonstrated and presented “signal-free mobility” in which vehicles can run without colliding with each other on streets with no traffic signals by using digital twins (**Fig. 8**). In a demonstration using digital twins in the virtual world and miniature cars in the real world, we showed that optimal traffic control could be achieved through mutual feedback between these two worlds. Therefore, we expect signal-free mobility to put an end to existing traffic problems such as congestion at traffic intersections.

3.5 Environment and Energy

In the category of “Environment and Energy,” we exhibited technologies for achieving a comfortable environment on Earth with a view to achieving the



DBR laser: distributed Bragg reflector laser

Fig. 9. Semiconductor laser diode for carbon dioxide gas sensing.

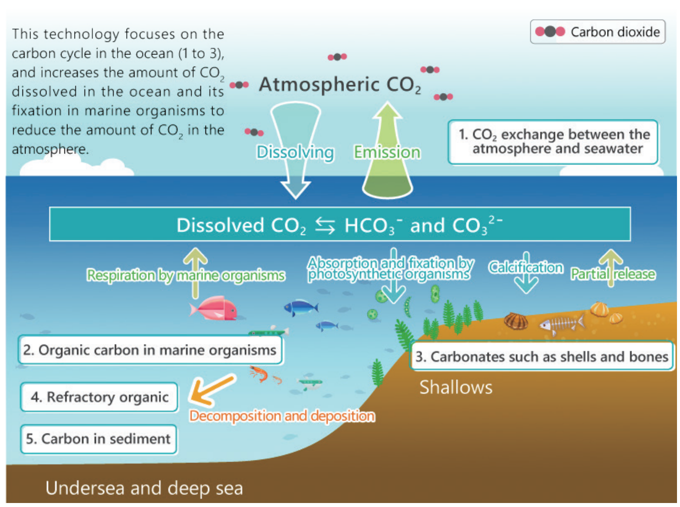


Fig. 10. Biological conversion technology to reduce CO_2 in the ocean.

Sustainable Development Goals (SDGs) and carbon neutrality.

In "Semiconductor laser diode for carbon dioxide gas sensing," we described sensing technology that uses a semiconductor laser to accurately measure the state of carbon dioxide (CO_2) gas (**Fig. 9**). This technology can measure CO_2 concentrations in real time even in environments with large state changes such as thermoelectric power stations, which has not been possible with conventional lasers. It can contribute to a decrease in environmentally harmful gases and the easing of global warming.

In "Biological conversion technology to reduce CO_2 in the ocean," we introduced genome-editing technology to enhance carbon fixation in algae, fish, and shellfish that absorb CO_2 in the ocean and technology for evaluating the annual amount of carbon fixation (**Fig. 10**). Decreasing the amount of CO_2 in the ocean will help reduce its impact on the marine ecosystem, solve a variety of global environmental problems, and achieve carbon neutrality.

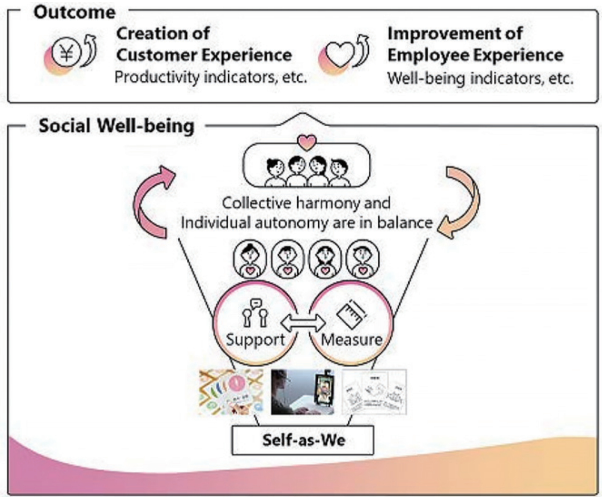


Fig. 11. Social well-being to enhance employee experience and create customer experience.

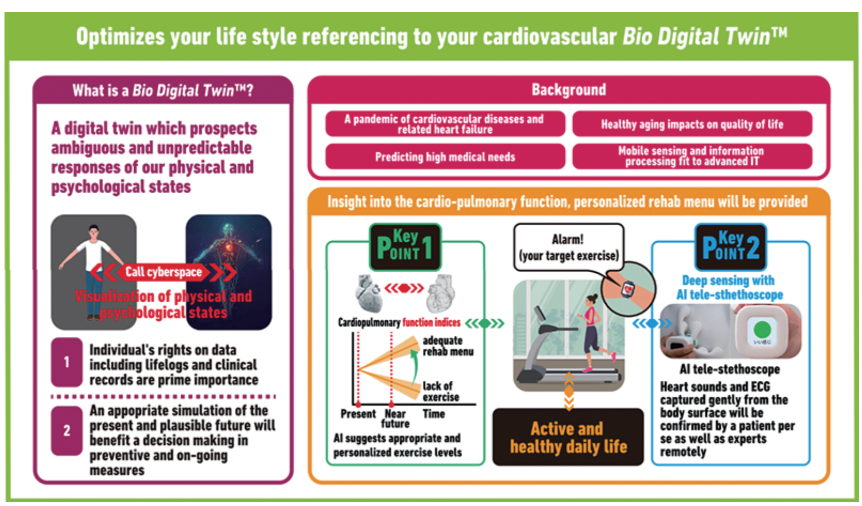


Fig. 12. Assessing one's physical performance through mobile sensing and bioinformatics.

3.6 Basic Research

Finally, in the category of "Basic Research," we introduced basic research in diverse fields to foster innovation in society as in the R&D of physical neural networks and bio digital twins. In "Social well-being to enhance employee experience and create customer experience," we exhibited research focusing on values (well-being) that do not depend only on economic rationality (**Fig. 11**). This research treats "Self-as-We"—a view of self based on East Asian traditions of thought—as a key concept and establishes technologies for supporting and measuring engagement between the individual and the group together with methodologies to achieve both individual well-being, or employee experience, and the creation of group achievements, or customer experience.

In "Assessing one's physical performance through mobile sensing and bioinformatics," we presented research on preventing cardiovascular disease—for which the number of patients is increasing yearly—by using an individual's Bio Digital Twin to generate coronary and other physical conditions in cyber space from the biological data of that person (**Fig. 12**).

Thus, measurement of cardiopulmonary functions by a simple examination and effective rehabilitation proposals will contribute to enhanced health maintenance and the prevention of serious illnesses for many people, giving hope for tomorrow.

4. NTT R&D Forum comes to a close

NTT R&D Forum 2022, which was held online for the third time in a row, introduced a variety of research projects, and to present exhibits that were visually easy to understand, we used illustrations that made it easy to imagine the content of research and panels that enabled key technical points to be understood at a glance. With an eye to the launch of IOWN services, we used examples of specific systems and initiatives to convey to everyone cutting-edge technologies that will brighten up the future in a multitude of ways.

Going forward, the NTT Group will continue the work of technology development to solve a wide variety of social problems. It is our wish to deliver new experiences and emotions and create a new future together with everyone. Please follow the evolution of IOWN in the years to come!

The keynote speeches (videos) and exhibitions are posted on the special website "Report on NTT R&D Forum—Road to IOWN 2022" (https://www.rd.ntt/e/forum/2022/index.html).

Members of NTT R&D Forum Secretariat: (from left) Yoshifumi Shiraki, NTT Science and Core Technology Laboratory Group; Hirofumi Abe, NTT Service Innovation Laboratory Group; Keita Takahashi, NTT Information Network Laboratory Group/NTT IOWN Integrated Innovation Center; Shunsuke Mori, Research and Development Planning Department, NTT Corporation; Tokinobu Mitasaki, Research and Development Planning Department, NTT Corporation; Takayuki Onzuka, Research and Development Planning Department, NTT Corporation; Hironari Yokoi, Research and Development Planning Department, NTT Corporation; and Taeko Tamada, Research and Development Planning Department, NTT Corporation.

External Awards

SIGGRAPH Asia 2022 Emerging Technologies Best Demo Award

Winners: Kengo Sato, Tokyo Institute of Technology; Hiroki Terashima, NTT Communication Science Laboratories; Shin'ya Nishida, Kyoto University/NTT Communication Science Laboratories; Yoshihiro Watanabe, Tokyo Institute of Technology
Date: December 9, 2022
Organization: Special Interest Group on Computer Graphics and Interactive Techniques (SIGGRAPH) Asia 2022

For "E.S.P.: Extra-sensory Puck in Air Hockey Using the Projection-based Illusion."
Published as: K. Sato, H. Terashima, S. Nishida, and Y. Watanabe, "E.S.P.: Extra-sensory Puck in Air Hockey Using the Projection-based Illusion," Proc. of SIGGRAPH Asia 2022, Article no. 3, Daegu, South Korea, Dec. 2022.

Best Paper Award

Winners: Masahiro Kohjima, NTT Human Informatics Laboratories; Yuta Nambu, NTT Human Informatics Laboratories; Yuki Kurauchi, NTT Human Informatics Laboratories; Ryuji Yamamoto, NTT Human Informatics Laboratories
Date: December 13, 2022
Organization: The 29th International Conference on Neural Information Processing (ICONIP 2022)

For "General Algorithm for Learning from Grouped Uncoupled Data and Pairwise Comparison Data."
Published as: M. Kohjima, Y. Nambu, Y. Kurauchi, and R. Yamamoto, "General Algorithm for Learning from Grouped Uncoupled Data and Pairwise Comparison Data," ICONIP 2022, Nov. 2022.

Specially Selected Paper

Winners: Ayako A. Hasegawa, National Institute of Information and Communications Technology; Naomi Yamashita, NTT Communication Science Laboratories; Mitsuaki Akiyama, NTT Social Informatics Laboratories; Tatsuya Mori, Waseda University
Date: December 15, 2022
Organization: Information Processing Society of Japan (IPSJ)

For "Experiences, Behavioral Tendencies, and Concerns of Non-native English Speakers in Identifying Phishing Emails."
Published as: A. A. Hasegawa, N. Yamashita, M. Akiyama, and T. Mori, "Experiences, Behavioral Tendencies, and Concerns of Non-native English Speakers in Identifying Phishing Emails," Journal of Information Processing, Vol. 30, pp. 841–858, 2022.

Young Scientist Award of the Physical Society of Japan

Winner: Yuki Takeuchi, NTT Communication Science Laboratories
Date: March 22, 2023
Organization: The Physical Society of Japan

For research on quantum supremacy of measurement-based quantum computation and its verification.
Published as: Y. Takeuchi, A. Mantri, T. Morimae, A. Mizutani, and J. F. Fitzsimons, "Resource-efficient Verification of Quantum Computing Using Serfling's Bound," npj Quantum Information, Vol. 5, Article no. 27, 2019.
Y. Takeuchi and T. Morimae, "Verification of Many-qubit States," Phys. Rev. X, Vol. 8, 021060, 2018.
Y. Takeuchi and Y. Takahashi, "Ancilla-driven Instantaneous Quantum Polynomial Time Circuit for Quantum Supremacy," Phys. Rev. A, Vol. 94, 062336, 2016.

Japanese Society of Crop Science Young Scientist Award

Winner: Kazuma Sakoda, NTT Space Environment and Energy Laboratories
Date: March 29, 2023
Organization: Crop Science Society of Japan

For his physiological and genetic study on leaf photosynthesis in crops in fluctuating environments.
Published as: K. Sakoda, Y. Tanaka, S. P. Long, and T. Shiraiwa, "Genetic and Physiological Diversity in the Leaf Photosynthetic Capacity of Soybean," Crop Science, Vol. 56, pp. 2731–2741, 2016.
K. Sakoda, S. Suzuki, H. Fukayama, Y. Tanaka, and T Shiraiwa, "Activation State of Rubisco Decreases with the Nitrogen Accumulation during the Reproductive Stage in Soybean [*Glycine max* (L.) Merr.], Photosynthetica, Vol. 57, No. 1, pp. 231–236, 2019.
K. Sakoda, A. Kaga, Y. Tanaka, S. Suzuki, K. Fujii, M. Ishimoto, and T. Shiraiwa, "Two Novel Quantitative Trait Loci Affecting the Variation in Leaf Photosynthetic Capacity among Soybeans," Plant Science, Vol. 291, 110300, 2019.

Papers Published in Technical Journals and Conference Proceedings

Topological Thouless Pumping in Arrays of Coupled Spin Chains

V. M. Bastidas

Physical Review B, Vol. 106, No. 22, L220308, December 2022.

Thouless pumping is a mechanism to perform the topologically protected transport of particles by adiabatically modulating the Hamiltonian. The transported current is a topological invariant that is intimately related to the integer quantum Hall effect. Most of the previous works focus on topological pumping in linear and square lattices. In this Letter, we theoretically propose a mechanism to perform topological pumping in arrays of spin chains with complex geometries. To achieve this, we consider an array where the spin chains are coupled through their edges, which allows us to split the populations to generate superpositions of spin excitations in different spin chains. We show that due to the topological protection, the quantum superpositions can be transported through the array against the effect of disorder. This approach will open another avenue to transport excitations and correlated states with potential applications in quantum technologies and information processing. Our ideas can be realized in state-of-the-art quantum simulators such as cold atoms and superconducting qubit arrays.

Finite-key Security Analysis of Differential-phase-shift Quantum Key Distribution

A. Mizutani, Y. Takeuchi, and K. Tamaki

arXiv:2301.09844, January 2023.

Differential-phase-shift (DPS) quantum key distribution (QKD) is one of the major QKD protocols that can be implemented with a simple setup using a laser source and a passive detection unit. Recently, an information-theoretic security proof of this protocol has been established in [npj Quant. Inf. 5, 87 (2019)] assuming the infinitely large number of emitted pulses. To implement the DPS protocol in a real-life world, it is indispensable to analyze the security with the finite number of emitted pulses. The extension of the security proof to the finite-size regime requires the accommodation of the statistical fluctuations to determine the amount of privacy amplification. In doing so, Azuma's inequality is often employed, but unfortunately we show that in the case of the DPS protocol, this results in a substantially low key rate. This low key rate is due to a loose estimation of the sum of probabilities regarding three-photon emission whose probability of occurrence is very small. The main contribution of our work is to show that this obstacle can be overcome by exploiting the recently found novel concentration inequality, Kato's inequality. As a result, the key rate of the DPS protocol is drastically improved. For instance, assuming typical experimental parameters, a 3 Mbit secret key can be generated over 77 km for 8.3 hours, which shows the feasibility of DPS QKD under a realistic setup.
