# Sharing Moments of "This Is It!" with Colleagues to Research and Develop Optical Communication Technology for Revolutionizing Society

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**Overview**

The development of information and communication technology (ICT) has revolutionized people's social lives. Amidst the current unprecedented situation due to the worldwide spread of the novel coronavirus, services and applications that use ICT, such as teleworking and online diagnosis, have been supporting people's lives and economic activities. According to the White Paper on Information and Communications in Japan issued by the Ministry of Internal Affairs and Communications, the number of Internet-of-Things devices installed worldwide is said to reach 40 billion in a few years. We asked NTT Fellow Yutaka Miyamoto, NTT Network Innovation Laboratories, about his research and development on the optical communication infrastructure that supports these ICT services and application and path to its practical application and his attitude as a researcher.

*Keywords: high-capacity optical communication, capacity crunch, scalable optical-communication technology*

## Challenge to overcome the capacity crunch

*—Please tell us about the research you are currently undertaking.*

NTT has been a world leader in the research and development (R&D) of optical communication technology. We started practical application of time-division multiplexing (TDM) optical-fiber transmission systems in 1981. By triggering three paradigm shifts concerning optical transport systems, namely, the development of optically amplified transmission systems, wavelength-division-multiplexing (WDM) systems, and digital coherent systems, we have increased transmission capacity by about $10^6$ times over the past 40 years. The amount of data traffic continues to increase at an annual growth rate of

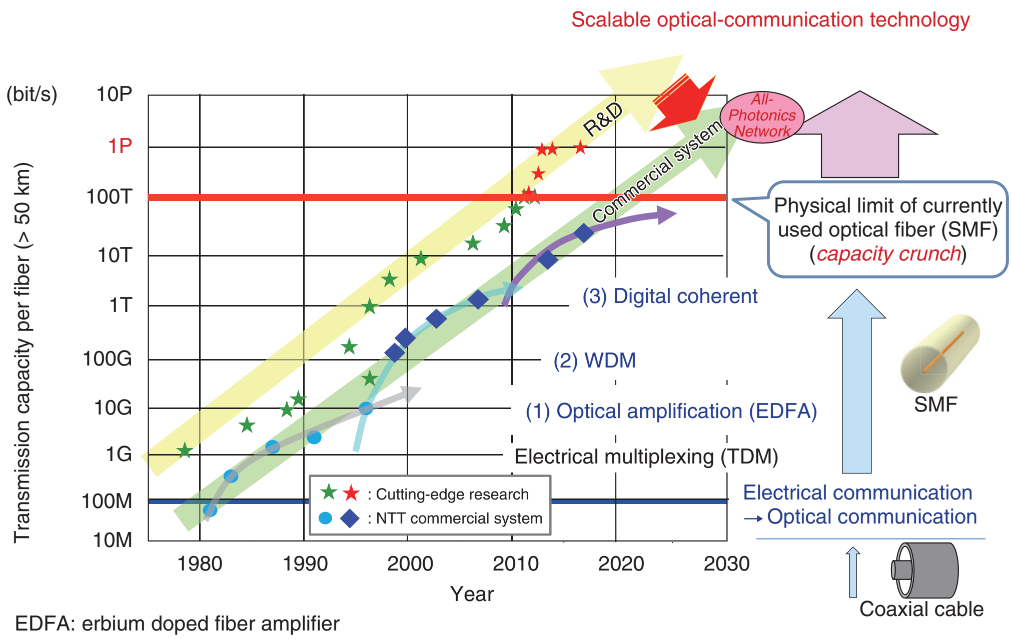


Fig. 1. Challenge to overcome the capacity crunch by using scalable optical-communication technology.

about 1.4 times, and as the full-scale introduction of fifth-generation mobile communication systems (5G) and the Internet of Things progresses, it is expected to continue to increase exponentially [1].

A high-capacity WDM system using digital coherent detection with a channel capacity of 100 to 400 gigabits per second (Gbit/s) per wavelength has recently been developed and installed in our network, enabling high-capacity long-distance transmission with the total system capacity of 8 terabits per second (Tbit/s) via a single fiber [2, 3]. Through further upgrading of the digital coherent system, a channel capacity of 600-Gbit/s per wavelength will soon be commercially available. It is expected that high-speed transmission exceeding 1 Tbit/s per wavelength will be achieved by pursuing cutting-edge R&D [3, 4].

If the development of the optical-communication infrastructure over the next 10 years is predicted based on the trend concerning commercial systems shown in **Fig. 1**, it becomes clear that long-distance transmission with petabit-per-second (Pbit/s)-class capacity will be required by the 2030s. According to recent research, however, the ultimate physical limit of transmission capacity in long-distance transmission using an installed optical fiber, that is, single-mode fiber (SMF), has become apparent near 100 Tbit/s—the so-called *capacity crunch*. The R&D that we are conducting to overcome this capacity crunch and create a petabit-class optical communication infrastructure that can economically accommodate 100 times or more the current data traffic while ensuring low power consumption is called *scalable optical-communication technology* [1]. To achieve this, I believe that we must pursue technological innovation that combines the optical transmission technology that we have been developing with new transmission medium technology (optical fiber). In other words, a *fourth paradigm shift* is necessary.

As an example of such R&D, working closely with the optical materials and devices research group at NTT, we are researching a space-division multiplexing (SDM) optical-communication technology that can increase transmission capacity per optical fiber exceeding 1 Pbit/s, which is more than 125 times that of a practical system using SMF. In 2012, in collaboration with domestic and overseas research institutes, we experimentally demonstrated a transmission capacity of 84 Tbit/s per core, namely, transmitting optical signals at 1.01 Pbit/s per fiber (i.e., 84 Tbit/s × 12 cores) over 52.4 km. This was the world's first 1-Pbit/s transmission experiment by using a multi-core fiber (MCF) housing with 12 cores (i.e., paths of optical signals transmitted within the optical fiber) in one optical fiber and by wavelength multiplexing 32 quadrature-amplitude modulation (32QAM) signals

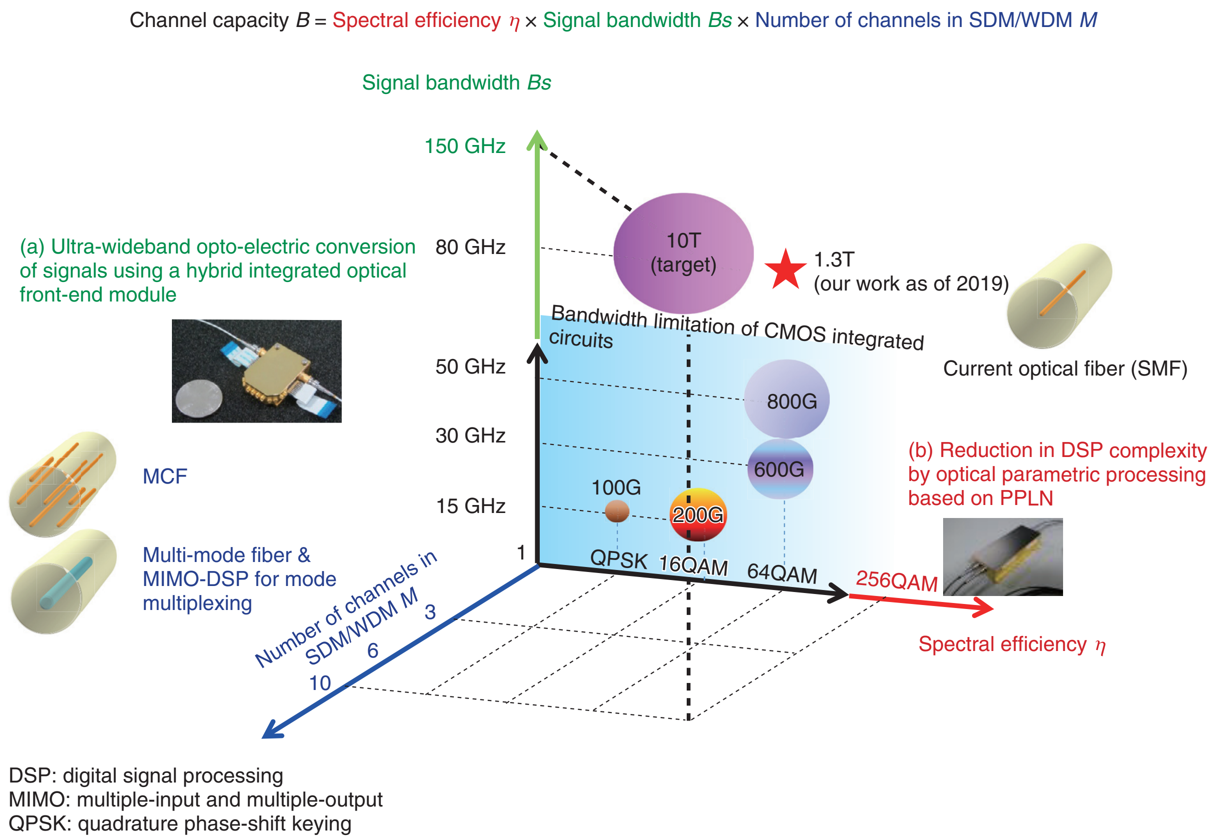


Fig. 2. Efforts to achieve 10-Tbit/s capacity per channel.

(an advanced higher-order QAM digital-coherent technology). In 2017, we confirmed the feasibility of a long-distance optically amplified transmission system over 1000 km at 1 Pbit/s using a 32-core MCF (Fig. 1).

To increase transmission capacity per wavelength (channel capacity), we are working closely with the device research group at NTT toward optical-transmission technology with 10-Tbit/s-class channel capacity. For example, by using SMF, we demonstrated the world's first long-distance WDM transmission system with a channel capacity of 1 Tbit/s, which has been difficult to achieve with conventional silicon complementary metal oxide semiconductor (CMOS) circuits and device-packaging technology. In 2019, on the basis of a new opto-electronic integrated configuration of an ultrahigh-speed optical transceiver front-end circuit, we successfully demonstrated a long-distance WDM transmission system with the world's fastest channel capacity of 1.3 Tbit/s. This was enabled by integrating an analog-multiplexer integrated circuit (AMUX IC) (with bandwidth over 100 GHz) and a broadband indium phosphide (InP) semiconductor modulator into an optical front-end module (**Fig. 2(a)**).

We are also researching and developing optical parametric amplification technologies based on periodically poled lithium niobate (PPLN) that NTT laboratories have been developing over several years. These technologies dramatically reduce the complexity of digital signal processing and significantly enhance the bandwidth of optical amplification and wavelength conversion, which are difficult to accomplish with conventional technologies only (**Fig. 2(b)**).

*—You have been producing world-first achievements. Do you feel that you are driving trends and are on the cutting edge?*

I feel that we have somehow caught up with the times. For the optical communication infrastructure we have been researching and developing at NTT (Fig. 1), it took about 10 years from the time target performance was first experimentally verified (yellow line) in the R&D stage until systems were installed in commercial networks (green line). The reason that so much time is needed is that once the optical communication infrastructure is introduced, it must be maintained and operated over a system life of 10 years or more. In other words, it cannot be removed immediately once installed, so careful consideration is required. During global competition in the advanced-research phase when the target performance was experimentally demonstrated for the first time was when we developed a method for achieving the desired performance. Since communication systems cannot be created with one elemental technology, researchers devise various elemental technologies during the first half of the decade and repeatedly test the system performance of various combinations of such technologies. In the later practical-application phase, through various efforts such as (i) determining which combination of elemental technologies can withstand the economic and reliability requirements and (ii) investigating the possibility of internationally standardizing the necessary components of the system while finding a development partner, we will continue to select our technology candidates. Through these considerations, we have put the selected technologies into practical use. Technologies that survive the original idea to be put to practical use account for about 20 to 30% of the technologies we are researching; the remainder have been shelved. To reach the final goal of practical application, it is therefore always important to have multiple technology portfolios regarding system development.

Various optical communication technologies developed for telecoms have recently started to be introduced into datacenters of corporations such as GAFA (Google, Apple, Facebook, and Amazon), who demand performance from a different perspective than telecom applications. Since the life cycle of technologies for these corporations is short and the approach to maintenance and operation differs significantly, the performance required by R&D and the speed of R&D are also changing significantly. In other words, R&D that matches the changing times is needed.

Interestingly, I feel that the optical communication infrastructure and new information services are developing in a balanced relationship, like a chicken-and-egg situation. I joined NTT in 1988, when the telecommunication infrastructure mainly carried telephone traffic. At that time, the paradigm shift in optical communication systems using optical amplification technology began. I was fortunate to be able to engage in R&D and practical application of a long-distance optically amplified transmission system with a total capacity of 10 Gbit/s using one wavelength per optical fiber. When such transmission was first installed in a practical network in 1996, some people said that its capacity was too large for telephone traffic and it might be unnecessary to expand that capacity further. However, in the late 1990s, as the spread of the commercial Internet in Japan accelerated, Internet providers were appearing one after another, and we entered an era in which transmission capacity was insufficient, even in regional networks. Under those circumstances, 10-Gbit/s optical-communication infrastructure was quickly introduced throughout Japan and spread globally. I have had many similar experiences. The era of using smartphones as a matter of course has recently arrived, and to adequately accommodate the demands concerning data traffic on the mobile Internet, the 100-Gbit/s per wavelength optical communication infrastructure using the digital coherent technology I mentioned earlier was deployed in a timely manner. With the spread of 5G services, which started commercial services in 2020 in Japan, it is assumed that the transmission capacity will be insufficient again as new services and industries are created. Therefore, I believe it is necessary to continue our R&D to provide the communication infrastructure required by society of a particular time.

Thus far, I couldn't have predicted all the technological trends that I mentioned above. Rather, by perpetuating the R&D cycle and practical application of transmission systems that satisfy the current required performance, we were able to catch up with current performance demands. I think that the reward of continuing this R&D cycle and practical application is being able to feel the huge impact that these practical optical fiber communication technologies have on society. For example, due to the novel coronavirus pandemic, this interview is being conducted via a web conference. Such real-time video communication, which many people now take for granted, was unthinkable a short while ago. The importance of the telecommunications infrastructure is emphasized in the event of such a sudden pandemic or natural disaster, but this infrastructure cannot evolve overnight. Therefore, it is necessary to work diligently in responding to development and future social infrastructure needs. I believe that only through steady R&D can we provide technology that meets people's expectations in a timely manner.

### Timely R&D, practical application, and converting irrational ideas into common sense are required

*—You have focused on creating robust technology that can quickly meet the needs of the society of a particular time. How did you actually feel on becoming an NTT Fellow? And please tell us what you have valued in your research.*

Playing my part to prevent the spread of the novel coronavirus, I've been working from home, so I haven't really felt much about being an NTT Fellow yet. I think that what NTT laboratories have been constantly pursuing as a world leader on the cutting edge from before I joined until now can be condensed in the sentence, "Let's conduct research by drawing from the fountain of knowledge and providing specific benefits to society through practical applications" by Goro Yoshida, the first director of the Electrical Communication Laboratory of Nippon Telegram and Telephone Public Corporation (currently NTT).

In other words, I think this mantra has been passed from generation to generation by mobilizing all kinds of "intellectual fountains" of NTT laboratories while continuing the R&D cycle and practical application that I have talked about. I think that one of my roles as an NTT Fellow is to receive the baton that has passed the fountain of knowledge from which ideas and knowledge spring up like water from a fountain to the next generation through everyday R&D.

In the R&D cycle and practical application, common problems are identified in the first phase of R&D and many irrational ideas are brought to light. Then, the next practical phase is the act of selecting the idea with outstanding practicality and converting what was born from an irrational idea into common sense. By continuously repeating this process, we accumulate knowledge and ideas, creating the next ideas and insights, that is, it becomes a fountain of knowledge. I think it is important to develop and accumulate ideas and knowledge in this manner so that they do not wither. The words of Goro Yoshida I mentioned above are a kind of motto to me as a researcher, and as an NTT Fellow, I think they will be a guide for me to lead the people around me and implement ideas.

I remember that when I joined NTT, my superiors taught me that the Japanese Kanji character "chi" has two meanings. One is knowledge and the other is wisdom. Although I didn't really understand it at that time, as I gained experience, I finally came to understand that knowledge is an insight into various fields and wisdom is how to use that insight. As new people enter your team, new knowledge will flow in. I think making that knowledge into something useful depends on wisdom to apply that knowledge in a timely manner in accordance with the demands of the times. When we are engaged in R&D and practical application while confronting the times and the trends in technology, there are moments when we feel the inspiration of wisdom and shout, "This is it!" Although it is very difficult to express this feeling in words, I think it is very important to not let such moments get away and to focus on them. In my case, I've experienced the process from R&D to practical application about three times, and within those experiences, I've had moments in which I shared the feeling of "This is it!" with my research colleagues. This moment is exactly like when the fountain of knowledge is gushing. That is, we can share our goals and values only by repeating trial and error through daily experiments and commercialization efforts together with colleagues involved in the same R&D, and we can feel that wisdom resonate between us through the phrases, "This is it!" and "That's right!" I want to proceed with R&D by sharing such moments with as many colleagues and development partners as possible.

About five years ago, I had the opportunity to collaborate with an overseas R&D partner. I experienced that how Japanese people communicate with each other did not work in such a collaborative situation. At that time, I wondered how to handle such a situation and realized that no matter what country the partner is from, the key to success is to share the same goals and express them clearly in words. Even if there are conflicting opinions, if you can share your goals and values, you can return to the basics and overcome those conflicts.

In the early 2000s, by applying communication methods (e.g., error-correction codes and differential phase modulation) that use the properties of light waves, we experimentally demonstrated the world's first long-distance WDM transmission with a capacity of 43 Gbit/s per wavelength. However, while conducting field investigations at the practical-development stage, we discovered that sufficient performance could not be secured with a combination of elemental technologies we prepared at the beginning. Under this circumstance and to meet the performance required by a practical system, we were forced to develop additional elemental technologies.

At that time, I was the project leader for the development of signal-processing large-scale integrated circuits (LSIs) for optical transport networks, but I was pretty much overwhelmed by this situation. Even so, we managed to launch elemental technology prepared as future technology ahead of schedule and put it to practical use. In the real world, it is impossible to predict what will happen, and many things cannot be understood without actually measuring them in a real environment. It is often the case that certain tasks cannot be done by one person alone; however, I had the experience that I could somehow reach my goal even at such times if the technology portfolio was prepared. I think that having the courage to take the next step in difficult situations and overcoming various difficulties faced thus far has stemmed from being able to make the right decisions by sharing objectives and wisdom with many outstanding colleagues and development partners and resonating with them through the phrases, “This is it!” and “That’s right!”.

To make a calm decision even in such a difficult situation, it is sometimes important to rest the mind and body to keep your feeling fresh. As I mentioned above, I often feel run down when I don’t get the desired results, so I may not be able to proceed without resetting my mind. For that reason, I think it’s good to have your own reset mechanism, such as hobbies and meditation. I enjoy appreciating art. Above all, I like Rene Magritte’s “The Large Family.” In addition, Samuel Ullman’s timeless poetic masterpiece “Youth” gives me courage. A friend read me the following line from that poem, “In the center of your heart and my heart there is a wireless station; so long as it receives messages of beauty, hope, cheer, courage and power from men and from the Infinite, so long are you young.” As a researcher of telecommunications technology, I’m moved by the fact that the author uses an expression associated with wireless communication, namely, a “wireless station” of the heart. When that poem was written about 100 years ago, it was just before the first practical use of wireless communication enabling transoceanic communication, and it was the first time a maritime disaster—the sinking of the Titanic—was wirelessly detected in the middle of the Atlantic Ocean, so lives were probably saved by this first use of wireless technology. Knowing the importance of wireless communication, which enabled global real-time communication for the first time, was recognized around the world and used as a metaphor for works of art, I believe that telecommunications technology can have a huge impact on society and people’s minds in any period and am encouraged every time I read that poem.

*—Would you say a word or two to our young researchers?*

As a researcher at NTT laboratories, I feel that although the time spent on one research theme may seem long, it is actually short. I really hope that by making the best use of the various intellectual fountains unique to NTT laboratories and using your time well, you will strive to come across research themes that only you can pursue. I believe that if you continue to make that effort, you will surely meet the moment when you say, “This is it!” Since I was assigned to NTT laboratories, I have delved into the research theme of optical communication systems, which was a completely different field from my specialty as a student. At first, I sometimes got depressed because I couldn’t participate in any discussions but I continued trying and encountered challenging research themes. When such an opportunity arises, I want you to do your best to tackle the technical challenges that you will face.

I believe that one of the missions of researchers in the field of system development for corporations is to create something useful for the world while balancing R&D and practical application. In particular, R&D on communication systems cannot be done by one person because of the wide variety of elemental technologies. The happiest time for researchers is when they reach their goals. I’d like to experience such times with outstanding partners and colleagues, and I’d like all researchers who are taking up challenges in new fields to experience that happiness over and over again. As I said before, technology concerning social infrastructure is critical, and its importance is highlighted in times of emergency; however, it usually goes unnoticed. It takes ten years for time-appropriate technological development to be put into practical use. Although such development does not receive much attention, it is important to continue it, so I’ll do my best to do so.

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## ■ Interviewee profile

**Yutaka Miyamoto**

NTT Fellow, Director, Innovative Photonic Network Research Center, NTT Network Innovation Laboratories.

He received a B.E. and M.E. in electrical engineering from Waseda University, Tokyo, in 1986 and 1988, and a Dr. Eng. from the University of Tokyo. He joined NTT Transmission Systems Laboratories in 1988, where he engaged in R&D of high-speed optical communications systems including the first 10-Gbit/s terrestrial optical transmission system (FA-10G) using erbium-doped optical fiber amplifier (EDFA) inline repeaters. He was with NTT Electronics Technology Corporation between 1995 and 1997, where he engaged in the planning and product development of high-speed optical modules at data rates of 10 Gbit/s and beyond. Since 1997, he has been with NTT Network Innovation Labs, where he has been researching and developing optical transport technologies based on 40/100/400-Gbit/s channels and beyond. He has been investigating and promoting scalable optical transport networks with Pbit/s-class capacity based on innovative optical transport technologies such as digital signal processing, space division multiplexing, and cutting-edge integrated devices for photonic pre-processing. He is a member of the Institute of Electrical and Electronics Engineers (IEEE) and a Fellow of the Institute of Electronics, Information and Communication Engineers (IEICE).