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.

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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,

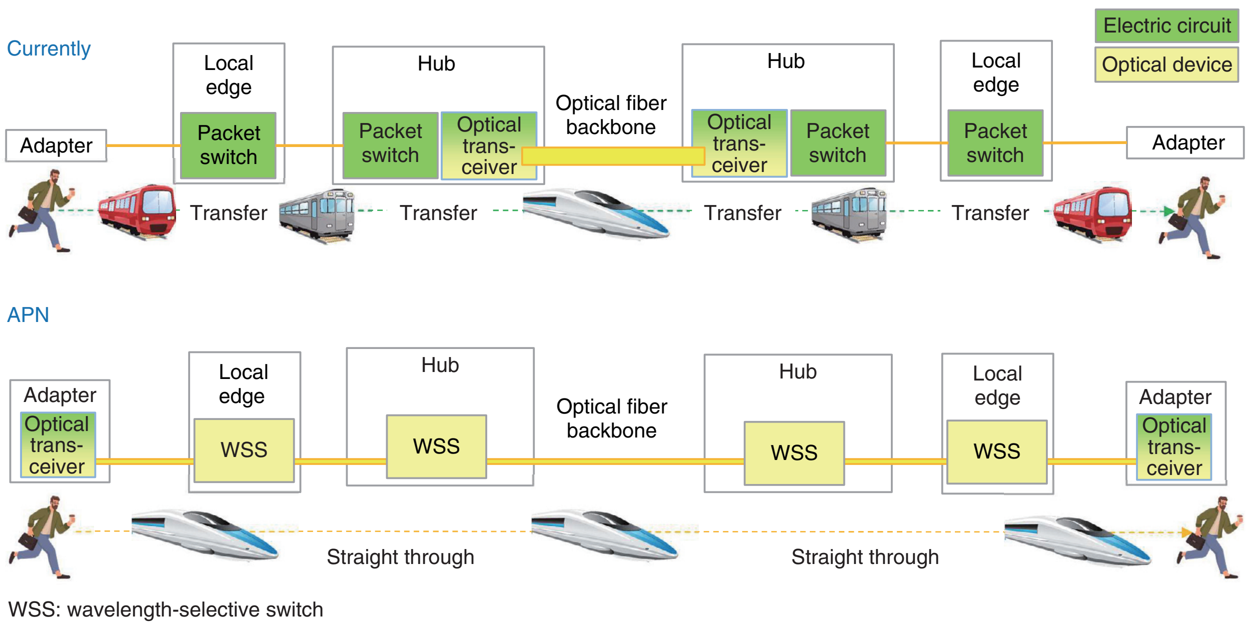


Fig. 1. All-Photonics Network (APN).

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*.

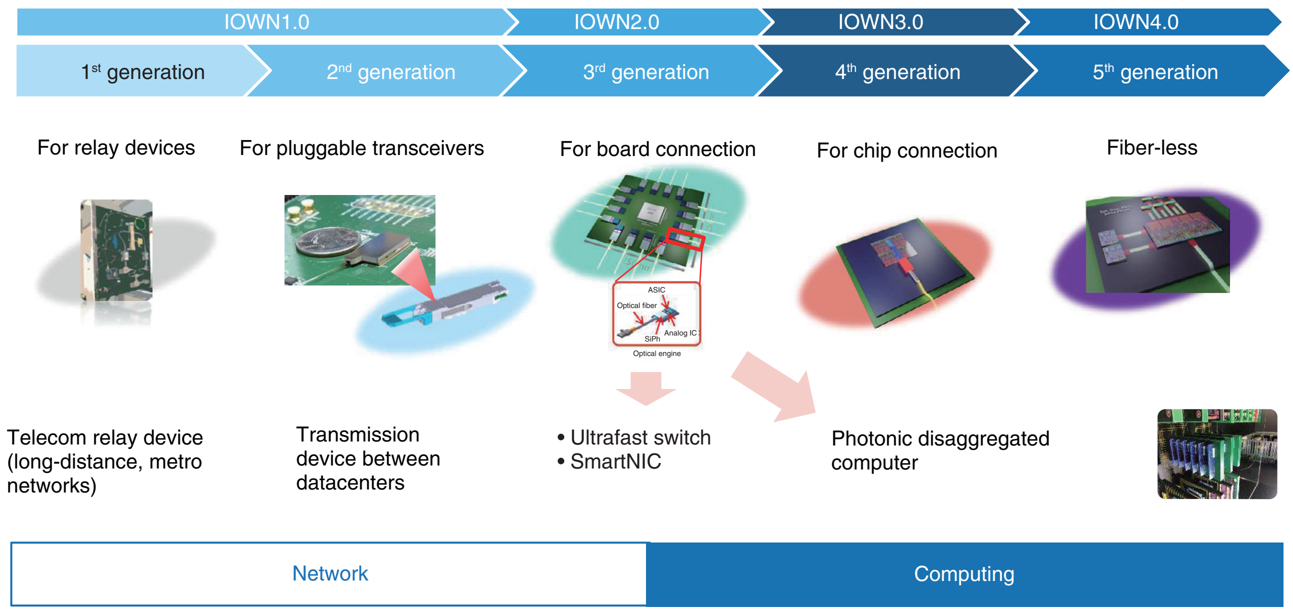
2. Where did IOWN actually originate from?

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



ASIC: application specific integrated circuit
SiPh: silicon photonics
SmartNIC: smart network interface card

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

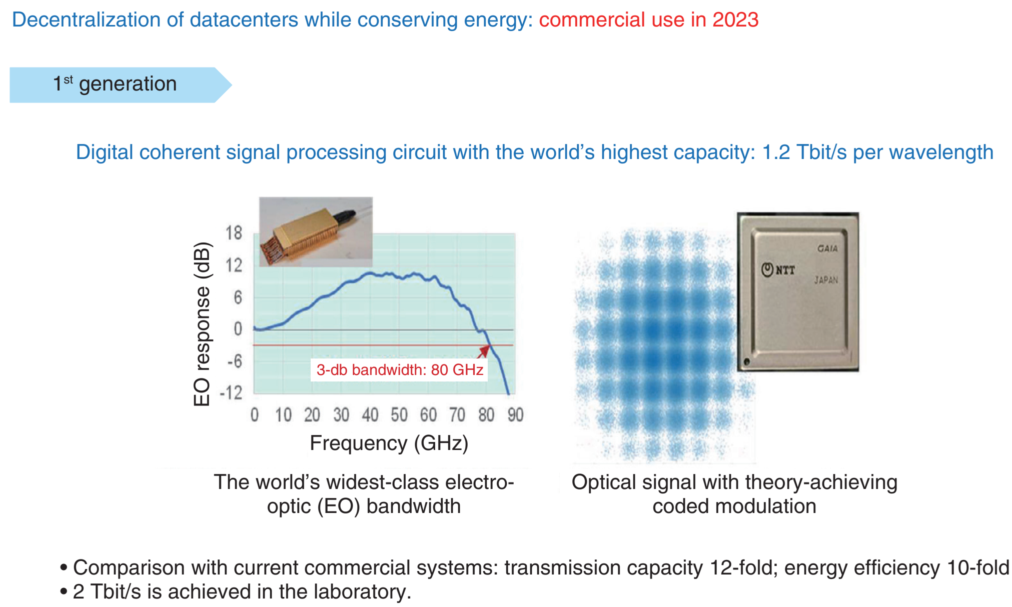


Fig. 3. Digital coherent signal processing circuit capable of optical fiber transmission at 1.2 Tbit/s per wavelength.

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

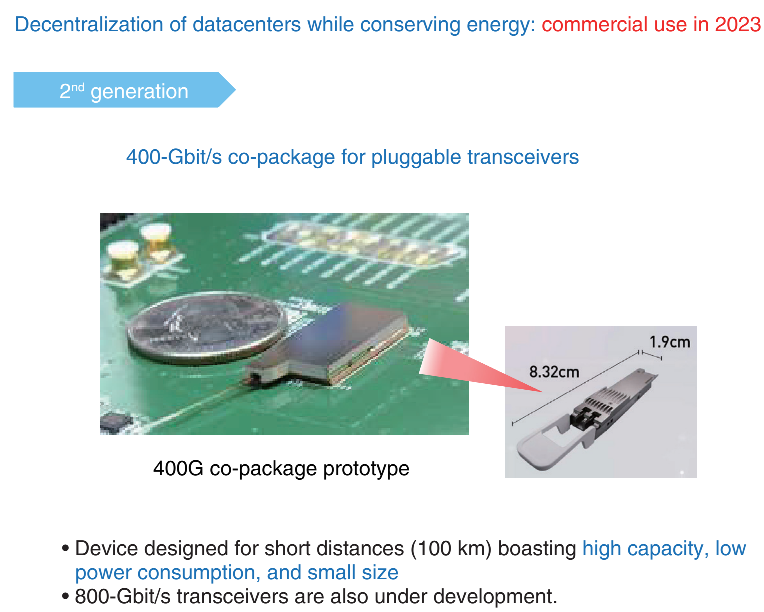


Fig. 4. 400-Gbit/s co-packaged optics prototype for transceivers.

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

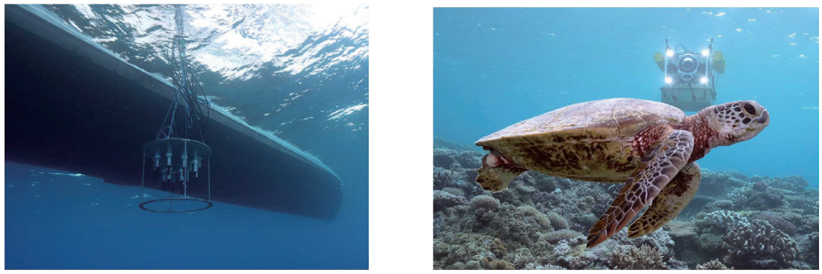


Fig. 5. Acoustic communication technology.

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.