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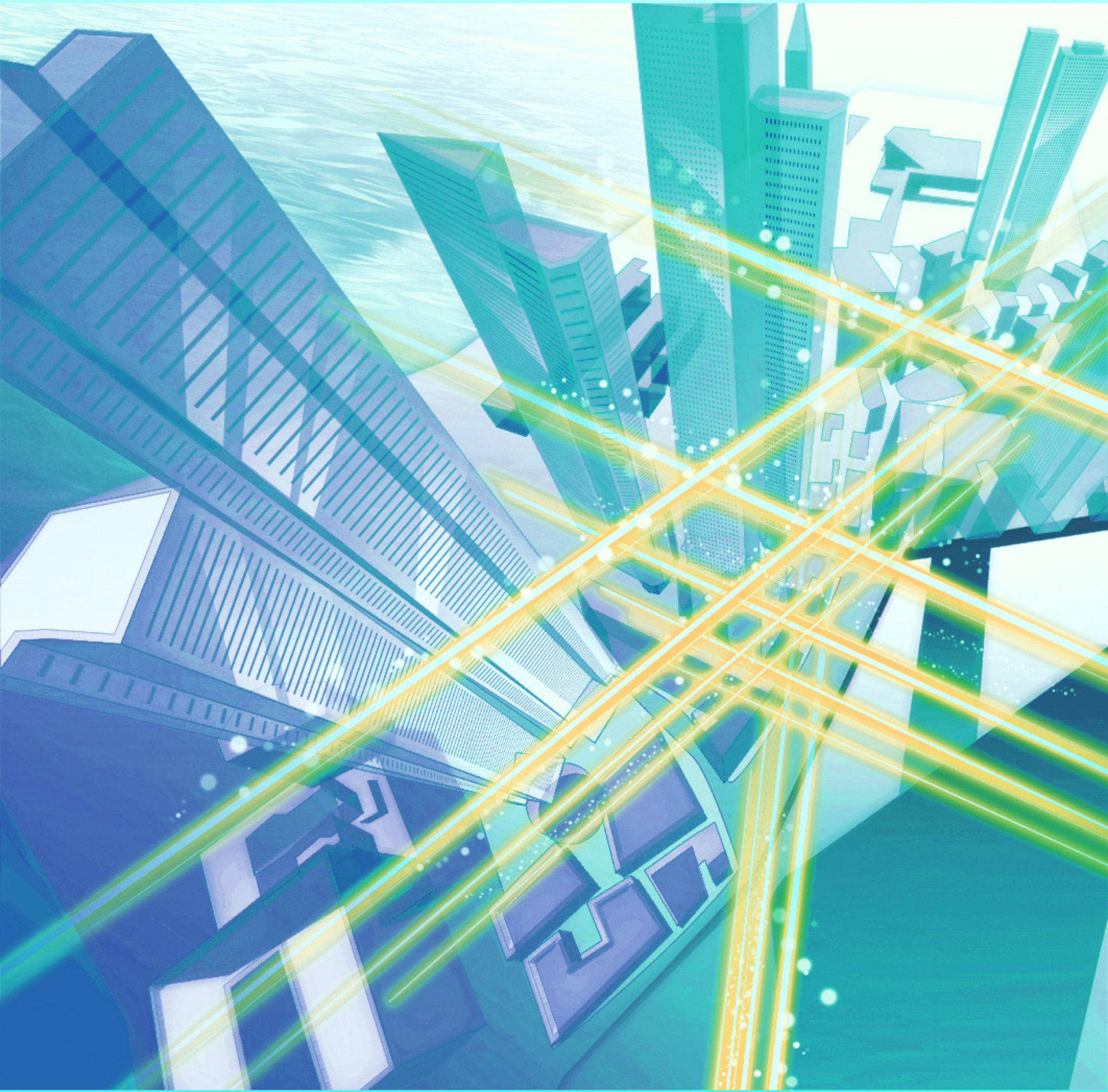

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No Pain No Gain. Communication in Uncomfortable Environments and Unfamiliar Fields Creates a Chance to Grow

Naoyuki Taniguchi
Director, NTT Anode Energy

Overview

After the Great East Japan Earthquake in 2011, Japan decided to review its energy and environmental policies from scratch. Accordingly, Japan has been promoting the introduction of renewable energy to replace some of the energy demand supplied by nuclear power and energy-saving technologies to reduce overall demand. *Green growth*, namely, fostering economic growth by introducing and expanding renewable and other green energies, is a global issue. We asked Naoyuki Taniguchi, director of NTT Anode Energy, about the business strategy of the company, which was established in June 2019 as a strategic company that oversees the energy-related business of the NTT Group.

Keywords: renewable energy, smart-energy solution, environmental issue

Providing a new *smart-energy solution* for social issues related to the environment and energy

—NTT Anode Energy was established in June 2019. Could you tell us the purpose of establishing an NTT Group company for handling energy business?

The NTT Group is working with partners to solve social issues by promoting digital transformation among its customers by using information and communication technology (ICT) on the basis of its new medium-term management strategy called "Your Value Partner 2025." In line with this strategy, we are aiming to address social issues related to the environment and energy by providing a new *smart-energy solution* to complement the existing AC (alternating current) network. This smart-energy solution is composed of information technology, power-supply technology such as direct current (DC) power supplies, central-office resources such as storage batteries, and DC grids that leverage NTT Group's technologies, know-how, and assets. We provide new value by improving energy efficiency, offering global-warming countermeasures, increasing the use of renewable energy, and enhancing disaster resilience.

To swiftly promote new smart-energy-solution businesses, NTT Anode Energy was established as a strategic company for supervising the energy-related business of the NTT Group, which had been conducted by NTT Facilities, Ennet, and NTT Smile Energy, and has expanded in annual sales to 300 billion yen through cooperation with gas utilities. While continuing to promote this business, we are fostering business creation by using people, technology, and assets as well as bolstering smart-energy business for medium to long-term business growth. We are aiming to double the sales volume of energy-related business by NTT Anode Energy and its group companies Ennet and NTT Smile Energy to 600 billion yen by FY 2025.

—What are your specific areas?

In November 2019, we announced the NTT Anode Energy Medium-Term Vision for creating a new energy-distribution system and contributing to creating a sustainable society. This vision states that NTT Anode Energy has three roles: (1) *customer-value creation*, i.e., building a connected value chain by providing solutions using distributed energy resources such as renewable energy and storage batteries, invigorating industries by improving the efficiency of energy use and increasing environmental value; (2) *strengthening social infrastructure*, i.e., constructing new distributed systems that enable sophisticated use of energy through autonomous and optimal control using ICT and data, providing stable energy in a resilient manner to local communities by complementing existing power-supply systems; and (3) *environmental adaptation*, i.e., creating an energy-recycling society by securing energy centered on renewable energy and maximizing its use as a locally produced locally consumable power source with high environmental value.

Taking on these roles, we are expanding the following five businesses: (i) *backup power supply*, i.e., transforming multiple businesses into a community and strengthening local resilience; (ii) *virtual power plant (VPP)*, i.e., aggregating energy resources and adjusting demand according to supply conditions; (iii) *green power generation*, i.e., creating environmental value (including local production for local consumption of power sources); (iv) *electricity retail*, i.e., providing energy with environmental value; and (v) *new services*, i.e., providing an energy-data platform that integrates energy with ICT and local industry (agriculture, etc.).

Specifically, we will start services to provide solar power and batteries on customers' premises that can be used as backup power in emergencies to public and critical institutions such as municipalities and medical institutions. We are also investigating providing emergency-power services using electric vehicles owned by the NTT Group in line with the "EV100" initiative that the Group is working on as well as applying the Innovative Optical and Wireless Network (IOWN) to the energy field in the future. Installing sensors, cameras, 5G (fifth-generation

mobile communication systems), etc. in cities will enable us to comprehend information on energy use in those cities in the digital world. When a power outage occurs, it will be possible to digitally check information on where the people and facilities that actually need electricity are, instantly simulate how much energy is needed to support such people and facilities, and what to do to cover that energy demand by using IOWN, including artificial intelligence, and give feedback to the real world. Thus far, countermeasures have been taken after investigating damage due to disasters or accidents; however, IOWN makes it possible to immediately comprehend the necessary actions and energy allocation to minimize the effect of power outages. Accordingly, I believe it is necessary to diffuse new energy resources, such as storage batteries and solar power, throughout society. On top of that, in cooperation with Ennet and NTT Smile Energy, in anticipation of the further spread of electric vehicles, we are conducting demonstration experiments in several regions of Japan, such as on managing the charging of electric vehicles and using them as power sources.

If you create your own scenario, make it a reality according to your convictions

—What kind of competence and responsibilities were required when launching the company?

The energy business we support is characterized by an extremely long timeframe. A large renewable-energy project requires ten years and even a small one requires a few years. The world is changing so fast that it is difficult to foresee the world 10 to 20 years from now. On the other hand, if we don't decide on such a project now, we won't get the energy that we envision in 10 years. Therefore, even in very uncertain situations, we need to make quick decisions so that we can fulfill our role promptly. I think that such decision making is required of me—which is a huge responsibility.

Moreover, to make these actions worthwhile, I think it is important to watch social trends, imagine the future, and build one's own scenario, even though one cannot be completely certain. Then, when moving towards making that scenario a reality, ask yourself what should be valued and make decisions according to your convictions.

Regarding environmental issues, at the United Nations Climate Action Summit 2019, 16-year-old Swedish schoolgirl Greta Thunberg said, "You have stolen my childhood dreams with your empty words." In response to such pressure, future measures to prevent global warming include various options: simply introduce renewable energy, create new methods of curtailing CO_2 in a different way as a result of the emergence of a new means of energy distribution, or reduce CO_2 by reducing energy consumption in the first place. This issue is closely related to our company, and I believe it is important to take actions believing that one of these options is the best.

—How do you find the knowledge for making a decision?

What I value is how I can create as many communication channels as possible with people from different types of business. I think people tend to avoid communication in uncomfortable environments and unfamiliar fields, so they often participate in gatherings directly related to their businesses and industries. However, the fact that the world changes means that the values and common perceptions of society will also change. Therefore, instead of staying in the same place, we should dare to step into places that are not directly related to our type of business and obtain information from those places. However, time is limited, so the scope of these activities is also limited. To expand my horizons as much as possible, I have made an effort to not only jump into other worlds but also create non-profit circles and attract people with a sense of purpose. I'm managing a circle in which highly motivated people can gather—regardless of nationality or industry—to exchange valuable information.

Through these activities, I met an American who once said to me, "No pain, no gain." I say this to myself when I hit a wall or get a little down. This phrase resonated deeply in my heart perhaps because of the situation I faced then.

Get advice to "jump into the ring of the opponent"

—Will communication in uncomfortable environments and unfamiliar fields lead to great opportunities?

Not exactly an opportunity, but I've had the experience of asking for others' opinions even when I can solve a problem myself. At a meeting held abroad, I became acquainted with a person in a completely different industry. I asked him that I'm thinking about such and such and what did he think. He thought hard and gave me advice. With that advice, I was able to establish a business model here in Japan that was good enough to be taken up by the mass media. Rather than arguing about ideas and opinions in discussions, I could get advice by gaining trust and asking questions.

—Through these experiences, what do you think the role of senior management is?

I feel that I have grown through my work and hope to grow further in step with the growth of the company. In that sense, work is a place where we can enhance ourselves, and that is a great way to contribute to society. Regarding being in senior management, I believe that each person has an appropriate role assigned to them that suits society, the time, and environment. It's a matter of finding the right role you should play in the environment that you are in, always being conscious, and persistently striving to fulfill your assigned role.

From now onwards, NTT Anode Energy will expand its activities in the invisible but essential world of energy. Electricity in Japan has been supplied very stably. Power outages in Japan are rare compared to other countries, and people have the common notion that electricity can be used at any time. However, inconvenience concerning electricity was exposed by recent environmental problems and disasters that occurred in various parts of Japan. Under these circumstances, the NTT Group is working to create a society in which people can feel the improvement of convenience through energy use and use energy appropriately with peace of mind.

Keeping an eye on changes in public sentiment and opinion

—Please give a few words to engineers and researchers.

As I used to be, people tend to be biased toward creating networks in the same business category. As the development of new technologies, such as IOWN and quantum computing, advances, the era in which the Fourth Industrial Revolution will come to fruition is imminent. Society can change in a completely different way than before, and current social perceptions and values can also change. To survive this transformation period, we must pay close attention to not only actions and perspectives based on values and economic rationality that simply extend previous thinking but also diversity, public sentiment and opinion. I have a sense of urgency that if we don't act while thinking ahead, we may not survive. At the same time, business and game-changing opportunities may arise in various places. From this viewpoint, to strengthen the basic skills for taking on various initiatives, I recommend networking and information exchange with people in a variety of businesses and industries that may seem irrelevant and taking actions that broaden your ideas. It's really difficult to communicate in an environment in which you are not good at. However, I think that some of the information and ideas that can be obtained will become beneficial. Therefore, to produce new technologies and outstanding results in response to changes, I'd like you to, by all means, actively step into new areas, relationships, and places.

Interviewee profile

■ Career highlights

He joined NTT in 1989. He became general manager of the Corporate Planning Department, Ennet in 2000, deputy branch manager of NTT Facilities Tokai branch in 2006, and deputy general manager of the Solar Project, NTT Facilities in 2008. He again became general manager of the Corporate Planning Department, Ennet in 2010 and director of NTT Facilities in charge of Smart Energy in 2019. He has been director of NTT Anode Energy since September 2019.

Research Is Enjoyment. Long-term Research Can Be Useful to Society

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

Overview

The Government of Japan's initiative "Society 5.0" envisions the future of Japan. It describes that in that future society, by analyzing an enormous amount of big data using artificial intelligence that exceeds human ability and feeding the results back to humans through robots and other technologies, it will be possible to create new value that could not be created before and provide it to industry and society. We interviewed Jun-ichi Kani, a senior distinguished researcher at NTT Access Network Service Systems Laboratories, who researches and develops network technologies that will support such a future, about his current research and what is the perfect world for researchers.

Keywords: access network, Full Service Access Network (FSAN), softwarization

The common language is "technology"—coordinate with peers around the world

—Could you start from your current research?

Our team is researching a new optical access network that will accelerate the evolution of information and communication services. We aim to create and spread new optical access networks through (i) research on elemental technologies and architectures that will radically enhance system performance and flexibility and (ii) global collaboration activities. In current optical access networks, data traffic is transferred to the core network at a central office in a manner much like a bus passenger transfers to a train at a station. By integrating access networks to the core network in the future, we aim to create a network that can transmit optical signals to designated locations in an end-to-end manner without the transfer of traffic (**Fig. 1**).

Optical access networks have supported the development of a broadband service called fiber to the home (FTTH). You may think that wired optical networks are no longer needed in the age of the mobile Internet. However, the equipment in central offices will be connected to 5G (fifth-generation mobile communication system) antennas, next-generation wireless local area network (LAN) antennas and so on all by optical fiber networks. What's more, given that all things—from factory machines and various sensors to transportation systems and electric-power systems—are connected by networks, requirements such as bandwidth and latency will be more diverse than before. With this background in mind, we are researching and developing optical access networks for the future on the basis of the idea that optical

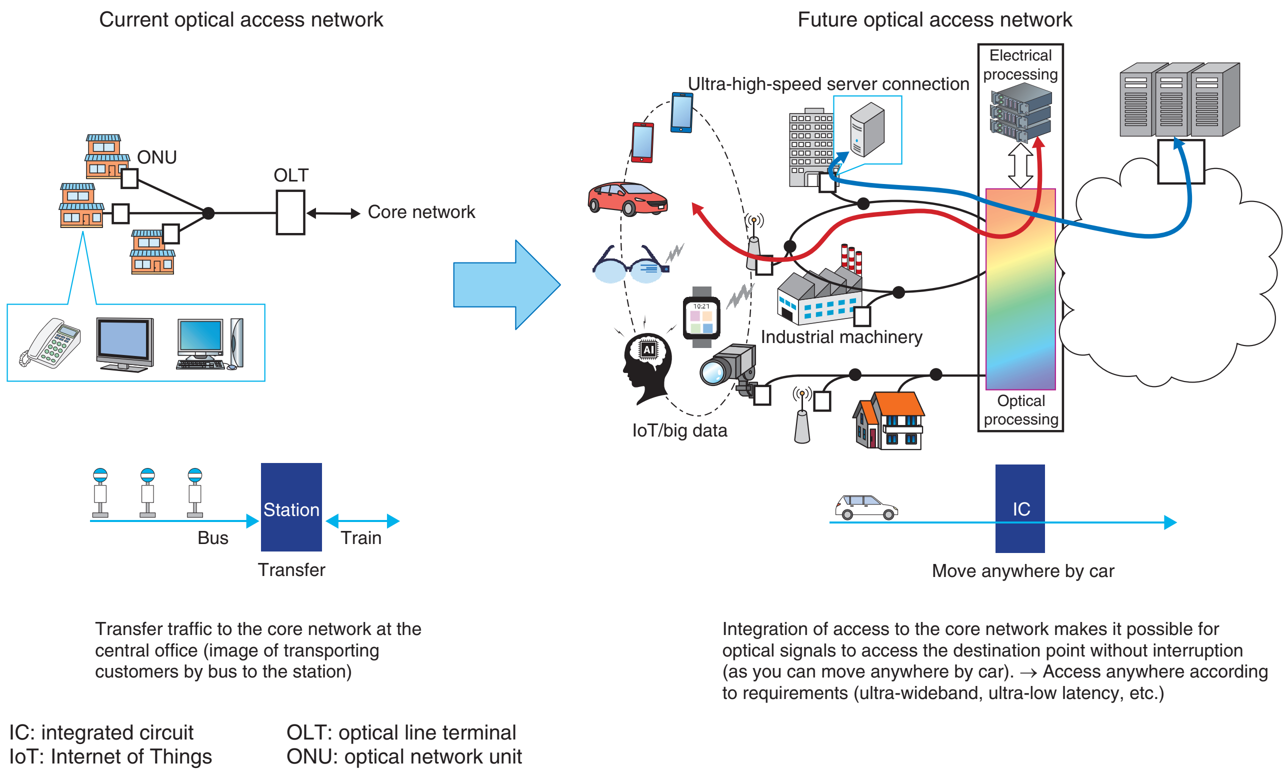
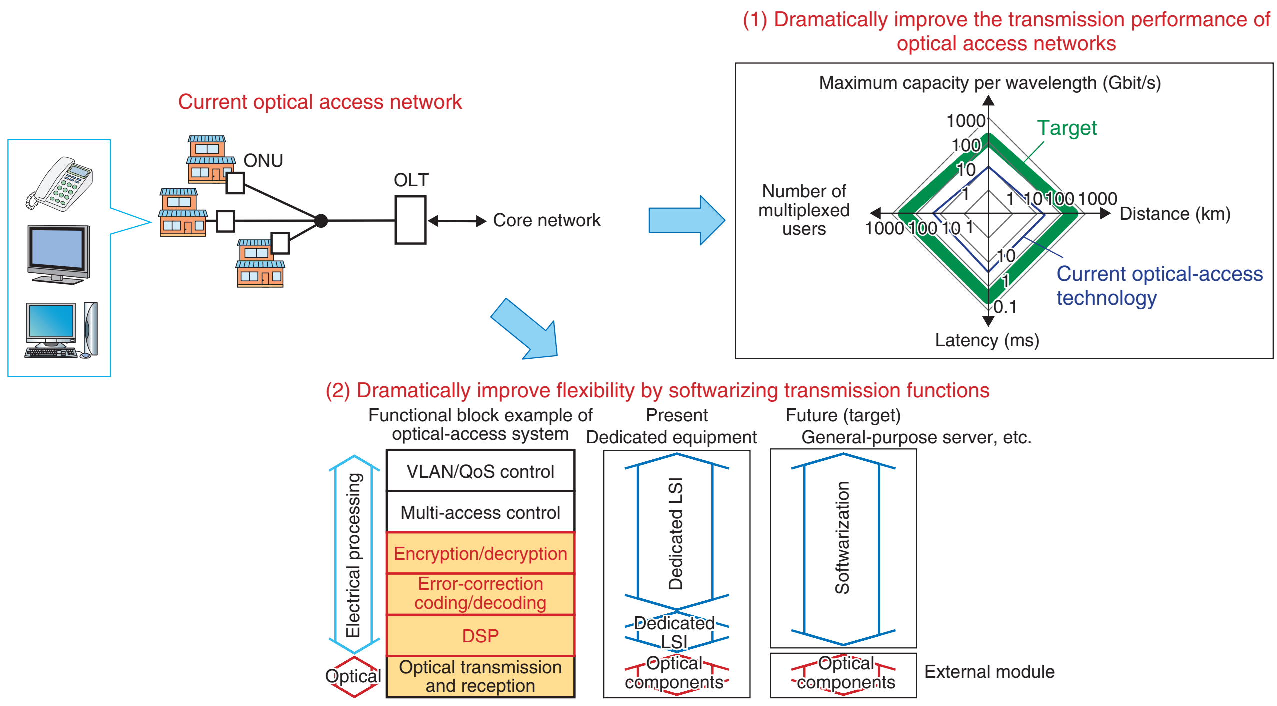


Fig. 1. Future image of optical access network.

access networks will become the common access network platform for various services and systems beyond FTTH.

Specifically, to satisfy a wider range of requirements (such as broadband and low latency) than before, we are taking on the challenge of drastically improving transmission performance of optical access networks (**Fig. 2**). As an example of taking this challenge, the world's first real-time digital coherent optical transceiver for optical access networks has been implemented by our team. Although the digital coherent reception system is used for large-capacity transmission in backbone networks, when it is applied to access, it is necessary to receive intermittent ("burst") signals with large power differences transmitted from different optical network units (ONUs). By devising and developing a real-time-signal-processing circuit in addition to a burst-compatible coherent receiving circuit, we made it possible to transmit 20-Gbit/s signals with a power difference of 20 dB (100 times) or more without errors. At the European Conference on Optical Communication (ECOC) 2016, one of the world's largest international conferences in the field of optical communications, we received a top-score evaluation in the access-network area.

To drastically improve network flexibility, we are also conducting research on softwarizing the transmission functions (Fig. 2). If the transmission functions can be executed as software on general-purpose devices such as servers and personal computers (PCs), replacement, combination, and tuning of transmission functions according to bandwidth and distance requirements will become incredibly easy. This *softwarization* is the key to creating a new network that can be accessed by optical means from anywhere, as I mentioned earlier. We are using graphics processing units and studying new algorithms in collaboration with the University of Tokyo. We achieved a processing speed of 10 Gbit/s regarding error correction, which requires the heaviest processing in current access systems, and received the Best Paper Award (in Access Networks & Systems Track of the Selected Areas in Communications Symposium) at the IEEE Global Communications Conference (GLOBECOM) 2016, a key international conference on communications. Furthermore, by implementing high-speed software processing for digital



LSI: large-scale integrated circuit
QoS: quality of service
VLAN: virtual LAN

Fig. 2. Research for creation of a new optical access network.

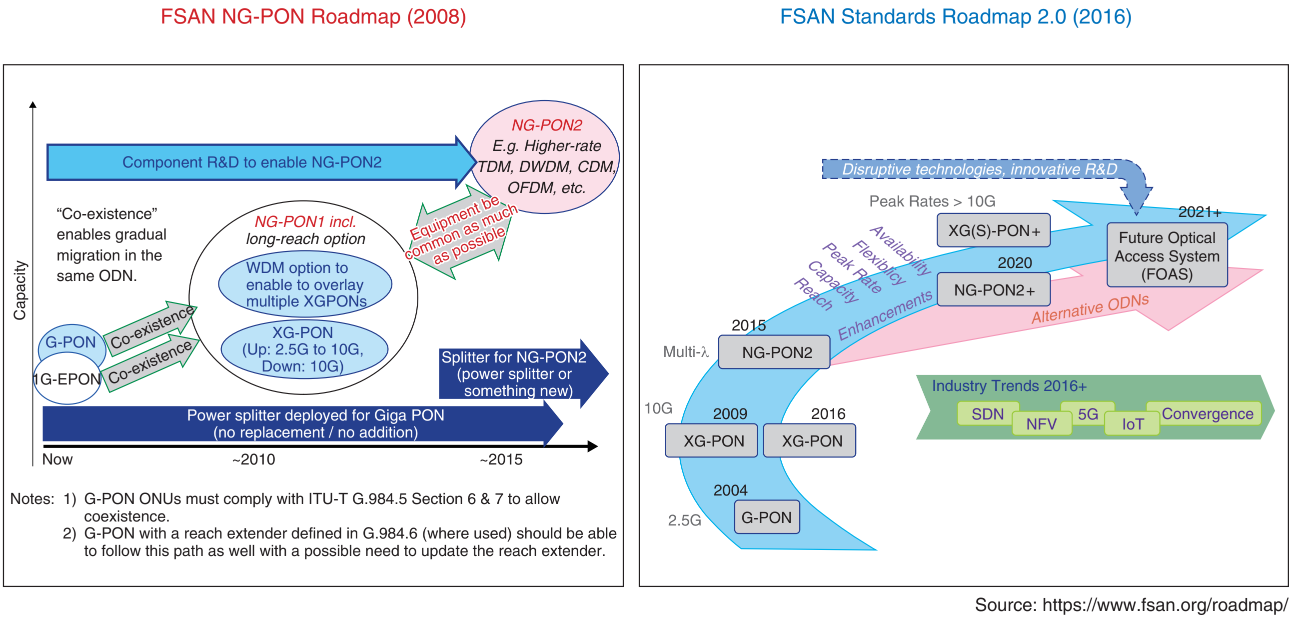
signal processing (DSP), we achieved the world's first softwarization of digital coherent optical transmission and received the top score in the access-network category at the Optical Fiber Communication Conference and Exposition (OFC) 2018, the world's largest international conference on optical communications.

—It seems like you're really leading the world with cutting-edge ideas.

I owe these achievements to our team members. As for improving the performance of the optical access networks, how to upgrade FTTH systems has been debated since around 2004 when current FTTH systems were introduced. I also started to study this issue around that time and have been researching it for over 10 years. In the meantime, mobile networks had emerged. Ahead of that mobile era, in early 2010, I began research on improving the flexibility of optical access networks. During that time, I was able to advance research and development (R&D) by always having good teams.

As part of these research activities, it is also important to be going in the same direction as other researchers and engineers. Technology will not spread unless you coordinate with your peers around the world. To that end, we are discussing and setting directions at the Full Service Access Network (FSAN), a forum in which key operators and vendors of optical access networks discuss optical access network technology. As co-chair of the Next-Generation Passive Optical Network (NG-PON) Task Group from 2003 to 2010 and as chair of that group since 2015, I have been promoting global technology collaboration.

In the early days of co-chairing the NG-PON Task Group with the other co-chair, we sometimes had difficulty in proceeding discussion. When the participants of the task group brought a variety of technical proposals, we couldn't determine the way forward. Given such a state of affairs, in 2008, we talked about making a roadmap for the evolution of optical access network technology, and created such a roadmap through discussions. It was an important milestone in terms that it not only helped to align the discussions



CDM: code division multiplexing
DWDM: dense wavelength division multiplexing
EPON: Ethernet PON
G-PON: Gigabit-capable PON
NFV: network functions virtualization
ODN: optical distribution network
OFDM: orthogonal frequency division multiplexing
SDN: software-defined network
TDM: time division multiplexing
WDM: wavelength division multiplexing
XG-PON: 10Gigabit-capable PON

Fig. 3. Technology roadmap by FSAN.

in FSAN go in the same direction but also stimulated and promoted R&D of NG-PONs. In 2016, we released FSAN Roadmap 2.0 (**Fig. 3**).

While the roadmap enabled us to head in the same direction, we still face differences of opinion. In such cases, I try to understand the reason for the difference from a technical viewpoint and think of a way we can come together through a new technical proposal. The more you discuss things technically, the more answers you will come up with. Because we are all professionals, we can discuss things in the common language of technology. Despite all the difficulties faced, technology is the ultimate solution.

Open up the future by interacting with people with different values domestically and internationally

—Could you tell us how you started your career as a researcher and what kind of researcher you envision to become?

When I was in elementary school and then junior high school, one of my hobbies was computers. At that time, fields such as biotechnology were evolving, and there were many things I was interested in, not limited to PCs and biotechnology. As I couldn't narrow my interests down to one, I entered the department of applied physics at university to try learning various subjects. Of particular interest was optical physics, and I was researching the properties of a material by using lasers. At the same time, Internet browsers emerged, and I was amazed when I saw one in the lab. At that time, optics and the Internet were completely different entities to me, but I joined NTT because it is related to both and I thought that would be interesting. Since then, the fusion of optics and the Internet has advanced rapidly. I'm not saying I could clearly predict this outcome; my interest was simply triggered by both aspects. In this way, I believe it is very important to have something interest you.

Our current research is on systems, and in some cases, it has to be divided into tasks within a team to work toward a larger goal. Motivation, such as intellectual curiosity, is necessary to produce results as a team, so I want to value this. Accordingly, I tell team members that it is interesting when I find something is interesting from the bottom of my heart. In fact, our job is really interesting. Whether you are experimenting, thinking about new ideas, or discussing experimental results, I think it's important to share things you truly interested in while moving forward. I work with a good team that acknowledges other members genuinely regardless of age or position.

By the way, when I was a new employee, the research laboratory to which I was assigned had a development center, and I imagined that everyone there would create something useful for society through practical research. Therefore, I wanted to start with creating ideas and launch new technologies useful to society. I thought that desire was the way to be a researcher, and I'm still taking on that challenge. However, it is difficult to define "useful" research. At one point, I thought that R&D that yielded results in a short period was more useful. In reality, research targeting a distant-future society does not mean that it is useless in regard to today's society. For example, the Nobel Laureate Shuji Nakamura's research on blue light emitting diodes (LEDs) and blue lasers is a result of extremely practical research. The development of blue LEDs made it possible to double the storage capacity of a disk and create white LED lights, thus it is practical research but a tremendous long-term challenge. It's easy to think something becomes more useful as it becomes reachable in the short term, but I realize that this is not always the case.

—What do you value when you work?

Do you know about Amara's law? That is, the impact of new technologies is often overestimated in the short term and underestimated in the long term. Various new technologies are studied extensively in the short term as technology trends, but bold predictions in the long term tend to be avoided. However, if we look at the span of 10 or 20 years, many things have changed much more than expected. When creating the roadmap for FSAN, I heard about this law from a fellow German researcher. I thought it was important at that time, but as I got to work, its importance really sank in. As I mentioned earlier, I once thought that short-term considerations would be more useful, but now I don't. It's fun to imagine how the world will change from a long-term perspective, so I try to enjoy researching without underestimating the impact of various technologies. In fact, I've been doing R&D for more than 20 years, and the most fun part has been envisioning a future world. I want to talk to various people. In the case of research, although it is important to think for yourself, talking with people can be very stimulating. Either in our laboratories or on the global stage, you can get inspiration from people with different values.

Whatever you get yourself involved with will eventually be meaningful

—Please say a word to young researchers.

Everyone has an edge in a good way and wants to do something. I want you to extend that ambition as much as possible. Do whatever you are interested in. A famous speech by Steve Jobs is called "Connecting The Dots." While at university, he became interested in calligraphy, which led to a variety of fonts on Mac PCs. He said "You can't connect the dots looking forward; you can only connect them looking backwards." I think it applies to our research, and in my case, my interest in optics and the Internet has led to current research in a similar manner. It's a shame to stop researching on your interests just because it doesn't immediately lead to results. I think that some things could lead to results later, so I'd like you to try various things even if they are unrelated to the current research.

Stand on the global stage. Researchers and engineers around the world are purely amazing, and many people have completely different approaches to thinking, so the range of stimulation is very large. There might be a language barrier, but we have technology in common. It is difficult, but I think this barrier can be overcome by a common language, that is technology.

—How will you proceed in the future?

The Science and Technology Basic Plan by the Japanese Government shows the future of Japan. That future society is called "Society 5.0." Put simply, it is a fusion of cyber space and physical space. Artificial intelligence and virtual reality are thought to be the major players to make this a reality. It is also very important that information be transmitted smoothly by optical communication on an infrastructure that supports them. Although optical communication is behind the scenes in terms of technology that supports the infrastructure, I think it is a crucial technology that will help society by accelerating the evolution of information and communication technology (ICT) services. I'd like to continue to take the challenge of developing advanced technologies of optical access.

Part of my desire is to help the world in a supporting role, but another part is driven purely by intellectual curiosity. NTT has announced the Innovative Optical and Wireless Network (IOWN) as a future vision of an optical-based network and information-processing platform. To make this vision a reality, our team will take on the challenge of creating a new world and new ways of networking, and we hope to create a new ICT world around 2030.

■ **Interviewee profile**
Jun-ichi Kani

Senior Distinguished Researcher, Group Leader, Optical Access Systems Project, NTT Access Network Service Systems Laboratories.

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

Initiatives Concerning All-Photonics-Network-related Technologies Based on IOWN

Arata Itoh

Abstract

With the ongoing rapid digitization of society, various issues are expected to arise in the near future. Accordingly, NTT is advocating the Innovative Optical and Wireless Network (IOWN) and is working with partners to conduct a variety of research and development activities to bring about innovations based on IOWN. The related technologies NTT is working on to create the All-Photonics Network—one of the three components of IOWN—are introduced in this article.

Keywords: IOWN, All-Photonics Network, network technology

1. Introduction

For the last ten years, our lifestyles have been changing dramatically due to our use of the Internet—which is now an indispensable part of our lives. With various services made available on smartphones, our working styles are also evolving in various business scenes.

Global data traffic is increasing rapidly since the number of devices connected to the Internet is exploding with the development of the Internet of Things. As a result, there will be issues such as the limitations of both transmission and processing capabilities of information and communication technology (ICT) equipment and the increase in energy consumption of the equipment. Although Moore's Law (stating that the number of transistors per area of an integrated circuit doubles every 18 months) has been a measure of developments in the information-processing industry, concerns have been pointed out regarding its future sustainability. In particular, the size of existing transistors has been reduced to the order of several nanometers, and problems concerning heat generation and physical limitations in manufacturing have been pointed out.

2. What is IOWN

From the above circumstances, we are proposing the Innovative Optical and Wireless Network (IOWN) [1]. IOWN will create an innovative information-processing infrastructure that will transform existing information and communication systems and significantly improve the potential of networks beyond the limitations of conventional technologies and the barriers to power consumption, and we have started activities concerning IOWN with various partners [2]. On the basis of two major changes, namely, from *electronics to photonics* and the resulting *digital to natural*, we are promoting environmentally sustainable growth along with safety and security to benefit both individuals and society as a whole.

IOWN consists of three components: (i) the All-Photonics Network (APN), (ii) Cognitive Foundation® (CF), and (iii) Digital Twin Computing (DTC). The main approaches concerning network-related technology for creating the APN, which will greatly improve the potential of the information-processing infrastructure, are introduced in this article.

3. What is the APN

The APN converts all information transmission and

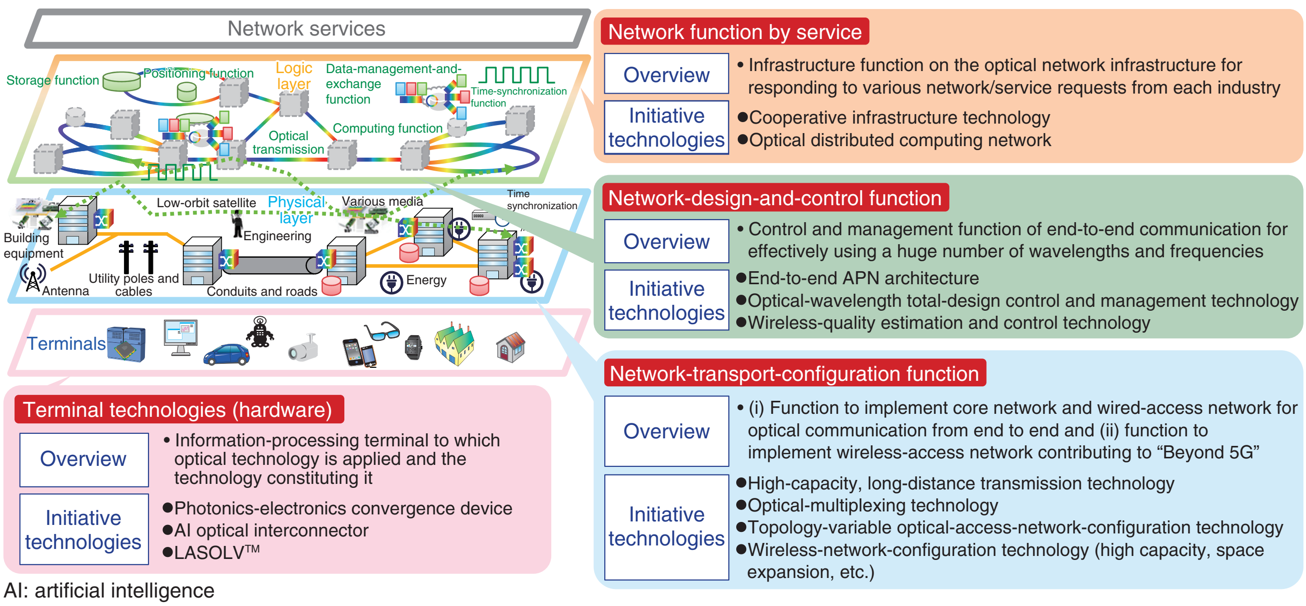


Fig. 1. Basic functions comprising the APN.

relay processing to photonics-based processes; thus, it is possible to fully use broadband properties and the flexibility of light and provide full-mesh-connection optical paths between multiple points (in wavelength units) for each terminal, user, and service. For current communication systems, it is necessary to convert optical and electrical signals in the network multiple times. In contrast, the ultimate target of the APN is to establish communication using only optical signals, that is, no electrical signals are involved.

With the APN, different wavelengths can be assigned to each piece of information. For example, while high-definition content (such as an 8K120P data stream) is being sent, it will be possible to provide mission-critical communications (such as those concerning automated driving and remote surgery) simultaneously with ultra-low delay. Unlike services provided by best-effort Internet lines, ultra-low-latency services that have large capacity and guaranteed bandwidth can be provided by IOWN.

The APN is composed of the following three basic functions (**Fig. 1**): (i) a network-transport-configuration function that creates an optical full-mesh network and wireless-access network for high-speed, high-quality data transfer from end-to-end; (ii) a network-design-and-control function for efficiently accommodating the huge number of wavelengths and frequencies required for building and operating those networks; and (iii) a network function by service that optimally combines ICT resources (such as network resources and computing resources) to provide a dedicated environment that satisfies various service requirements. In addition, terminal technologies, e.g., photonics-electronics convergence devices that achieve low power consumption and low delay per data volume, are indispensable as core technologies for configuring the devices and terminals that implement those three functions.

4. Network-related technologies for implementing the APN

NTT is currently engaged in a variety of research and development activities to implement the APN [3], and our initiatives concerning four characteristic key technologies ("topics") are introduced in the Feature Articles in this issue. As an initiative tackling a new optical transmission infrastructure, Topic 1 concerns ultra-high-capacity optical communication technology related to cutting-edge devices and components to increase the capacity of backbone networks by combining wavelength-division multiplexing and space-division multiplexing [4]. Topic 2 concerns investigations related to the above network-transport-configuration function to increase the capacity of wireless sections and increasing the degrees of freedom in deploying wireless areas [5]. Topic 3 concerns an optical full-mesh network-configuration technology that provides a transport function with large capacity and low delay [6]. Topic 4 concerns an initiative related to the network-design-and-control function, namely, a study on network-design technology for efficiently accommodating a large number of optical paths in the APN [7].

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Ultra-high-capacity Optical Communication Technology

Kazuhide Nakajima, Yutaka Miyamoto, Hideyuki Nosaka, and Mitsuteru Ishikawa

Abstract

We are researching two new technologies for sustainably and economically responding to the exponentially increasing demand for data communications: (i) optical-fiber technology for space-division multiplexing transmission overcoming the capacity limitations of existing optical fiber and (ii) terabit-class high-speed optical-transmission technology that increases channel speed per wavelength by more than one digit. By integrating new optical-fiber and high-speed optical transmission technologies, we aim to implement a new optical-transmission infrastructure with more than 100 times the potential of current optical fiber.

Keywords: high-capacity transmission, wavelength-division multiplexing, space-division multiplexing

1. Introduction

Data-communication capacity is increasing at an annual rate of 10%, and it is expected to increase exponentially on the full-scale introduction of 5G (fifth-generation mobile communication) and the Internet of Things (IoT). It is a concern that in the latter half of the 2020s, the capacity limit of the currently used optical fiber, namely, single-mode fiber (SMF), will be reached. Therefore, we are promoting research to overcome the current capacity limit by using space-division multiplexing (SDM) in addition to conventional wavelength-division multiplexing (WDM) [1]. Our research on ultra-high-capacity transmission technologies, namely, optical-fiber technology for SDM transmission and high-speed optical transmission with transmission speeds up to terabits (10^{12} bits) per second, is introduced in this article.

2. SDM optical-fiber technology

As shown in **Fig. 1**, to create SDM optical fiber that can exceed the capacity limit of existing SMF, it is feasible to increase the number of cores and modes (types of light). The type that uses core multiplexing is generally called multi-core fiber (MCF), and the type that uses mode multiplexing is generally called few-mode fiber (FMF). For few-mode multi-core optical fiber (FM-MCF), which combines N cores and M modes, it is conceivable that the transmission capacity of one optical fiber can be increased up to N × M times.

As shown in the cross-sectional photograph in **Fig. 2(a)**, MCF with four cores within the standard cladding diameter can be manufactured with the same fineness (125-µm diameter) as existing SMF. By making MCF have the same diameter as that of existing SMF, it is possible to use current cable and connector technology. On top of that, each core of the resulting MCF is fully compatible with existing SMF; as a result, compatibility with current optical transmission systems can be improved, and practicality is assured. In fact, while making the optical performance of each core the same as that of existing SMF, in proof-of-principle experiments in collaboration with multiple vendors, we prototyped a 100-km-long 4-core fiber with common specifications, sufficiently reduced leakage between cores (crosstalk), and succeeded in optically amplifying and relaying data at a transmission capacity of more than 100 terabits per second over 300 km [2]. At NTT R&D Forum

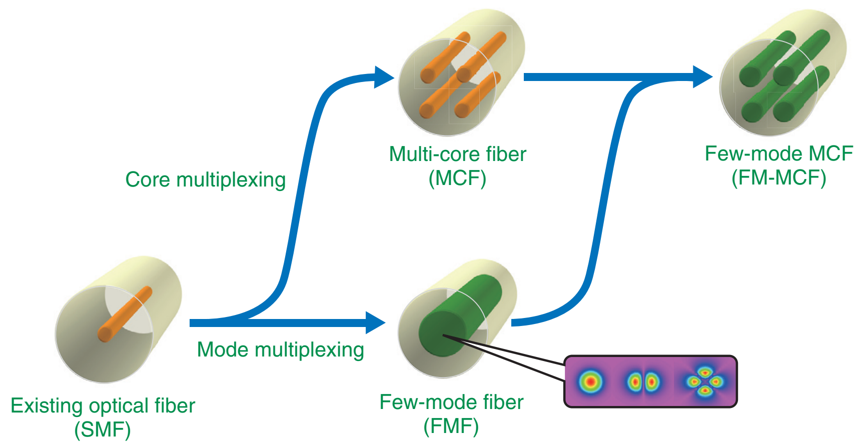
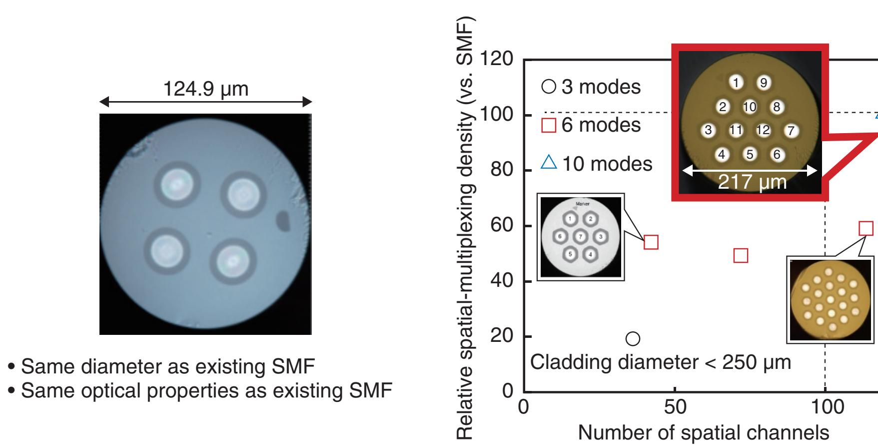


Fig. 1. Creation of optical fiber for SDM transmission by core and mode multiplexing.



(a) Standard-cladding-diameter MCF

(b) FM-MCF

Fig. 2. Examples of R&D on standard-cladding-diameter MCF and FM-MCF.

2019, a dynamic exhibition using 4-core fiber based on the above technologies was held.

An example of the future possibility of increasing the amount of spatial multiplexing by more than 100 times by using FM-MCF (in which each core of the MCF supports multi-mode propagation) as the transmission path is shown in **Fig. 2(b)**. The horizontal axis shows the number of spatial channels (obtained by multiplying the number of cores and number of modes), and the vertical axis shows relative spatial-multiplexing density based on that of existing SMF. The circular, square, and triangular plots represent the number of modes that can be propagated by each core; 3, 6, and 10 modes, respectively. Studies using 6 modes, 42 (7 cores × 6 modes) and 114 (19 cores × 6 modes) spatial channels have been conducted (e.g., [3]). However, the relative density of the FM-MCF was only about 50 times that of existing SMF. Accordingly, by increasing the number of modes per core to 10, we achieved the world's highest number of spatial channels; 120, via 12 cores × 10 modes and, at the same time, a relative density exceeding 100 [4]. This is the world's first study demonstrating that the best mix of core multiplexing and mode multiplexing can achieve 100 times the potential of existing SMF in terms of both spatial-multiplexing amount and spatial-utilization efficiency. To construct the above-mentioned FM-MCF system, it is necessary to (i)

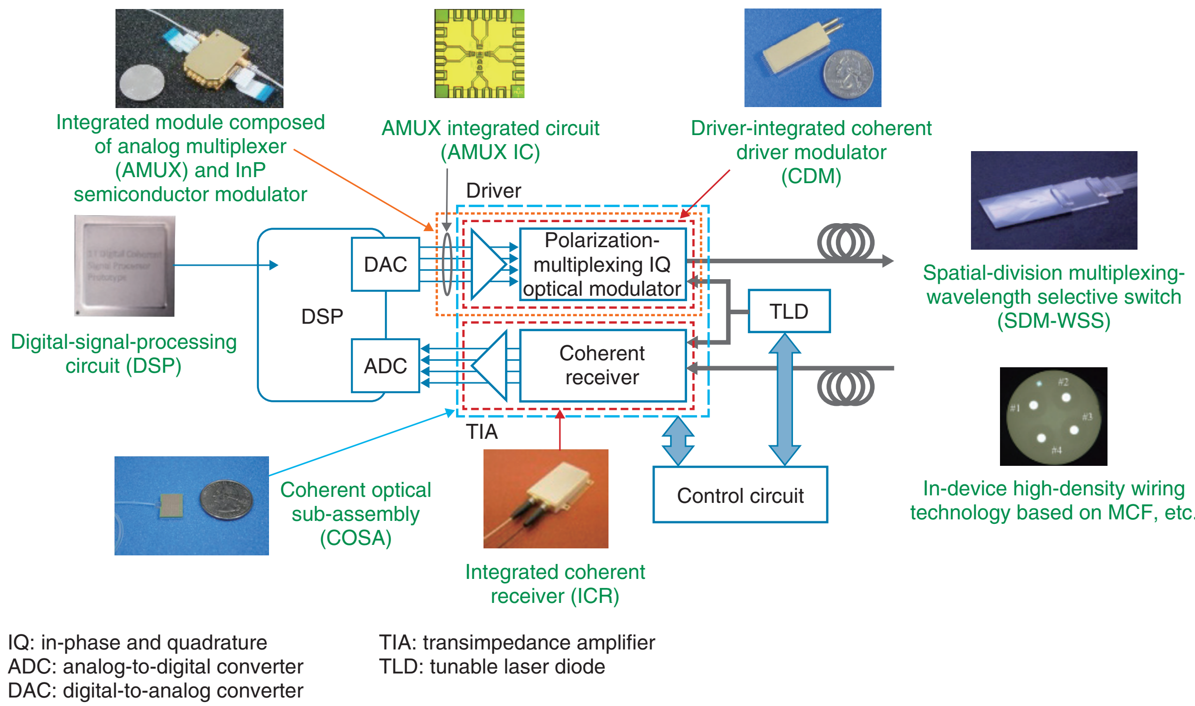


Fig. 3. Fundamental technologies for enabling 1-Tbit-class high-speed transmission.

increase the diameter of FM-MCF to about 1.5 times (about 200 μm) that of existing SMF and (ii) improve the manufacturability that can handle large-diameter optical fiber and to develop technologies for fabricating cables. We are also working on large-scale digital-signal-processing technology for stably multiplexing/dividing modes on the transceiver/receiver side.

3. Terabit-class high-speed optical-transmission technology

To economically increase the capacity of optical communication, it is important to increase channel capacity per wavelength, increase the symbol rate, and apply high-order multilevel digital modulation/demodulation technology. Fundamental technologies for configuring an ultra-high-speed optical transceiver required for 1-terabit-class optical transmission are shown in **Fig. 3**. The ultra-high-speed optical transceiver mainly consists of an ultra-high-speed digital-signal-processing circuit, namely, a digital signal processor-application specific integrated circuit (DSP-ASIC), and an ultra-high-speed optical front-end circuit (which converts optical signals to electrical ones and vice versa). Currently, digital-signal-processing technology that can operate up to a channel capacity of 600 Gbit/s and an optical front-end circuit—consisting of a driver-integrated coherent driver modulator (CDM) and an integrated coherent receiver (ICR)—are in the practical implementation phase. Long-distance-transmission experiments applying these fundamental technologies in the field have been successful [5]. From the standpoint of datacenter interconnection and metropolitan area networks, etc., optical transceiver circuits must be downsized and their power consumption reduced. To achieve dramatic miniaturization of ultra-high-speed optical-front-end circuit technology, research and development (R&D) on a coherent optical sub-assembly (COSA), in which all optical circuits, except for the wavelength-tunable light source, are integrated on a single chip, is progressing well.

R&D on achieving high-speed channel transmission exceeding 1-Tbit/s capacity per wavelength is also underway [6]. Recently, a long-distance WDM transmission experiment using existing SMF achieved a world-first capacity of 1 Tbit/s per wavelength by using a new approach to optical front-end circuit technology, namely, an optical and electronic integrated configuration. Moreover, by integrating an analog multiplexer integrated circuit (AMUX IC) (with a bandwidth of over 100 GHz) and a broadband indium phosphide (InP) semiconductor modulator into an integrated module, the world's fastest channel capacity of 1.3-Tbit/s transmission was achieved. These fundamental technologies can be used with the above-described MCF composed of a conventional single-mode core.

For future high-capacity, flexible optical networks, fundamental technologies such as (i) SDM-wavelength selective switch (SDM-WSS) integrated technology (which enables selective switching of signal light multiplexed in the space and wavelength domains), (ii) high-efficiency wavelength-conversion technology, and (iii) in-device high-density wiring technology using MCFs are expected to be improved, and we will continue to accelerate our R&D accordingly [1, 7].

4. Future developments

We will work to establish standard-cladding-diameter MCF and its related technologies. By using terabit-class high-speed optical-transmission technology, we also plan to create an ultra-high-capacity optical-transmission platform that has 100-times more potential than that of existing SMF.

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Efficiently Accommodating High-frequency-band Wireless Systems by Using Analog Radio-over-fiber

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Abstract

Large-capacity wireless transmission is possible with high-frequency-band wireless systems, but it is necessary to deploy wireless base stations at high density. Under the assumption that the number of wireless systems will increase to meet diversifying needs, the number of wireless base stations to be installed is expected to increase dramatically. At NTT Access Network Service Systems Laboratories, we propose a system configuration that uses analog radio-over-fiber (RoF) technology to enable multiple high-frequency-band wireless systems to share wireless equipment for drastically reducing the number of wireless base stations and their operating loads. This system configuration and its fundamental technology, namely, our remote-beamforming technology, are introduced in this article.

Keywords: analog RoF, beamforming, efficiently accommodate

1. Introduction

To further expand wireless-transmission capacity, it is effective to use radio waves in the high-frequency band (such as millimeter waves*1), which can secure a wide bandwidth. However, the propagation distance of radio waves becomes shorter as their frequency becomes higher. Therefore, to cover a wide area with a high-frequency-band wireless system, it is necessary to install wireless base stations with high density. In the past, wireless base stations had to be installed for each wireless system. Accordingly, as high-frequency-band wireless systems diversify to meet diversifying needs, an enormous number of wireless base stations will need to be installed. To drastically reduce the number of wireless base stations to be installed and effectively manage their operation, we propose a system configuration that allows multiple wireless systems to share a wireless base station. This system configuration and our remote-beamforming technology—which is indispensable when accommodating high-frequency-band wireless systems with this system configuration—are introduced in this article.

2. Separation of functions and simplification of base stations by using analog RoF

Analog radio-over-fiber (RoF)*2 technology modulates the intensity of an optical signal with a wireless signal and transmits the optical signal in the form of a wireless signal via an optical fiber. The transmitted optical signal is then subjected to optical-to-electrical (O/E) conversion*3 to extract the original wireless

*1 Millimeter wave: A radio (wireless) wave with a very short wavelength of 1 to 10 mm and frequency of 30 to 300 GHz.

*2 RoF: A technology for transmitting the waveform information of wireless signals via optical fiber. Analog RoF converts the waveform into an analog signal as is, and digital RoF converts the waveform to a digital signal before transmitting via optical fiber. Compared to digital RoF, analog RoF does not require A/D (analog-to-digital) or D/A (digital-to-analog) conversion, and the required optical transmission bandwidth can be narrowed.

*3 O/E conversion: A photodiode is generally used to convert an optical signal into an electrical signal.

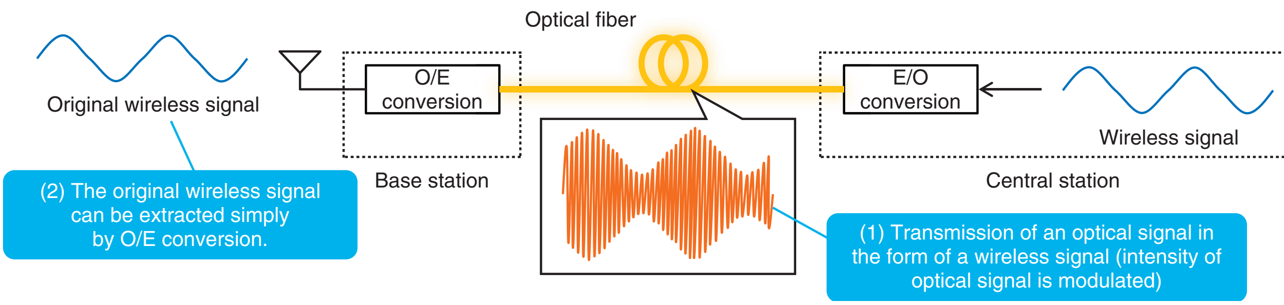

Fig. 1. Analog RoF.

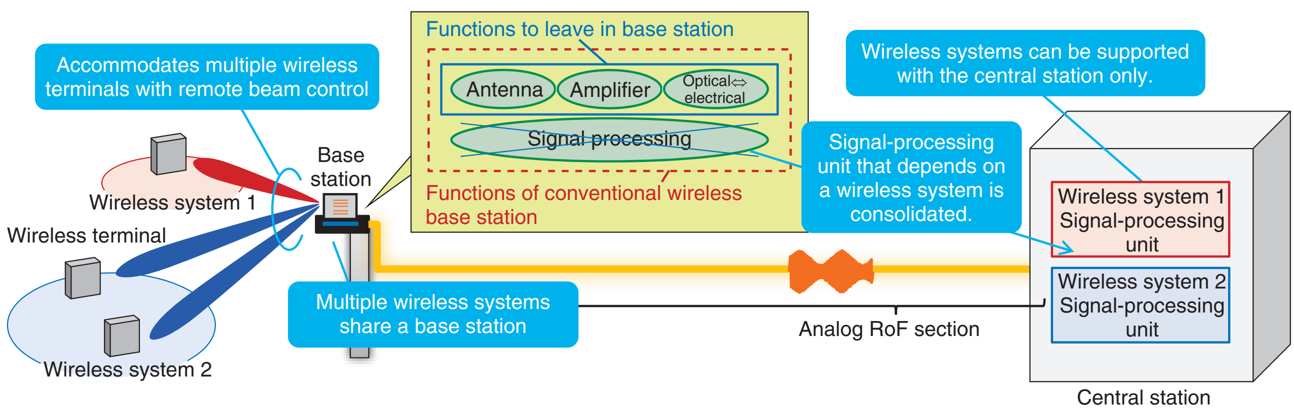

Fig. 2. Function consolidation by using analog RoF.

signal (**Fig. 1**).

By applying analog RoF, the functions of a conventional wireless base station can be separated into two locations, i.e., a central station (accommodating the signal-processing unit) and the base station (accommodating the antenna unit) (**Fig. 2**). Conventional wireless base stations have multiple pieces of equipment and functions: antenna, amplifier, electrical-to-optical (E/O) and O/E conversion, and signal processing. By applying analog RoF to consolidate signal processing at the central station, it is possible to simplify the functions of the base station. As a result of such consolidation, installation flexibility and economic efficiency will improve by reducing the size and power consumption of base stations.

By having only signal processing (which depends on the wireless system) be in the central station, the common functions that do not depend on the wireless system can be left at the base station. Therefore, it is possible for multiple wireless systems to share a base station as long as its frequency range is compatible with the station's antenna and amplifier. New wireless systems can be installed or renewed, and operations can be carried out on the central-station side only; thus, efficient deployment and operation of wireless systems will become possible. It is also expected that the number of wireless base stations and operational costs can be drastically reduced.

3. Remote-beamforming technology

Beamforming*4 is an essential technology for high-frequency-band wireless systems—which can only achieve short propagation distances. For conventional

*4 Beamforming: A technology for electrically controlling the directivity of a wireless signal (beam) by using an array antenna with multiple arranged antenna elements. By controlling the phase of the radio waves transmitted and received by each antenna element, it is possible to enhance the transmission of a radio wave in a specific direction ("transmitting beam") and to receive and enhance the radio wave arriving from a specific direction ("receiving beam").

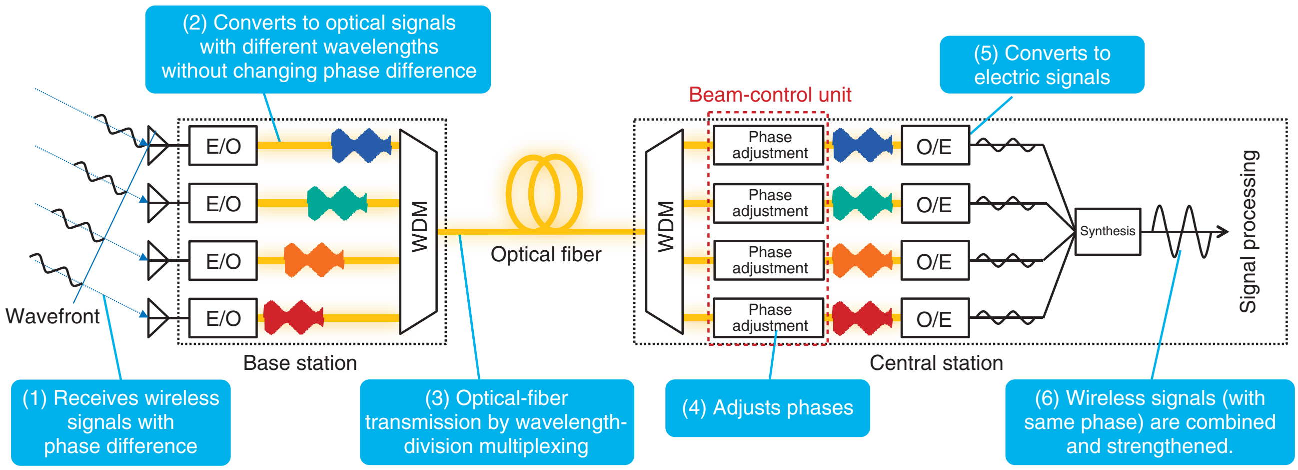

Fig. 3. Remote-beamforming technology (receiving side).

wireless base stations, beamforming is executed by their signal-processing units. When functions are separated and base stations are simplified by applying analog RoF, the problem of how to carry out beamforming at base stations that do not have signal-processing units arises. Therefore, we previously proposed and have been investigating a technology called remote beamforming that can remotely control the beam formed at the base station from the central station [1, 2].

Our remote-beamforming technology is explained with the example of using a receiver in **Fig. 3**. When a wireless signal arrives at a base station with multiple antenna elements, each element receives a wireless signal with a phase difference. While this phase difference is maintained, the wireless signals received by each antenna element are converted into optical signals with different wavelengths and transmitted to the central station via optical fiber by wavelength-division multiplexing (WDM). The central station de-multiplexes the wavelength-multiplexed signals with each wavelength, adjusts the phases of these optical signals, converts the optical signals to electrical ones (O/E conversion), and combines the electrical signals. The original wireless signals are then combined in a state of matching phases and strengthened to form a receiving beam in the direction of the arrival of the wireless signals. Although the optical signals are phase-adjusted in **Fig. 3**, it is also possible to adjust the phases of the electrical signals after O/E conversion and synthesize the signals. The transmitting beam can be formed on the basis of the same principle. At this time, the base station only performs O/E and E/O conversions of the received signal and does not require any control.

There are two conventional remote-beamforming technologies: one assigns a separate optical fiber (a separate core in the case of multi-core fiber) to each antenna element [3] and the other [4, 5] uses chromatic dispersion[*5] to switch the beam direction by changing the wavelength assigned to each antenna element. By overcoming the problems of these conventional technologies (by fixing the wavelength assigned to each antenna element), our remote-beamforming technology has four advantages: (i) only one optical fiber (core) is used; (ii) optical-fiber-distance information is unnecessary; (iii) control of the optical filter at the base station is unnecessary; and (iv) the format of the wireless signal is unrestricted even if a high-frequency band and long-distance optical fiber are used.

Our remote-beamforming technology not only ensures communication quality of high-frequency-band wireless systems but also enables a base station to simultaneously accommodate multiple wireless terminals by executing space-division multiplexing (SDM). Since the beam direction can be controlled remotely, it is not necessary to physically adjust the antenna direction when configuring the base station.

We demonstrated our remote-beamforming technology in a receiving system at the NTT R&D Forum

*5 Chromatic dispersion: A phenomenon by which propagation time differs because the speed of light propagating in an optical fiber varies according to the wavelength of the light. It occurs because the refractive index of an optical fiber also depends on the wavelength.

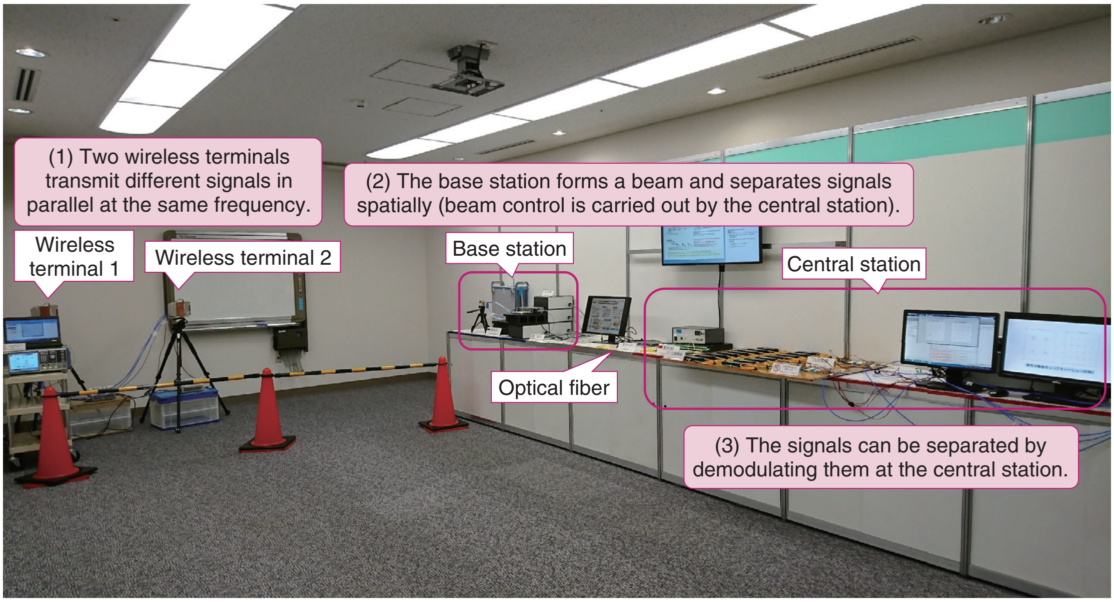

Fig. 4. Setup of exhibition.

2019 (**Fig. 4**).

4. Future outlook

We will improve wavelength-utilization efficiency by improving our remote-beamforming technology and work with researchers of optical communications to study practical applications of this technology.

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Optical Full-mesh Network Technologies Supporting the All-Photonics Network

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Abstract

This article introduces the concept of an optical full-mesh network for achieving ultra-low-latency transmission of diverse and large-capacity content in ultra-realistic services and the technologies underlying this network. It also introduces a demonstration of 8K uncompressed video transmission in a large-capacity optical transmission system as an embodiment of the optical full-mesh network concept.

Keywords: ultra-low latency, full-mesh network, large-capacity optical transmission

1. Introduction

NTT laboratories aim to provide ultra-realistic services [1] that break through the time-space wall by enabling the real-time sharing of not only ultra-high-definition video information but also diverse content that includes information conveyed through the five senses such as touch and hearing. However, providing such services to a large number of people will require a network that can transmit diverse and large-capacity content with low latency. To this end, our aim is to achieve the innovative All-Photonics Network (APN) based on photonics technology as a part of NTT's Innovative Optical and Wireless Network (IOWN) [2]. Researchers at NTT Network Service Systems Laboratories, NTT Network Innovation Laboratories, NTT Network Technology Laboratories, and NTT Access Network Service Systems Laboratories are studying an optical full-mesh network as a means of achieving a large-capacity, low-latency transport function for the APN.

2. Concept of optical full-mesh network

In a conventional network, accommodating content to be transmitted requires data compression due to restrictions in the communication line capacity, conversion to Internet protocol (IP) packets for routing control by the IP protocol, and packaging of the data in Ethernet frames for multiplexing/switching control. These requirements generate latency due to data-compression processing, packet-queuing processing, etc., thus have been the dominant factors in communication latency between terminals.

In contrast, the optical full-mesh network shown in **Fig. 1** provides end-to-end optical paths for each service by directly connecting the optical access network and optical backbone network through a

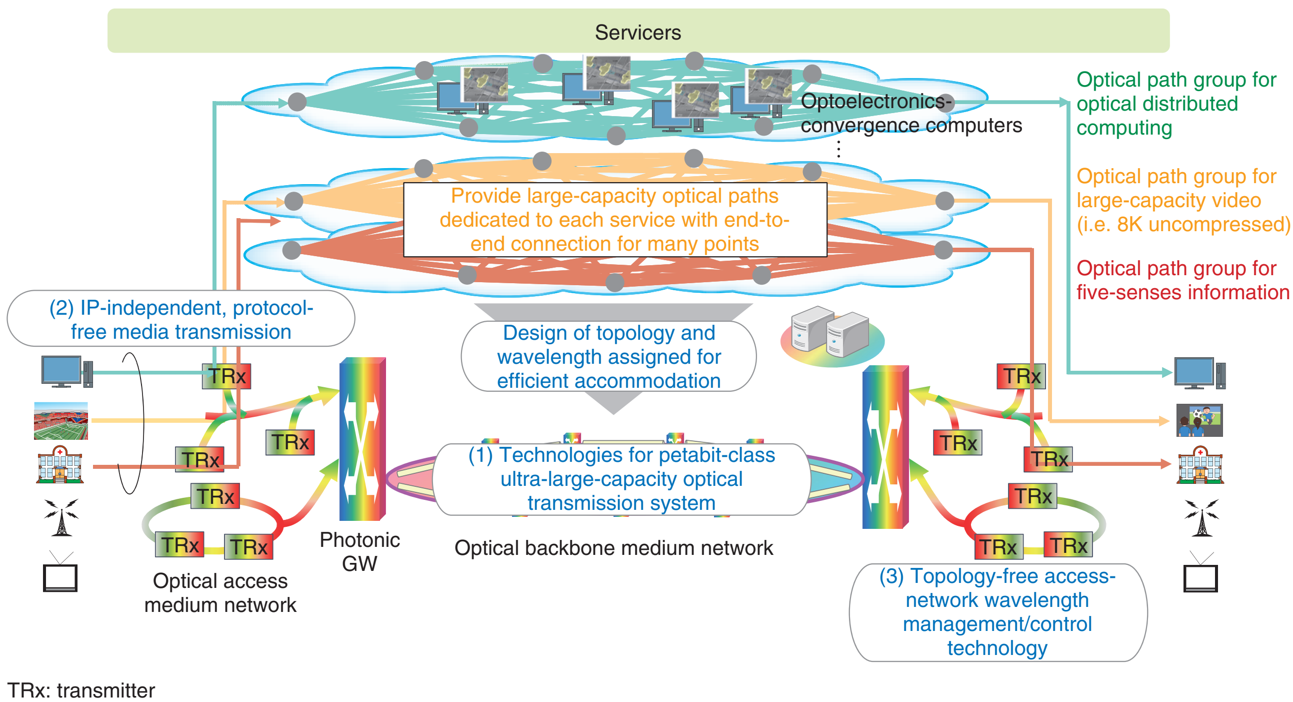

Fig. 1. Overview of optical full-mesh network.

photonic gateway (Ph-GW) that minimizes electronic processing for packet conversion, multiplexing/switching control, etc. This scheme eliminates the latency associated with data compression, packet-queueing processing, etc., which enables to provide a large-capacity and ultra-low-latency network.

3. Key technologies for optical full-mesh network

The following three key technologies are being extensively studied for optical full-mesh network.

(1) Technologies for petabit-class ultra-large-capacity optical transmission system

With the aim of deploying a petabit-class ultra-large-capacity optical transmission system, optical system architecture is being studied based on high-speed optical signal technology, multi-band transmission technology for transmitting wavelength-multiplexed signals over multiple wavelength bands, and spatial multiplexing transmission technology for transmitting optical signals over new types of optical fiber such as multicore fiber. Please see the article "Ultra-high-capacity Optical Communication Technology" in this issue [3] for details on the device technologies supporting these ultra-large-optical transmission systems.

(2) IP-independent, protocol-free media transmission technology

We are studying the transmission technology of diverse types of media data including uncompressed video/audio, the five senses, and emotions as an elementary stream unconcerned with protocol, interface type, and format. Our goal is to achieve large-capacity and ultra-low-latency media transmission via end-to-end optical paths connected by IP-independent path control. Various types of signals, such as 4K/8K uncompressed video signals that flow through serial digital interface (SDI)/high-definition multimedia interface (HDMI) cables, audio signals that flow through multichannel audio digital interface (MADI)/Audio Engineering Society (AES) cables, and peripheral component interconnect (PCI) bus signals that flow among storage, memory, and network interfaces, will be directly accommodated in the all-photonic media transmission paths. To begin with, we have set out to develop interface technology to accommodate SDI signals on optical paths. Although SDI is used to connect video equipment within a broadcast station, our interface technology will enable users to make a connection with a remote location in the same manner as that within a broadcast station without considering transmission protocol, path control, etc. The real-time outside broadcasting of sporting events, concerts, etc. currently requires the dispatching of outside broadcasting vans carrying editing crews and editing equipment. IP-independent and protocol-free media transmission technology will provide an efficient production workflow (remote production) using uncompressed video/audio transmitted from the event venue via an end-to-end optical path. We can envision totally new applications as seen above.

(3) Topology-free access-network wavelength management/control technology

Achieving the APN that provides end-to-end optical paths with diverse user equipment requires remote management/control of wavelengths that user equipment transmits/receives for each optical path. In this regard, studies are underway on wavelength management and control in the access area as one of the main functions of the Ph-GW that connects the access area with a local full-mesh area. To prevent duplication of wavelengths among optical paths that share the same transmission medium, the Ph-GW interacts with the upper-level system that allocates wavelengths to assign wavelengths to each unit of user equipment. It also sends wavelength control instructions to user equipment and performs regular wavelength monitoring. User equipment, in turn, sets the optical transceiver wavelength according to the wavelength control instructions received from the Ph-GW. In this regard, a method is being studied for sending wavelength control instructions from the Ph-GW to user equipment by superposing the management/control signal on the same wavelength as the user signal but in a low-frequency band as an auxiliary management and control channel (AMCC) to prevent interference. The aim is to use an AMCC as a means of achieving an optical network that any type of user equipment can immediately connect to as long as the equipment can connect to optical fiber irrespective of any communications protocol, optical modulation scheme, or network topology.

4. Demonstration: 8K uncompressed video transmission in a large-capacity optical transmission system

We conducted a demonstration to show the effectiveness of an optical full-mesh network based on the key technologies described above. First, we constructed a prototype optical transmission system with a capacity of 0.24 Pbit/s per fiber (approximately 30 times the capacity of current commercial systems) as a large-capacity optical transmission system supporting an optical full-mesh network. In conjunction with this system, we developed a state-of-the-art real-time transponder capable of generating 600-Gbit/s/λ optical signal. As shown in **Fig. 2**, up to 100 wavelengths of the above 600-Gbit/s/λ optical signal was high-density wavelength-multiplexed over the C-band and L-band. We also applied spatial multiplexing technology based on a prototype multicore fiber with four cores to transmit wavelength-multiplexed signals using all four cores. We achieved a large-capacity optical transmission system by using these key technologies.

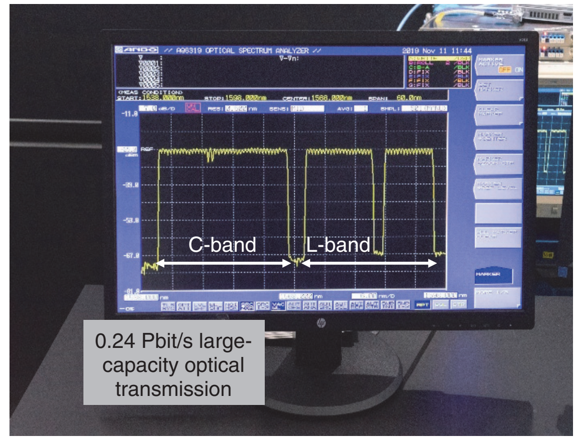

Fig. 2. Optical spectrum of large-capacity transmission system.

In the demonstration, we transmitted 8K video over a 600-Gbit/s/λ optical path using the optical transmission system. This large-capacity optical path enabled real-time transmission of 8K video without compression. We also transmitted 8K compressed video over the same optical path for comparison purposes. The 8K uncompressed video, which is shown on the right in **Fig. 3**, showed no degradation in image quality and achieved low latency about 1/30 that of the 8K compressed video. Further research of IP-independent media transmission technology will enable even further reduction in transmission latency.

5. Future outlook

This article introduced the concept of an optical full-mesh network for ultra-low-latency transmission of diverse and large-capacity content and the technologies needed for deployment. An optical full-mesh

Fig. 3. Transmission of 8K video content.

network can be applied to networks requiring low latency such as those for financial and medical-care systems and can provide stress-free communications unconstrained by bandwidth and transmission delays. Going forward, our aim is to achieve early development of elemental technologies while taking into account network requirements in various application fields.

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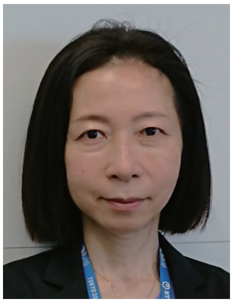

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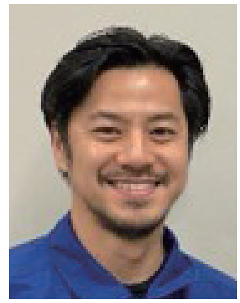

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Network Design Technologies Supporting the All-Photonics Network

Mika Ishizuka, Yasuharu Kaneko, Kohjun Koshiji, Saburo Seto, and Seisho Yasukawa

Abstract

This article introduces architecture, topology design, and wavelength design as elemental technologies for efficiently accommodating a massive number of optical paths toward advanced management and control of optical full-mesh networks. It also presents the results of simulations applying these technologies.

Keywords: optical full-mesh network, network optimization, network design

1. Introduction

NTT Network Technology Laboratories is conducting studies on network design technologies toward the implementation of the All-Photonics Network (APN).

In a current network, multiple users and services share a single optical path; however, the APN achieves high quality and low latency by allocating an optical path to each user or service. However, such a massive number of optical paths require wavelengths, and it is known that efficiently allocating wavelengths in a large-scale network is difficult [1].

Against this background, we are studying network design technologies that will enable a network to efficiently accommodate a massive number of optical paths by combining a variety of optimization techniques.

2. Issues in optical full-mesh network design

Allocating wavelengths to optical paths requires that the same wavelength be allocated end to end. Additionally, within the same link, only one wavelength can be allocated to one optical path. For example, in **Fig. 1(a)**, we consider the case of allocating a wavelength to optical-path 3. Wavelength λ1 is unused in link A, but since it is already being used in link B, wavelength λ2 is allocated to optical-path 3 while leaving wavelength λ1 unused in link A. Therefore, allocating wavelengths to optical paths in a sequential manner results in wavelength fragmentation. In contrast, allocating wavelengths in the manner shown in **Fig. 1(b)** can reduce the number of wavelengths needed. In other words, efficient accommodation of optical paths can be achieved by establishing rules for allocating wavelengths in anticipation of demand in combination with demand prediction technology.

3. Optical full-mesh network architecture

As described above, an increasingly larger network makes efficient end-to-end allocation of wavelengths difficult while also driving a computational explosion that makes the computation of optimal wavelength allocation difficult. Consequently, to use wavelengths efficiently and reduce the scale of the problem, we adopted architecture that divides the network into domains (**Fig. 2**). In this architecture, photonic gateways and photonic exchanges are deployed at domain boundaries and wavelength conversion is performed

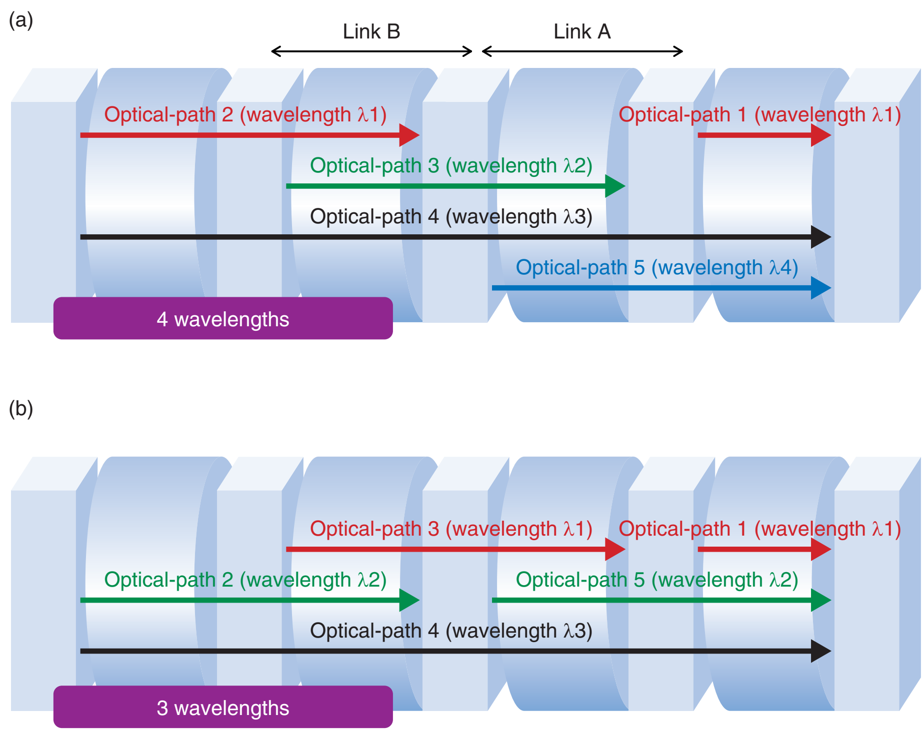

Fig. 1. Allocation of wavelengths to optical paths.

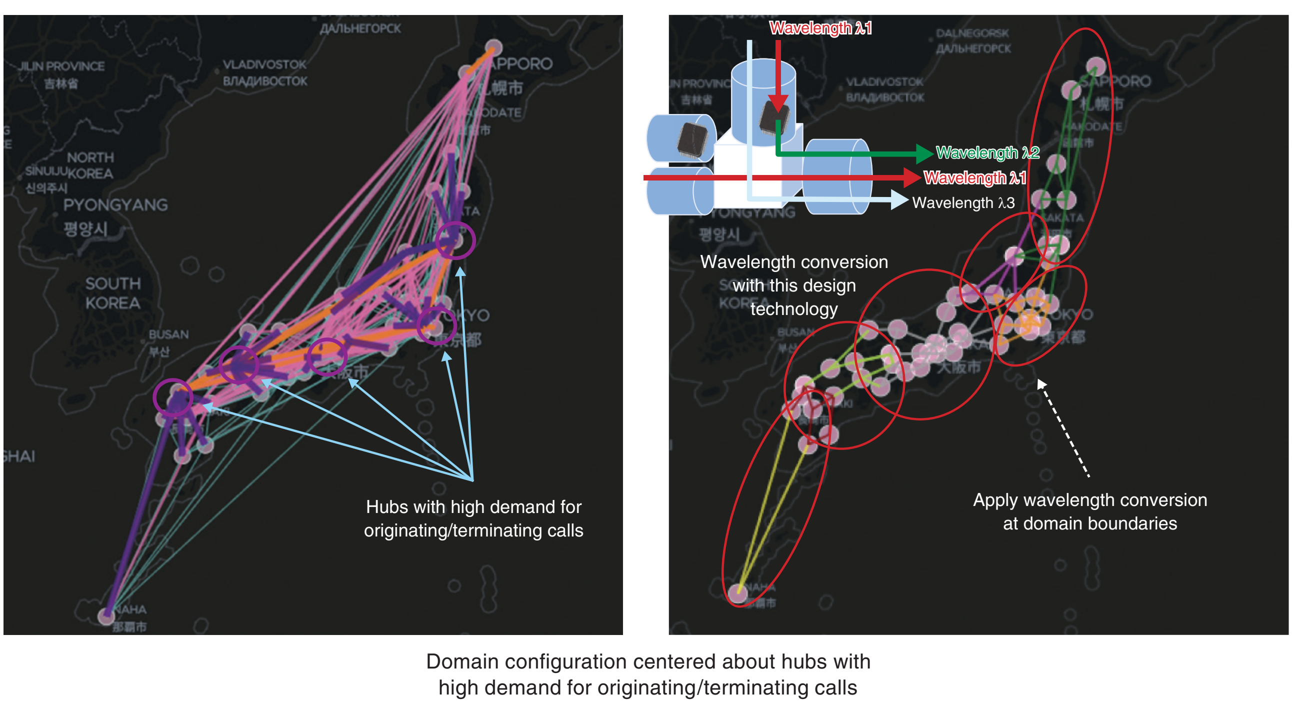

Fig. 2. Architecture of optical full-mesh network.

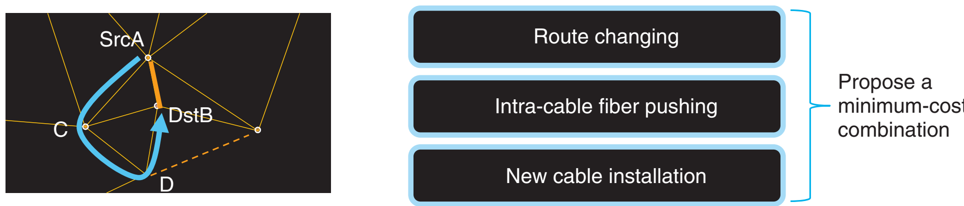

Fig. 3. Topology design.

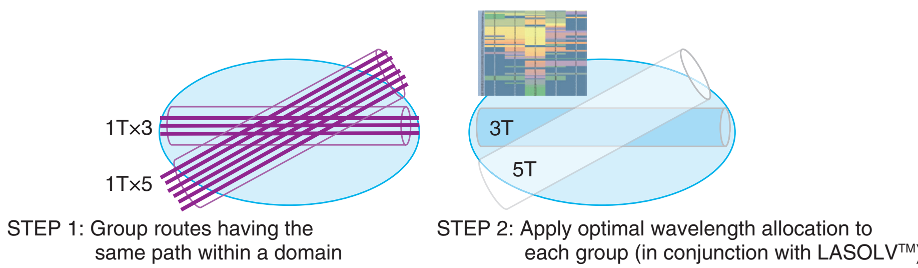

Fig. 4. Wavelength design.

at this equipment. Partitioning the network into domains can reduce the number of wavelengths needed while also reducing the scale of the problem to a level that allows for the application of wavelength-allocation optimization techniques. The number of paths crossing domain boundaries will be set to be as small as possible according to a demand distribution.

4. Topology/wavelength design in optical full-mesh networks

We will apply topology design and wavelength optimization to make effective use of wavelength resources within a domain. Regarding topology design (**Fig. 3**), we will apply such means as route design, intra-cable fiber pushing, and addition of new fiber routes that minimize cost and equalize as much of the level of demand as possible in each fiber within a domain. Regarding wavelength optimization (**Fig. 4**), we will apply the flexgrid wavelength-allocation optimization technique with respect to the combinations of start/end points within a domain to achieve optimal wavelength allocation. Quantum computing (LASOLV™ [2]) can be applied to this wavelength-allocation optimization problem.

5. Simulation results

Targeting Japan Photonic Network Model JPN48 [3], we introduce the results of simulations on accommodating a traffic model (communications among datacenters deployed in prefectures, cloud-based remotely operated applications, corporate communications) envisioning services of the Innovative Optical and Wireless Network (IOWN) era. When not applying the design technologies from NTT Network Technology Laboratories, a capacity of 3 Pbit/s per fiber is required to accommodate the above types of traffic. However, when applying these technologies, a capacity of only 1 Pbit/s per fiber is needed, reflecting a dramatic improvement in fiber-use efficiency (**Fig. 5**).

6. Future outlook

This article introduced architecture, topology-design, and wavelength-design technologies toward the implementation of an all-photonics full-mesh network that can efficiently accommodate a wide variety and large number of optical paths. Going forward, we plan to further develop these technologies to satisfy a variety of network requirements in a flexible manner while aiming for early rollout in real-world applications and fields.

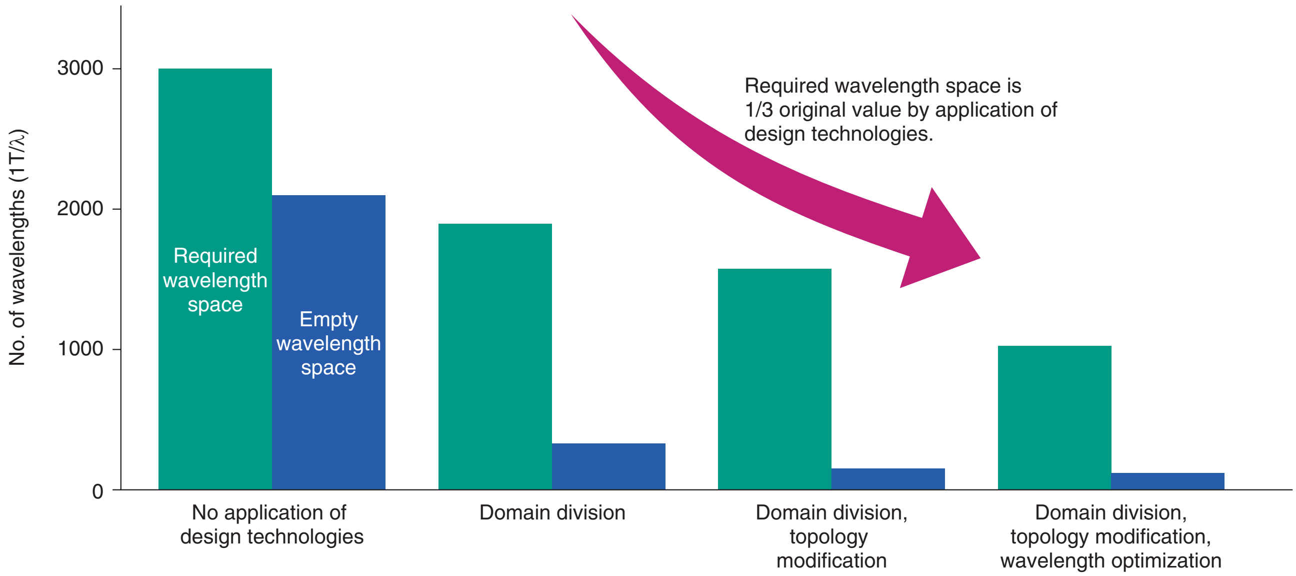

Fig. 5. Simulation results.

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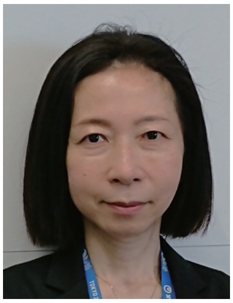

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Advances in PPLN-waveguide-based Monolithic-integration Technology for High-performance Phase-sensitive Amplifiers

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Abstract

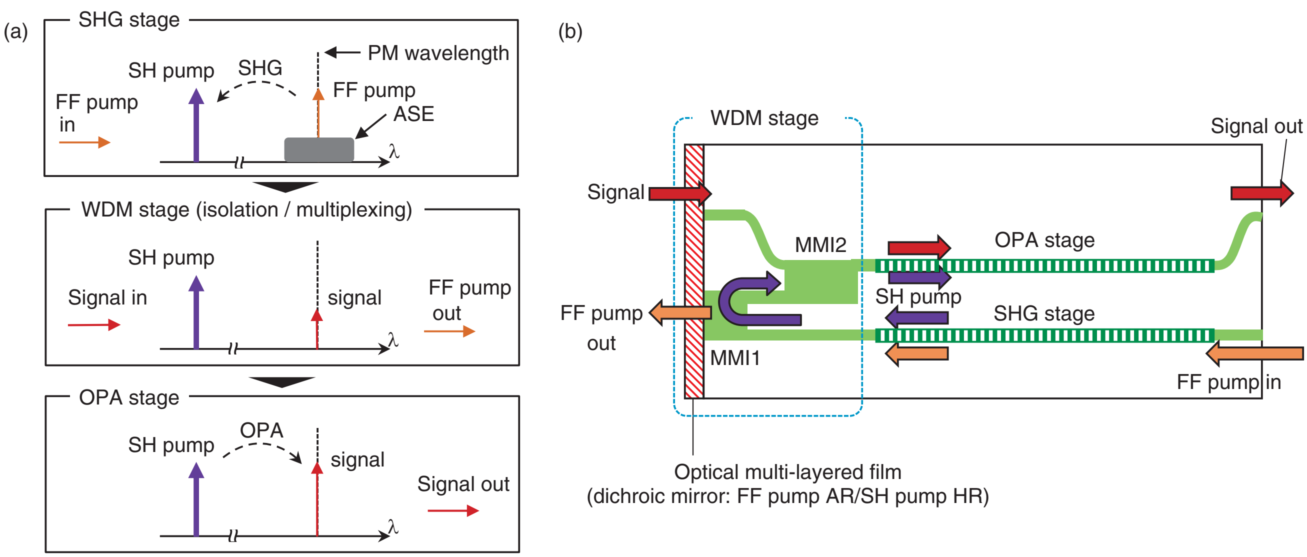
Phase-sensitive amplifiers (PSAs) are attracting a great deal of interest because they can break the quantum-limited noise figure of conventional optical amplifiers such as erbium-doped fiber amplifiers. We have been developing a PSA using periodically poled lithium niobate (PPLN) waveguides. This article introduces our recent progress in PPLN-waveguide-based monolithic-integration technology as a promising approach for the practical use of a highly functional PSA.

Keywords: nonlinear optics, phase-sensitive amplifier, lithium niobate

1. Introduction

Optical transmission reach and channel capacity will ultimately be limited by the degradation of the signal-to-noise ratio (SNR) resulting from nonlinear noise induced by the interplay between the Kerr effect in a fiber and amplified spontaneous emission (ASE) from optical amplifiers [1]. Phase-sensitive amplifiers (PSAs) are attracting much interest because they have the potential for low noise amplification while breaking the 3-dB quantum limit on the noise figure (NF) of conventional phase-insensitive amplifiers [2] and for signal regeneration capability [3]. These features mean that a PSA will be a promising candidate for solving the problem of transmission noise. PSAs based on $\chi^{(3)}$ and $\chi^{(2)}$ nonlinear processes can be implemented with different gain media (e.g. highly nonlinear optical fiber [4] or periodically poled lithium niobate (PPLN) [5]). We have used a PPLN waveguide as the gain medium in a $\chi^{(2)}$-based PSA. Recent advances in PPLN waveguides and related module packaging technology have enabled us to construct a $\chi^{(2)}$-based PSA for optical communication [6]. Using this PPLN-based PSA, we have successfully demonstrated a phase-sensitive amplification of polarization division multiplexing and wavelength division multiplexing signals with a practical gain of over 20 dB. However, such a highly functional PSA requires not only multiple PPLN waveguides but also many linear devices, such as beam combiners, polarization beam splitters, and delay or phase adjusters. The monolithic integration of PPLN waveguides is a promising approach for the practical use of a functional PSA with highly stable operation.

In this article, we introduce our recent work on PPLN-waveguide-based monolithic-integration techniques for high-performance PSAs. This article is organized as follows. In section 2, we describe a single-chip integration of two PPLN waveguides and a wavelength-division multiplexer (WDM) that are basic components of the PPLN-based PSA. We then discuss the design and fabrication of this integrated device and demonstration of a continuous wave



AR: Anti-reflectivity
FF pump: fundamental frequency pump
HR: high reflectivity
MMI: multi-mode interference
SH pump: second harmonic pump

Fig. 1. (a) Operation flow of PPLN-based OPA and (b) schematic of integrated device.

(CW)-pumped phase-sensitive parametric amplification using the device [7]. In section 3, we introduce a PSA using a high-power-tolerant electro-optic (EO) phase-modulator-integrated PPLN (PM-PPLN) waveguide. The PM-PPLN waveguide improves the SNR of the pump light and exhibits low-noise phase-sensitive amplification [8].

2. Monolithically integrated parallel PPLN waveguides with reflective WDM

The basic structure of a PPLN-based PSA generally consists of three stages, namely a second harmonic generation (SHG) stage, WDM stage, and optical parametric amplification (OPA) stage. The process flow is shown schematically in **Fig. 1(a)**. First, in the SHG stage, a strong fundamental frequency (FF) pump amplified using an optical amplifier, such as an erbium-doped fiber amplifier (EDFA), is used to generate a high-power second harmonic (SH) pump. Next, in the WDM stage, the SH pump and FF pump, which accompanies the ASE noise from the amplifier, are separated, and the SH pump is multiplexed with the signal. Finally, in the OPA stage, the signal and SH pump complete the parametric interaction.

Kanter et al. successfully demonstrated squeezing in a PPLN-integrated optical waveguide circuit based on an annealed proton exchange waveguide [9]. This was the first report of a single-chip device in which two PPLN waveguides and a WDM are integrated. In this circuit, the basic components of an SH-pumped parametric amplifier consisting of two PPLN waveguides and a WDM were connected in tandem in the longitudinal direction. This configuration limits the conversion efficiency because such efficiency of a PPLN waveguide is proportional to the square of the waveguide length. To develop an integrated device with a high conversion efficiency, we designed a device structure in which two PPLN waveguides are arranged in parallel, which enables us to use the entire length of the wafer for each PPLN waveguide except for the multiplexing region. There are certain difficulties to overcome if we are to achieve parallel configuration. It is difficult for the WDM to connect two waveguides because they are densely configured. Moreover, the WDM must perform low-loss multiplexing and high isolation of the FF pump. This is because the coupling losses of the signal directly degrade the SNR, and, if the FF-pump isolation is insufficient, the FF-pump leakage and the accompanying ASE noise interfere with the signal, which degrades the quality of the output signal.

Figure 1(b) shows a schematic of the integrated device. The parallel configuration of the two PPLN waveguides for SHG and OPA provide a long interaction length, and the reflection configuration of the

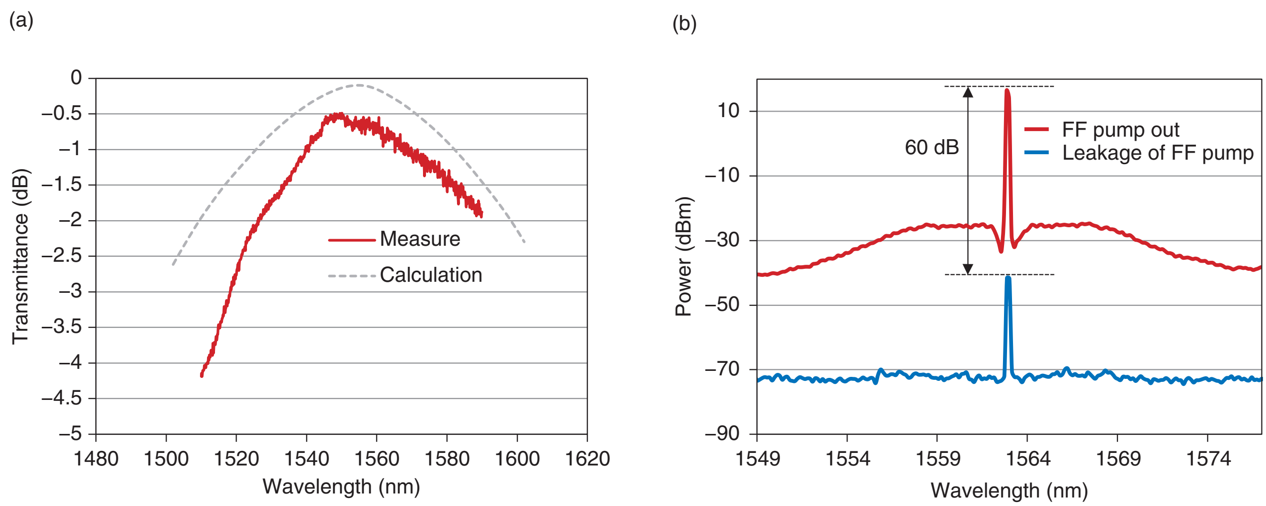


Fig. 2. (a) Transmittance of MMI for 1.56 μm and (b) FF-pump isolation of WDM.

WDM makes it possible to connect parallel waveguides that are configured densely. To achieve the high isolation of the FF pump and low loss coupling of the signal, the multi-mode interference (MMI) (de)multiplexers and dichroic mirror are integrated. We designed MMIs that exhibit straight coupling for a wavelength of 1.56 μm and cross coupling for a wavelength of 0.78 μm [10]. MMI1 is cut at around the center of the MMI length, and the cut surface is coated with dielectric multilayered film that functions as a dichroic mirror. The dichroic mirror has high reflectivity at the SH-pump wavelength (at 0.78 μm) and very low reflectivity at the FF-pump wavelength (at 1.56 μm). The SH pump is generated by SHG from a strong FF pump, which accompanies the ASE from the amplifier. In MMI1, the FF pump with ASE is filtered out from the edge of the chip, and only the SH pump reflects back to the cross port while the residual FF pump reflected from the chip edge reenters the PPLN waveguide for SHG. The SH pump from the cross (input) port and the signal from the bar (input) port are multiplexed in MMI2, where the residual FF pump can again be filtered out. The signal and ASE-suppressed SH pump are then injected into the PPLN waveguide for OPA to achieve wavelength conversion.

We prepared a Zn (zinc)-doped LN wafer for the waveguide core layer and a Mg (magnesium)-doped LN wafer for the substrate. The two wafers were directly bonded and a ridge waveguide was fabricated by dry etching [11]. We then deposited a dielectric multilayer on the end-face of the MMI1. To evaluate the excess losses of the MMI, we placed a straight waveguide along it as a reference. The PPLN section is 38-mm long, and the WDM section is 12-mm long giving a total device length of 50 mm. The fabricated waveguide thickness and width are 7 and 10 μm, respectively.

Figure 2(a) shows the normalized transmittance of MMI2 as a function of input wavelength at the 1.5-μm band. We obtained a low excess loss of about 0.5 dB, which is close to the theoretical value of 0.1 dB. To estimate the isolation of the integrated WDM, we measured the leakage of the FF pump and FF pump out, which is the FF pump that passed through the edge of MMI1. **Figure 2(b)** shows the measured spectra. The red line is the spectrum for the FF pump out and the blue is for leakage of the FF pump. The difference between the peak for the FF pump out and that for the leakage of the FF pump shows the isolation to be as good as 60 dB. This means that two MMIs and a dichroic mirror sufficiently suppress the fundamental.

Figure 3 shows the experimental setup for degenerate phase-sensitive amplification using the integrated device. The signal and FF pump at 1562 nm were generated using an external cavity laser (ECL) for degenerate parametric processes. To achieve a stable PSA output, a phase-locking scheme in which a PM is used for phase dithering and a piezoelectric-transducer (PZT)-based optical phase locking loop (PLL) is used to compensate for the slow relative phase drifts between the signal and SH pump caused by thermal or acoustic vibrations. Both in-phase

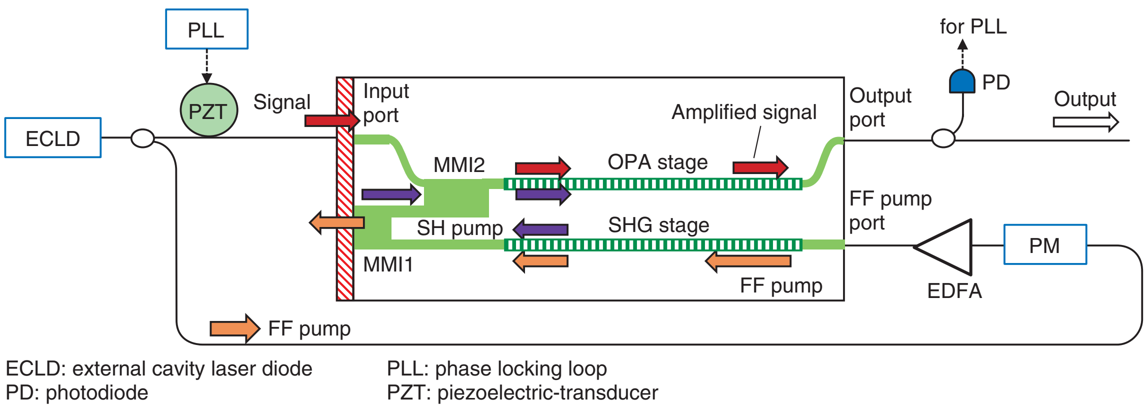


Fig. 3. Experimental setup for phase-sensitive amplification.

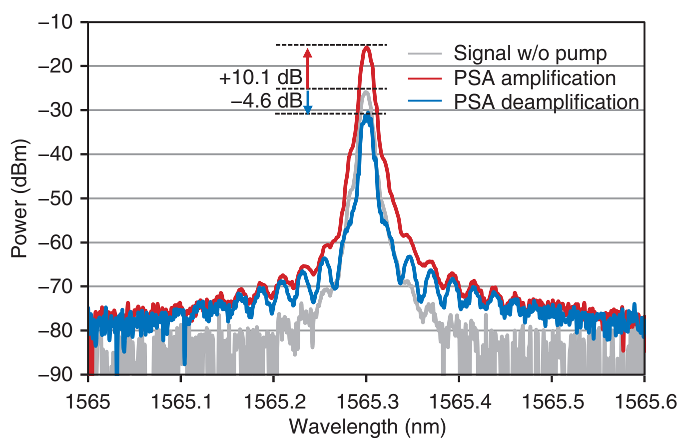


Fig. 4. PSA output spectra.

(amplification) and quadrature-phase (deamplification) condition of the relative phase between the signal and SH pump lights were obtainable individually by changing the setting of the PLL. **Figure 4** shows the in-phase and quadrature-phase PSA output spectra for the signal. For the in-phase setting, an amplification of +10.1 dB was obtained, while a deamplification of –4.6 dB was obtained for the quadrature-phase setting. The amplification and deamplification gains are defined as the signal output divided by the signal output without pump injection. These results clearly indicate phase sensitivity. We successfully demonstrated a degenerate PSA with a CW pump using the integrated device.

3. EO PM integrated SH-pump generator for low-noise amplification

A high SNR of the pump light is essential for achieving a low NF because the intensity noise of the pump is transferred to that of the amplified signal. The pump generator of $\chi^{(2)}$-based PSAs consists of an EDFA to boost the FF pump and SH generator of an FF pump. It also uses a phase-locking scheme, in which a PM is used for phase dithering and a PZT-based PLL to compensate for the slow relative phase drift between the signal and pump. To obtain both high-speed dithering and low-loss connectivity to other fiber pigtail components, a Ti (titanium)-diffused LN waveguide modulator has been used in $\chi^{(2)}$-based PSAs. Because of the low tolerance against the input power of a Ti-diffused LN waveguide due to

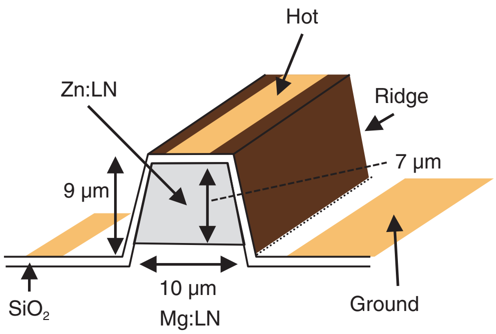


Fig. 5. Cross-sectional diagram of EO PM.

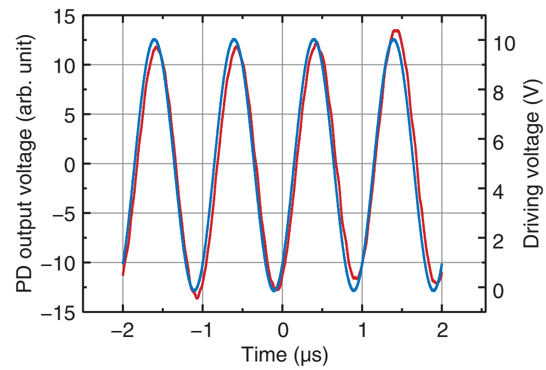


Fig. 6. Modulation characteristics of EO PM.

photorefractive damage, the waveguide must be placed before the booster EDFA for pump generation. This decreases the input power to the EDFA, which results in the degradation in the SNR of the FF pump. To improve the SNR of the pump of a $\chi^{(2)}$-based PSA, we fabricated a high-power-tolerant EO PM-PPLN-based SH-pump generator.

We used a directly bonded wafer consisting of Z-cut ZnO (zinc oxide)-doped LN as a core and MgO (magnesium oxide)-doped LN as a cladding layer, and a ridge structure was formed by dry etching. Next, we covered the ridges with an SiO_2 (silicon dioxide) buffer layer to prevent any waveguide propagation loss from being induced by the electrodes of the PM. We then evaporated an Au (gold) thin film over the buffer layer and patterned the film into lumped-constant electrodes with a wet-etching process. **Figure 5** is a schematic cross-section of the EO PM of the SH-pump generator. We formed a hot electrode on top of the ridge and two ground electrodes on the etched surface. With this structure, we were able to obtain a large index change with a vertical electric field. The lengths of the PPLN and PM regions were 37 and 18 mm, respectively, and the total length of the PM-PPLN waveguide was 55 mm. Finally, the PM-PPLN waveguide was packaged in a fiber pigtailed module using lens coupling without an optical adhesive. We also installed a dichromatic mirror in the module to filter the SH pump.

We measured the response of the output power from a modified crossed-Nicol setup to evaluate the phase-modulation characteristics. **Figure 6** shows how the output power changed when the integrated EO PM was driven with a sinusoidal voltage at a frequency of 1 MHz. We clearly observed a phase modulation at 1 MHz, which is sufficient for the phase dithering of the PLL. We also confirmed the 3-dB bandwidth of the modulator exhibited over 10 MHz, which is sufficient for phase dithering.

We then evaluated the potential of the PM-PPLN module in a PSA configuration. **Figure 7** shows the experimental setup for this PSA. The FF pump was tapped from the signal and input into the SH-pump generator using the PM-PPLN module. The SH-pump light was injected into the other PPLN module for OPA. The signal was modulated using a Mach–Zehnder (MZ) LN modulator with a 10-Gbit/s non-return-to-zero (NRZ) format, attenuated with a variable optical attenuator (VOA), and injected into the OPA-PPLN module. The input power was monitored with a power meter. To maintain a stable PSA output, EO phase dithering in the PM-PPLN module was used for phase locking, and a PZT-based optical PLL was used to compensate for the relative phase difference between the signal and SH pump caused by thermal or acoustic vibrations. The output was tapped with a coupler, detected with a photodiode, and input into the PLL circuit. We observed the PSA output with a sampling oscilloscope to confirm the phase-locking operation. **Figure 8** shows eye diagrams of the signal and output. Without phase dithering in the PM-PPLN module, although parametric amplification could be observed, the eye did not open because of fluctuations in the relative phase between the signal and SH pump, as shown in Fig. 8(b). With phase dithering at 1 MHz, the eye was clearly open, as shown in Fig. 8(c).

We examined the effect of improving the SNR of the pump light by evaluating the noise characteristics of a conventional PSA and a PSA using the PM-PPLN module. In the conventional PSA, we used a commercially available Ti-LN PM placed before the EDFA with an insertion loss of 5.5 dB. We generated

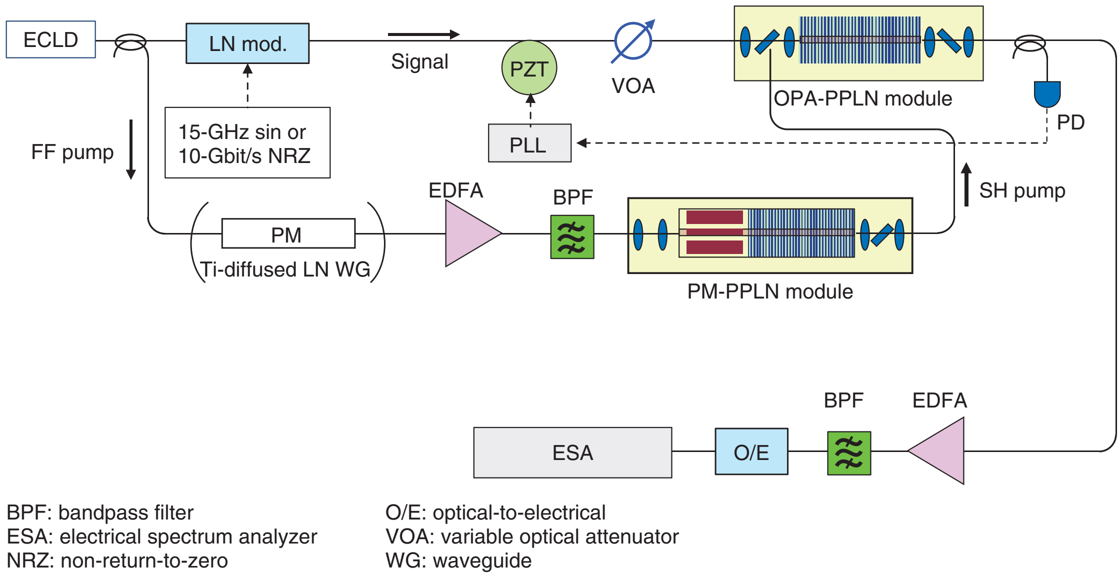


Fig. 7. Experimental setup for PSA using PM-PPLN module.

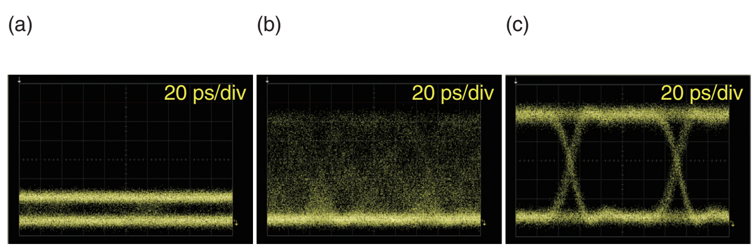


Fig. 8. Eye patterns of 10-Gbit/s NRZ signal and output of PSA using PM-PPLN. (a) Signal, (b) output without lock, and (c) output with lock.

an SH pump with the same PM-PPLN module. To evaluate the NF properties, we captured the noise components in the 1- to 14-GHz range with an electrical spectrum analyzer (ESA) [12]. We cascaded the PSA with an EDFA to mitigate the narrow dynamic range of the ESA. The signal was modulated using a chirp-less MZ modulator with a 15-GHz sinusoidal wave. The gain of the amplifiers was measured using the intensity at the modulation frequency of 15 GHz. We measured the output-noise power densities for the PSA using the PM-PPLN module and EDFA cascaded amplifier, for the conventional PSA and EDFA cascaded amplifier, and for a stand-alone EDFA used for a reference. **Figure 9** shows electrical noise spectra in the 1- to 14-GHz range for all the amplifiers under the same input signal-power condition of −28 dBm. The dashed straight lines in Fig. 9 show the average noise-power densities for the PSA using the PM-PPLN module and EDFA cascaded amplifier and for the conventional PSA and EDFA cascaded amplifier in the 2- to 12-GHz region. In all cases, the total gain of the PSAs and the cascaded EDFA were about 17.5 dB, as was the gain of the stand-alone EDFA. The cascaded amplifiers exhibited a lower noise level than the stand-alone EDFA over the entire frequency range. Specifically, the noise power was 0.96 dB lower for the PSA using the PM-PPLN module and EDFA cascaded amplifier than for the conventional PSA and EDFA cascaded amplifier. We then calculated the NF values of both PSAs by using the noise level of the stand-alone EDFA and gain values of the PSAs and cascaded EDFA and NF of the cascaded EDFA [12]. Under an input-power condition of −28 dBm and gain condition of 17.5 dB, the measured NF

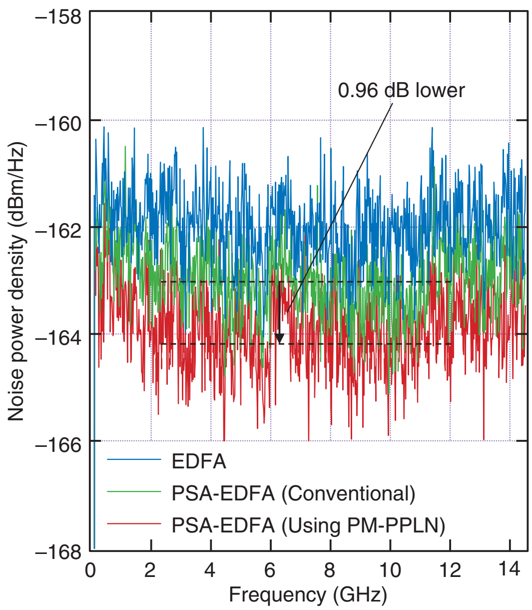


Fig. 9. Electrical noise spectra of EDFA and cascaded PSA and EDFA.

of the stand-alone EDFA used for the reference was about 5.35 dB. In contrast, the PSAs exhibited lower NFs. The calculated NFs of the conventional PSA and the PSA using the PM-PPLN module were about 3.09 and 2.22 dB, respectively. We confirmed that the SNR of the PSA using the PM-PPLN module improved by comparing the NF of the conventional PSA using a Ti-LN PM.

4. Summary

We introduced our recent results for PPLN-waveguide-based monolithically integrated devices for PSAs. We described the design and fabrication of the device that integrates two-stage SHG and OPA processes on one chip. We successfully demonstrated a CW-pumped PSA using this integrated device with an amplification gain of over 10 dB. A PM-integrated PPLN SH generator was also shown to improve the SNR of the pump light for the PSA. Using the PM-PPLN module as a pump source for a PSA, we confirmed low-noise phase-sensitive amplification. We believe that the integration of functional devices will be key to achieving a high-performance PSA that can extend the capacity of optical communication networks.

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Operation-visualization Technology to Support Digital Transformation

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Abstract

NTT Access Network Service Systems Laboratories (AS Labs) has developed various technologies to improve business operations using personal computers, for example, robotic process automation, annotation technology, and UI (user interface) augmentation technology. Based on this experience, we are researching and developing technologies useful for business-operation analysis. This article introduces the operation-visualization technology developed by AS Labs that supports objective/quantitative business-operation analysis.

Keywords: digital transformation, operation analysis, data visualization

1. Operation analysis to promote DX

Digital transformation (DX) means improvement through digital technology. In particular, business-operation improvement using digital technology is attracting the attention of many companies. NTT Access Network Service Systems Laboratories (AS Labs) has been working on technologies to improve business operations using personal computers (PCs). It developed the UMS (Unified Management Support System), which is a robotic process automation (RPA) technology [1], and NTT Advanced Technology Corporation is now selling it under the name of WinActor®*1 [2]. AS Labs is also working on annotation technology and UI (user interface) augmentation technology for improving operation performance that cannot be supported by RPA technologies (e.g., operations that are difficult to standardize and automate) [3]. NTT TechnoCross Corporation is now selling these technologies under the names BizFront/Annotation and BizFront/SmartUI*2, respectively [4, 5].

By introducing these technologies into NTT Group companies, AS Labs has clarified several issues when using the technologies in actual operational fields. In RPA, for example, automation personnel have to not only learn an RPA tool but also find automatable process flows or problematic operations from the target business operation to design automation processes for RPA. Ideally, field personnel who have business knowledge should learn RPA skills. Since this requires much time and effort, automation personnel having RPA skills and field personnel having business knowledge work together in many cases. In such a situation, automation personnel directly communicate with field personnel about the information needed to apply RPA. However, this is quite subjective, i.e., automation personnel cannot objectively and quantitatively analyze through only such communications.

This issue is the same not only regarding RPA but also in business-operation-improvement activities such as business process management. These activities require objective/quantitative analysis methods as well as direct communication. Based on this knowledge, AS Labs is researching and developing various technologies for business-operation analysis.

*1 WinActor® is a registered trademark of NTT Advanced Technology Corporation.

*2 BizFront/Annotation and BizFront/SmartUI are trademarks or registered trademarks of NTT TechnoCross Corporation.

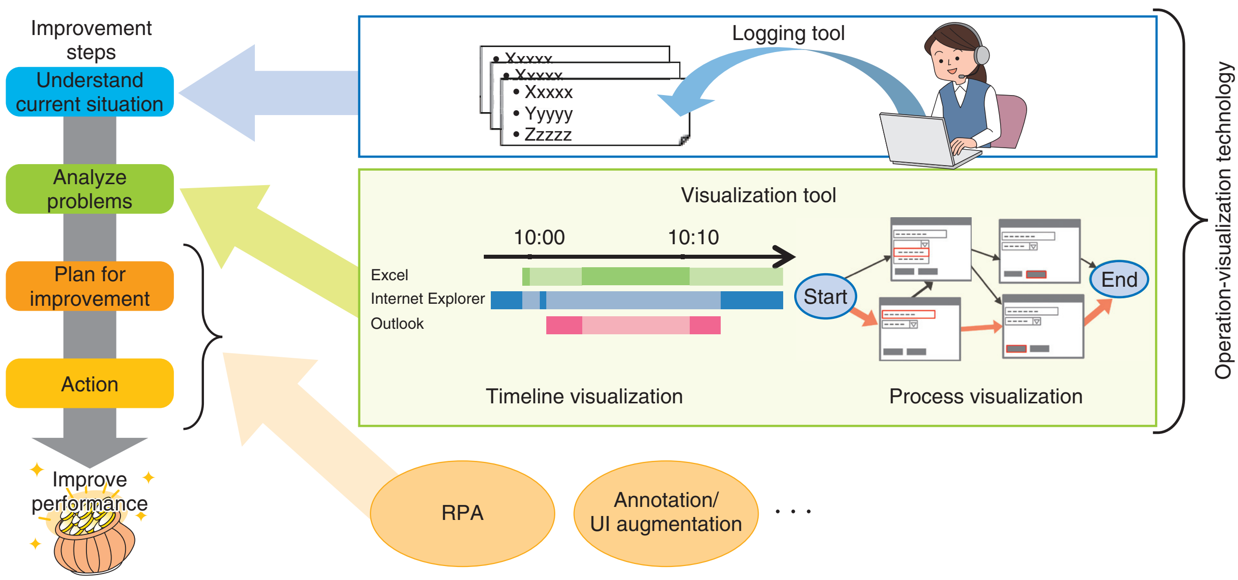

Fig. 1. Improvement steps and operation-visualization technology.

2. Operation-visualization technology

Business-operation improvement involves the following four steps: 1) understand current situation, 2) analyze problems, 3) plan for improvement, and 4) action, as shown in **Fig. 1** (to increase efficiency, these steps should be repeated as a cycle). The operation-visualization technology AS Labs is researching and developing supports steps 1 and 2. This technology contains a mechanism for recording manipulations on a PC, which AS Labs has cultivated over many years, and original visualization methods newly developed by AS Labs.

AS Labs is not only researching this technology but also developing software to be readily available for business operation. The software consists of two independent tools (executable files): logging and visualization. The logging tool is used on an operator's PC and detects operation manipulations on the PC and records them in a log file. The visualization tool is used on an analyst's PC to visualize the data of the log files to understand current operation and perform analysis. The visualization tool currently uses two visualization methods: timeline visualization and process visualization.

With these tools, an analyst can obtain objective/quantitative data about PC manipulations and analyze the data from various viewpoints. As a result, an analyst can more effectively analyze business operations than through direct communication.

3. Logging tool

The logging tool is currently targeted for Windows 7 and Windows 10. It does not require installation and can be executed by simply unpacking to any folder on a target PC.

During execution, the logging tool monitors the operator's PC manipulations and records the data to a log file (text format). When detecting a specific manipulation, the logging tool capture a window's screenshot and saves it in an image file. A folder for saving log/image files can be set freely (a shared folder on the network is also possible). If the size of the log/image files is too large, the operator can turn off the screen-capture function.

A summary of the data the logging tool can record is shown in **Table 1**. Currently, the logging tool supports only Internet Explorer for manipulation-information recording, but AS Labs is considering support for Microsoft Edge and Google Chrome.

4. Visualization tool

The visualization tool loads log files recorded with the logging tool and displays current operations through timeline visualization and process visualization, respectively. The analyst can obtain the visualization results by loading log files for multiple days, multiple PCs, and multiple users at the same time and display these merged data.

Table 1. Information recorded using the logging tool.

Type	Details	With screen capture
Window information	Information on all displayed windows. (included items: time, application name, window title, file name, URL, window handle, etc.)	
Active-window information	Information on changes to active window. (included items: time, window handle, etc.)	✓
Manipulation information on Internet Explorer	Information on manipulation events that occurred on Internet Explorer, such as "button click," "text input," and "list selection." (included items: time, manipulation type, window title, URL, HTML tag information, etc.)	✓
No-operation information	Times when no manipulation occurred. (included items: time, length)	
Order ID information	Information to separate log data for each workflow on process visualization. Pre-configuration is required.	

Fig. 2. Timeline visualization.

4.1. Timeline visualization

Timeline visualization is a visualization method for analyzing window-level situations. A conventional visualization method visualizes only situations for active windows*3, but timeline visualization also displays situations for inactive windows [6]. Therefore, it is easy to analyze complicated business operations that use multiple windows, for example, working in a business system's window while referring to a window displaying an operational manual.

As shown in **Fig. 2**, timeline visualization displays a two-axis graph with time on the horizontal axis and window attributes on the vertical axis. A window attribute means the information-type of a window (application name, window title, loaded URL, loaded file name, PC name, user name, etc.) recorded using the logging tool. An analyst can freely select the types on the window-attribute axis to change the row order. The row order can be selected hierarchically by selecting multiple window-attribute types. Moreover, an analyst can select multiple window-attribute values and add a new group name to aggregate them into neighboring rows so that the analyst can focus on the selected window-attribute values. For example, in Fig. 2, timeline visualization is set to be displayed in this order: group name, user name, date, application name, and window title.

*3 Active window: An active window is the currently focused window in a window-based system such as Microsoft Windows. The active window accepts user manipulations such as with a mouse and keyboard. There can only be one at a time.

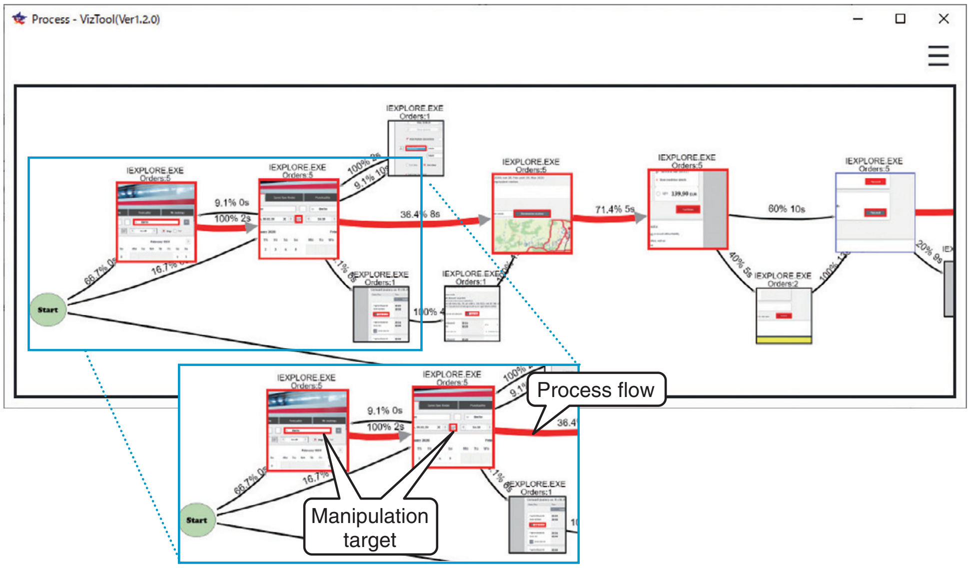

Fig. 3. Process visualization.

Timeline visualization then displays the window's activity state as rectangles. A rectangle has darker and lighter shades of a color; darker shades indicate that the window was active and lighter shades indicate inactivity. The period with no rectangles indicates that the window did not exist or was not visible (a minimized window is regarded as not visible.). If multiple rectangles exist at the same time in the same value row on the window-attribute axis (e.g., the log data when an operator used multiple windows of the same application are visualized on the window-attribute axis of the application-name type.), the rectangles are shown as overlapping. If a darker rectangle of an active window overlaps a lighter rectangle, the darker rectangle is brought to the front.

Timeline visualization has other features as follows.

- By hovering a mouse cursor on a rectangle, the analysist can access more information about the window.
- The analysist can freely set a color to the rectangle by the window-attribute value (e.g., application name, window title, file name and URL). This setting is independent of the vertical axis.

4.2. Process visualization

Process visualization is a visualization method for more detailed analysis of the manipulation level than of the window level (e.g., button click, text input, list selection). This method displays a graph*4 of the manipulation flow recorded with the logging tool. This method is more efficient than the conventional visualization method because it has various filter functions to narrow the number of nodes, manual editing functions (grouping nodes and deleting unnecessary nodes), etc. [7].

As shown in **Fig. 3**, process visualization displays a directed graph on which nodes represent each manipulation and directed edges represent each transition of the manipulation(s). If log data contain multiple events of the same manipulation, process visualization makes multiple events a single node. To be intuitively understandable for an analyst, process visualization displays a related captured-screen image on the node and manipulation position by adding a red frame around the image (e.g., an external rectangle of a manipulated button). The logging tool can currently record manipulation-level events only on Internet Explorer, so an analyst can only analyze a manipulation-level situation regarding Internet Explorer with process visualization.

Process visualization has other features as follows.

- By hovering a mouse cursor over the node, the analysist can check more information about this manipulation.
- Process visualization organizes the graph as follows: log data are separated by order identifier

*4 Graph: This term means a structure in graph theory (mathematics). This structure consists of nodes and edges.

(ID) for each workflow, and nodes of the same manipulation are united into one.
- Process visualization highlights the main route in red, which consists of nodes high in manipulating frequency, in the graph.
- The analysist can use filters to reduce nodes and observe only the more essential flow, for example, application name, user name, order ID, and manipulating frequency.
- The average transition time is shown on an edge of the graph. This indication represents the average time from manipulation of the previous node to that of the next node.

5. Use example of operation-visualization technology

Timeline visualization enables the following analyses.
- By quantitatively measuring work time for operations and determining operations that require a long time, the analysist can find operations that need to be improved.
- By comparing the work times of multiple operators in the same operation, the analysist can find experts for this operation.
- By focusing on periodic flows, such as repeated access to the same URL, the analysist can find effective operations to implement RPA.

Process visualization enables the following analyses.
- By checking the average transition times between process elements, the analysist can find operation flows that take a long time.
- By comparing operation processes between experts and beginners, the analysist can find problems experienced by beginners.
- By checking a merged process of multiple workflows of the same operation, the analysist can find a standard workflow (most common workflow) and create an automation flow for RPA based on the standard workflow.

6. Future work

As Labs will use the operation-visualization technology in NTT Group companies with their cooperation. We will use the feedback obtained in the trials to further improve its practicability. We will also research and develop not only the current visualization functions but also an analytical function using various artificial intelligence technologies to support the implementation of RPA. Through these activities, we will further improve the technologies for business-operation analysis.

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Trademark notes

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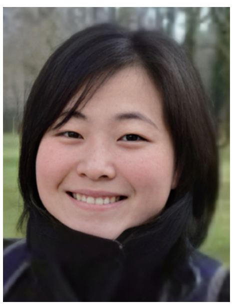

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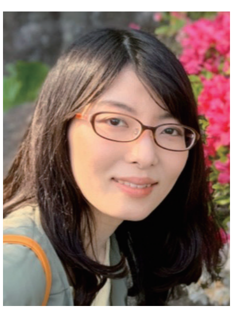

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ITU World Radiocommunication Conference (WRC-19) Report

Takeo Ichikawa, Kazuyoshi Saito, Junichi Iwatani, and Shinya Otsuki

Abstract

Because radio waves travel through space across national borders, there can be harmful radio interference between neighboring countries if each country determines how to use radio services on its own, such as in telecommunication and broadcasting. For this reason, the International Telecommunication Union (ITU), the United Nations organization specialized in telecommunication, sets forth the Radio Regulations (RR), a set of international rules for using radio at each frequency and in each region of the world. To revise the RR, concerned parties from all over the world gather at an international conference held about every four years called the ITU World Radiocommunication Conference (WRC). In Japan, the RR revised at the WRC will be reflected in laws such as the Radio Law. This makes the WRC an extremely important conference for the NTT Group, which provides customers with wireless services and wireless systems, such as mobile telecommunication and wireless local area network (LAN), and uses fixed microwave communication systems, satellite communication systems for remote islands, and disaster-response radio systems for its own networks. In this article, we report on the ITU World Radiocommunication Conference 2019 (WRC-19).

Keywords: wireless LAN (WLAN), International Mobile Telecommunications (IMT), Radio Regulations (RR)

1. ITU World Radiocommunication Conference 2019 (WRC-19)

WRC-19 was held in the city of Sharm El Sheikh, Egypt from October 28 to November 22, 2019. **Figure 1** shows the opening ceremony, which was attended by the President of Egypt. About 3300 people from 166 countries participated and discussed agenda items concerning revisions to the Radio Regulations (RR), as shown in **Table 1**. The Japanese delegation sent about 90 people to participate in discussions, representing the Ministry of Internal Affairs and Communications, as well as telecommunication carriers, broadcasters, manufacturers, research institutes, and other organizations (From NTT Group, this included NTT Access Network Service Systems Laboratories, NTT DOCOMO, NTT Advanced Technology, NTT DATA INSTITUTE OF MANAGEMENT CONSULTING, and NTT Technology Planning Division). The agenda items in blue in Table 1 are mainly related to the NTT Group. NTT Access Network Service Systems Laboratories and NTT Technology Planning Division were in charge of agenda items concerning wireless local area network (LAN) and wireless use by NTT EAST/NTT WEST, while NTT DOCOMO were in charge of agenda items concerning mobile telecommunication and wireless use by NTT DOCOMO. **Figure 2** shows the deliberation system of WRC-19. Agenda items related to wireless LAN and mobile telecommunication were discussed at COM 4. For the RR revisions to be approved, they must receive final approval at a plenary session attended by all participating countries.

1.1 Additional frequency allocation to 5-GHz-band wireless LAN for outdoor use

Discussions were held regarding agenda item 1.16, primarily concerning regulatory measures for wireless

Fig. 1. WRC-19 meeting at the opening ceremony.

access systems including wireless LAN in the 5-GHz band (5.15–5.925 GHz), meaning studies of the revisions to the RR to expand the use of 5-GHz band wireless LAN. Studies to enable outdoor use of wireless LAN and higher transmission power in the 5.2-GHz band (5.15–5.25 GHz) are especially relevant to Japan. In the RR, use of wireless LAN indoors and outdoors in the 5.6-GHz band was already permitted under certain conditions, but the 5.2-GHz band was restricted to indoor use only. Maximum equivalent isotropically radiated power (EIRP) was allowed up to 1 W in the 5.6-GHz band, while limited to 200 mW in the 5.2-GHz band. The reason for this was that the 5.2-GHz band was already in use internationally by other systems, such as satellite communications, so there was concern that there could be harmful radio interference if wireless LAN was used outdoors.

In Japan, the Information and Communications Council conducted technical studies with participation from NTT Access Network Service Systems Laboratories to discuss the possibility of sharing the 5.2-GHz band with satellite telecommunications under outdoor use of wireless LAN. One purpose of these studies is to facilitate the provision of wireless LAN services at venues for international sport competitions to be held in Tokyo. As a result of these studies, under the condition of increasing the maximum transmission power to the same level as the 5.6-GHz band that can already be used outdoors, it can be shared without harmful interference by limiting the number of wireless LAN access points used outdoors and limiting the elevation angle of the antenna. In 2018, Japanese laws and regulations were amended (wireless LAN access points for outdoor use were required to be registered to limit the number of access points, etc.), allowing for trial use of the 5.2-GHz band outdoors. NTT Broadband Platform and others are using the 5.2-GHz band outdoors in addition to the 5.6-GHz band.

At WRC-19, NTT Access Network Service Systems Laboratories took the lead, calling for the outdoor use of 5.2-GHz band wireless LAN and high transmission power under conditions equal to or higher than those in Japan. They succeeded in revising the RR by holding discussions until the last day of the conference with the countries using this band for satellite telecommunications. As a result, wireless LAN will continue to be available outdoors in the 5.2-GHz band under certain conditions, in addition to the 5.6-GHz band in Japan. Details of this matter will be published in the June 2020 issue of this journal.

1.2 Additional allocation to mobile telecommunications

In Japan, the 3.7-, 4.5-, and 28-GHz bands have already been allocated to mobile telecommunication operators as fifth-generation mobile communication system (5G) frequencies in April 2019, and 5G is being introduced in other countries as well. From this background, agenda item 1.13 included studies of

Table 1. Agenda items of WRC-19.

No.	Agenda item
1.1	Allocation of the frequency band 50–54 MHz to the amateur service in Region 1
1.2	Establishment of in-band power limits for earth stations operating in mobile-satellite service, meteorological-satellite service, and Earth exploration-satellite service in the frequency bands 401–403 MHz and 399.9–400.05 MHz
1.3	Consideration of possible upgrading of the secondary allocation to the meteorological-satellite service (space-to-Earth) to primary status and a primary allocation to the Earth exploration-satellite service (space-to-Earth) in the frequency band 460–470 MHz
1.4	Consideration of possible revision of Annex 7 to Appendix 30 of the RR
1.5	Use of the frequency bands 17.7–19.7 GHz (space-to-Earth) and 27.5–29.5 GHz (Earth-to-space) by earth stations in motion communicating with geostationary space stations in the fixed-satellite service
1.6	Studies of technical, operational issues, and regulatory provisions for non-geostationary fixed-satellite services satellite systems in the frequency bands 37.5–39.5 GHz (space-to-Earth), 39.5–42.5 GHz (space-to-Earth), 47.2–50.2 GHz (Earth-to-space) and 50.4–51.4 GHz (Earth-to-space)
1.7	Studies to accommodate spectrum requirements in the space operation service for non-geostationary satellites with short duration missions
1.8	Consideration of regulatory provisions for updating and modernization of the Global Maritime Distress and Safety System
1.9	1. Autonomous maritime radio devices operating in the frequency band 156–162.05 MHz
	2. Consideration of regulatory provisions and spectrum allocations to the maritime mobile-satellite service to enable the satellite component of the VHF Data Exchange System and enhanced maritime radiocommunication
1.10	Studies on spectrum needs and regulatory provisions for the introduction and use of the Global Aeronautical Distress and Safety System
1.11	Railway radiocommunication systems between train and trackside
1.12	Intelligent Transport Systems applications
1.13	Studies on frequency-related matters for International Mobile Telecommunications identification including possible additional allocations to the mobile services on a primary basis in portion(s) of the frequency range between 24.25 and 86 GHz for the future development of International Mobile Telecommunications for 2020 and beyond
1.14	Facilitating access to broadband applications delivered by high-altitude platform stations
1.15	Studies towards an identification for use by administrations for land-mobile and fixed services applications operating in the frequency range 275–450 GHz
1.16	Studies concerning Wireless Access Systems including radio local area networks in the frequency bands between 5150 MHz and 5925 MHz
2	Revision of references to the text of ITU-R Recommendations incorporated by reference in the Radio Regulations/Use of incorporation by reference in the RR
4	General review of the Resolutions and Recommendations of world administrative radio conferences and world radiocommunication conferences
7	Implementation of Resolution 86 (Rev. Marrakesh, 2002) of the Plenipotentiary Conference
8	Footnotes to the Table of Frequency Allocations in Article 5 of the RR
9.1	1. Implementation of International Mobile Telecommunications in the frequency bands 1885–2025 MHz and 2110–2200 MHz (Issue 9.1.1)
	2. Compatibility of International Mobile Telecommunications and broadcasting-satellite service (sound) in the frequency band 1452–1492 MHz in Regions 1 and 3 (Issue 9.1.2)
	3. Study of technical and operational issues and regulatory provisions for new non-geostationary-satellite orbit systems in the 3700–4200 MHz, 4500–4800 MHz, 5925–6425 MHz and 6725–7025 MHz frequency bands allocated to the fixed-satellite service (Issue 9.1.3)
	4. Stations on board sub-orbital vehicles (Issue 9.1.4)
	5. Consideration of the technical and regulatory impact of referencing Recommendations ITU-R M.1638-1 and ITU-R M.1849-1 in Nos. 5.447F and 5.450A of the RR (Issue 9.1.5)
	6. Studies concerning Wireless Power Transmission (WPT) for electric vehicles (Issue 9.1.6)
	7. Studies to examine: whether there is a need for possible additional measures to limit uplink transmissions of terminals to those authorized terminals, etc. (Issue 9.1.7)
	8. Studies on the technical and operational aspects of radio networks and systems for machine-type communication infrastructures (Issue 9.1.8)
	9. Studies relating to spectrum needs and possible allocation of the frequency band 51.4–52.4 GHz to the fixed-satellite service (Earth-to-space) (Issue 9.1.9)
9.2	Report of the Director on any difficulties or inconsistencies encountered in the application of the RR and comments from administrations
9.3	Action in response to Resolution 80 (Rev.WRC-07)
10	Preliminary agenda for the 2023 World Radiocommunication Conference

ITU-R: ITU Radiocommunication Sector
VHF: very high frequency

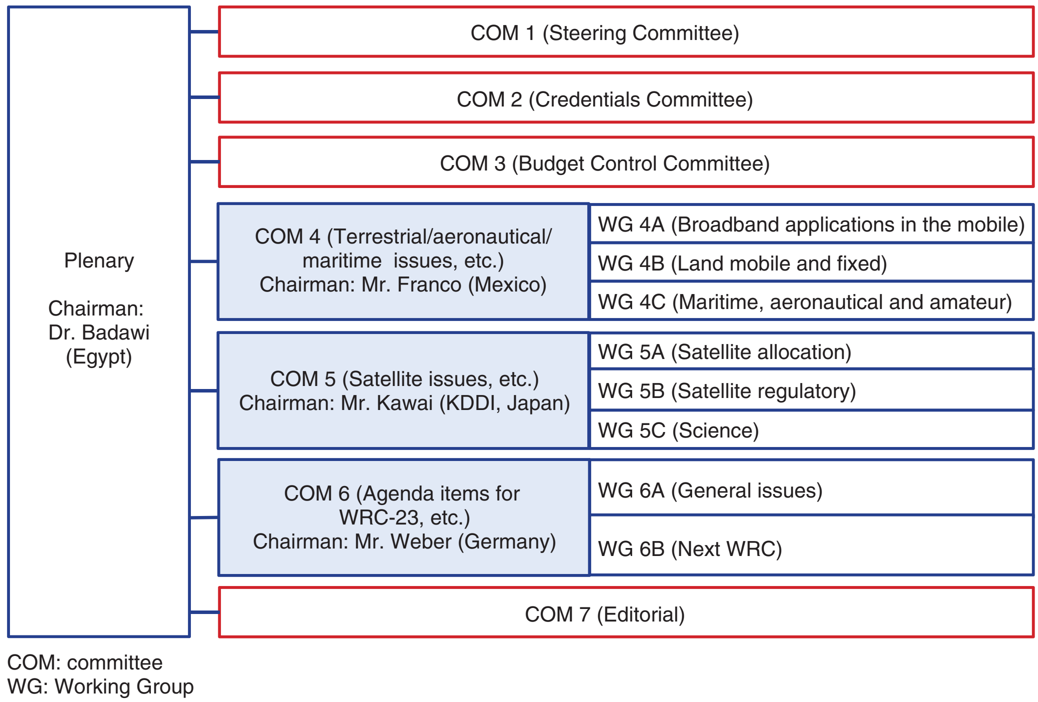

Fig. 2. Structure of WRC-19.

frequencies in the submillimeter and millimeter wave bands for the future development of International Mobile Telecommunications (IMT), which is to say studies of the revisions to the RR to add frequencies for mobile telecommunications such as 5G. At WRC-19, NTT DOCOMO and other mobile telecommunication operators and parties who are involved in existing wireless systems in Japan, such as earth exploration satellites, participated in discussions of these systems, which lasted from early morning to late at night for several days. Almost exactly as requested by Japan, the RR were successfully revised to add a 15.75-GHz bandwidth of new frequencies for IMT: 24.25–27.5, 37–43.5, 45.5–47, 47.2–48.2, and 66–71 GHz (45.5–47 GHz is not applicable to Japan). Of these bands, 26.6–27 and 39.5–43.5 GHz are undergoing technical studies by the Information and Communications Council in preparation for the next allocation of frequencies for 5G in Japan. The details of this topic will be published in the July 2020 issue of NTT DOCOMO Technical Journal.

1.3 Other agenda items

With regard to other agenda items, we focused on those that were mainly related to the NTT Group and acted to avoid the harmful effects on existing NTT Group wireless systems. No amendments to the RR agreed upon at WRC-19 have any harmful effects on wireless systems for the NTT Group.

1.4 Agenda items of ITU World Radiocommunication Conference 2023 (WRC-23)

At WRC-19, the agenda items for the WRC-23 were discussed and decided upon, as shown in **Table 2**. There is no agenda item concerning wireless LAN. With regard to mobile telecommunications, agenda item 1.2 is to consider IMT identification in multiple candidate frequency bands. Among the candidate frequency bands, the 7.025–7.125-GHz band is considered for IMT identification worldwide, which concerns Japan. Other candidate frequency bands are considered for IMT identification for the regions other than Asia-Pacific, and Japan is not involved. Agenda item 1.4 is to consider High Altitude Platform Station (HAPS) as IMT Base Stations (HIBS) in the frequency bands specified for IMT in the 2.7-GHz band or lower. It is aimed at mounting IMT base stations on high-altitude flying vehicles in the stratosphere to provide services of IMT to ground areas.

Table 2. Agenda items of WRC-23.

No.	Agenda item
1.1	to consider, based on the results of the ITU-R studies, possible measures to address, in the frequency band 4800–4990 MHz, protection of stations of the aeronautical and maritime mobile services located in international airspace and waters from other stations located within national territories and to review the pfd criteria in No. 5.441B in accordance with Resolution 223 (Rev.WRC-19)
1.2	to consider identification of the frequency bands 3300–3400 MHz, 3600–3800 MHz, 6425–7025 MHz, 7025–7125 MHz, and 10.0–10.5 GHz for International Mobile Telecommunications (IMT), including possible additional allocations to the mobile service on a primary basis, in accordance with Resolution 245 (WRC-19)
1.3	to consider primary allocation of the band 3 600–3800 MHz to mobile service within Region 1 and take appropriate regulatory actions, in accordance with Resolution 246 (WRC-19)
1.4	to consider, in accordance with Resolution 247 (WRC-19), the use of high-altitude platform stations as IMT base stations (HIBS) in the mobile service in certain frequency bands below 2.7 GHz already identified for IMT on a global or regional level
1.5	to review the spectrum use and spectrum needs of existing services in the frequency band 470–960 MHz in Region 1 and consider possible regulatory actions in the frequency band 470–694 MHz in Region 1 on the basis of the review in accordance with Resolution 235 (WRC-15)
1.6	to consider, in accordance with Resolution 772 (WRC-19), regulatory provisions to facilitate radiocommunications for sub-orbital vehicles;
1.7	to consider a new aeronautical mobile-satellite (R) service (AMS(R)S) allocation in accordance with Resolution 428 (WRC-19) for both the Earth-to-space and space-to-Earth directions of aeronautical VHF communications in all or parts of the frequency band 117.975–137 MHz, while preventing any undue constraints on existing VHF systems operating in the AM(R)S, the ARNS, and in adjacent frequency bands
1.8	to consider, on the basis of ITU-R studies in accordance with Resolution 171 (WRC-19), appropriate regulatory actions, with a view to reviewing and, if necessary, revising Resolution 155 (Rev.WRC-19) and No. 5.484B to accommodate the use of fixed-satellite service (FSS) networks by control and non-payload communications of unmanned aircraft systems
1.9	to review Appendix 27 of the RR and consider appropriate regulatory actions and updates based on ITU-R studies to accommodate digital technologies for commercial aviation safety-of-life applications in existing HF bands allocated to the aeronautical mobile (route) service and ensure coexistence of current HF systems alongside modernized HF systems, in accordance with Resolution 429 (WRC-19)
1.10	to conduct studies on spectrum needs, coexistence with radiocommunication services and regulatory measures for possible new allocations for the aeronautical mobile service for the use of non-safety aeronautical mobile applications, in accordance with Resolution 430 (WRC-19)
1.11	to consider possible regulatory actions to support the modernization of the Global Maritime Distress and Safety System and the implementation of e navigation, in accordance with Resolution 361 (Rev.WRC-19)
1.12	to conduct, and complete in time for WRC-23, studies for a possible new secondary allocation to the Earth exploration-satellite (active) service for spaceborne radar sounders within the range of frequencies around 45 MHz, taking into account the protection of incumbent services, including in adjacent bands, in accordance with Resolution 656 (Rev.WRC-19)
1.13	to consider a possible upgrade of the allocation of the frequency band 14.8–15.35 GHz to the space research service, in accordance with Resolution 661 (WRC-19)
1.14	to review and consider possible adjustments of the existing or possible new primary frequency allocations to EESS (passive) in the frequency range 231.5–252 GHz, to ensure alignment with more up-to-date remote-sensing observation requirements, in accordance with Resolution 662 (WRC-19)
1.15	to harmonize the use of the frequency band 12.75–13.25 GHz (Earth-to-space) by earth stations on aircraft and vessels communicating with geostationary space stations in the fixed-satellite service globally, in accordance with Resolution 172 (WRC-19)
1.16	to study and develop technical, operational and regulatory measures, as appropriate, to facilitate the use of the frequency bands 17.7–18.6 GHz, 18.8–19.3 GHz, 19.7–20.2 GHz (space-to-Earth), 27.5–29.1 GHz, and 29.5–30 GHz (Earth-to-space) by non-GSO FSS earth stations in motion while ensuring due protection of existing services in those frequency bands, in accordance with Resolution 173 (WRC-19)
1.17	to determine and carry out, on the basis of the ITU-R studies in accordance with Resolution 773 (WRC-19), the appropriate regulatory actions for the provision of inter-satellite links in specific frequency bands, or portions thereof, by adding an inter-satellite service allocation where appropriate
1.18	to consider studies relating to spectrum needs and potential new allocations to the mobile-satellite service for future development of narrowband mobile-satellite systems, in accordance with Resolution 248 (WRC-19)
1.19	to consider a new primary allocation to the fixed-satellite service in the space-to-Earth direction in the frequency band 17.3–17.7 GHz in Region 2, while protecting existing primary services in the band, in accordance with Resolution 174 (WRC-19)
2	to examine the revised ITU-R Recommendations incorporated by reference in the RR communicated by the Radiocommunication Assembly, in accordance with further resolves of Resolution 27 (Rev.WRC-19), and to decide whether to update the corresponding references in the RR, in accordance with the principles contained in resolves of that Resolution
4	in accordance with Resolution 95 (Rev.WRC-19), to review the Resolutions and Recommendations of previous conferences with a view to their possible revision, replacement, or abrogation
7	to consider possible changes, in response to Resolution 86 (Rev. Marrakesh, 2002) of the Plenipotentiary Conference, on advance publication, coordination, notification, and recording procedures for frequency assignments pertaining to satellite networks, in accordance with Resolution 86 (Rev.WRC 07), to facilitate the rational, efficient, and economical use of radio frequencies and any associated orbits, including the geostationary-satellite orbit
8	to consider and take appropriate action on requests from administrations to delete their country footnotes or to have their country name deleted from footnotes, if no longer required, taking into account Resolution 26 (Rev.WRC-19);
9.1	a) In accordance with Resolution 657 (Rev.WRC-19), review the results of studies relating to the technical and operational characteristics, spectrum requirements and appropriate radio service designations for space weather sensors with a view to describing appropriate recognition and protection in the Radio Regulations without placing additional constraints on incumbent services
	b) Review of the amateur service and the amateur-satellite service allocations in the frequency band 1240–1300 MHz to determine if additional measures are required to ensure protection of the radionavigation-satellite (space-to-Earth) service operating in the same band in accordance with Resolution 774 (WRC-19)
	c) Study the use of International Mobile Telecommunications system for fixed wireless broadband in the frequency bands allocated to the fixed services on primary basis, in accordance with Resolution 175 (WRC-19)
	d) Protection of EESS (passive) in the frequency band 36–37 GHz from non-GSO FSS space stations
9.2	on any difficulties or inconsistencies encountered in the application of the RR
9.3	on action in response to Resolution 80 (Rev.WRC-07)
10	to recommend to the Council items for inclusion in the agenda for the next WRC, and items for the preliminary agenda of future conferences, in accordance with Article 7 of the Convention and Resolution 804 (Rev.WRC-19)

EESS: Earth exploration-satellite service
Non-GSO: non-geostationary satellite orbits

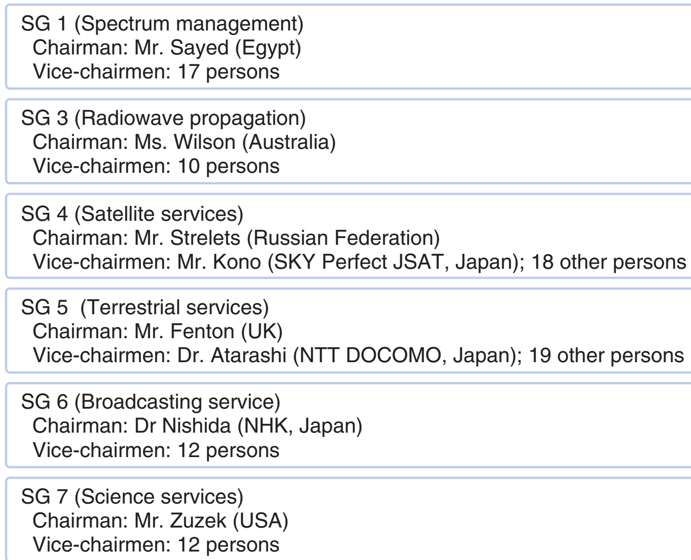

Fig. 3. Study Group structure and chairmen and vice-chairmen for 2019–2023.

2. ITU Radiocommunication Assembly 2019 (RA-19)

Prior to WRC-19, RA-19 was held in Sharm El Sheikh, Egypt from October 21 to 25, 2019. RA is a general meeting of ITU-Radiocommunication Sector (ITU-R) held about every four years, the same as the WRC. At the RA, the chair and vice-chair of the Study Groups (SGs) of ITU-R are appointed, and study items are approved. About 511 people from 88 countries participated in RA-19, including 36 people from Japan, with representatives from the Ministry of Internal Affairs and Communications. As shown in **Fig. 3**, the chair and vice-chair of various SGs were appointed, and from NTT Group, Dr. Hiroyuki Atarashi of NTT DOCOMO was appointed as one of the SG 5 vice-chairs responsible for study on terrestrial services including fixed, mobile, and radiodetermination systems. The study results from each SG will be published as recommendations or reports from ITU-R and will be referred to during the WRC discussions.

3. Future activities

In preparation for WRC-23, NTT aims to add more frequencies for wireless systems for the NTT Group and protect existing NTT Group wireless systems from harmful radio interference. To that end, we will continue our work at ITU-R, WRC preparatory meetings in the Asia-Pacific region, and related meetings in Japan.

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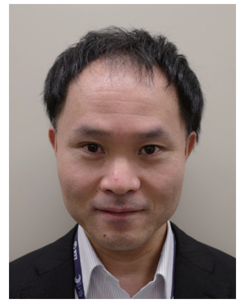
Senior Manager, Radio Division, NTT Technology Planning Department.

He received an M.E. from Waseda University, Tokyo, in 1993 and joined NTT the same year. He participated in the research and development of personal handy-phone system (PHS)-based packet systems and high-speed wireless LAN systems. He received the Young Researcher's Award from the Institute of Electronics, Information and Communication Engineers (IEICE) in 1999. He is a member of the Institute of Electrical and Electronics Engineers (IEEE) and IEICE.

Kazuyoshi Saito
Senior Manager, Radio Division, NTT Technology Planning Department.

He received a B.E. and M.E. in electronics engineering from Tohoku University, Miyagi, in 1996 and 1998 and joined NTT in 1998. From 1998 to 2004, he studied wireless LAN systems. In 2004, he joined NTT EAST, where he was involved in developing "Hotpot" services. Since 2018, he has been with Radio Division, Technology Planning Department, NTT.



Junichi Iwatani
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He received a B.E. and M.E. in electronics engineering from the University of Tokyo in 1994 and 1996. Since joining NTT Wireless Systems Laboratories in 1996, he has been engaged in research and development of wireless access systems. From 2006 to 2008, he researched next-generation networks in NTT Service Integration Laboratories. In 2010, he joined NTT Communications, where he was involved in developing global network services. Since 2013, he has been with NTT Access Network Service Systems Laboratories, where he has been engaged in research and standardization of wireless LAN systems. Since 2017, he has been involved in activities to revise the Radio Regulations of 5-GHz-band wireless LAN for WRC-19 at ITU-R meetings. He received the ITU-AJ Encouragement Award in 2018. He is a member of IEICE.

Shinya Otsuki
Senior Research Engineer, Wireless Access System Project, NTT Access Network Service Systems Laboratories.

He received a B.E., M.E., and Ph.D. in communication engineering from Osaka University in 1993, 1995, and 1997 and joined NTT in 1997. From 1997 to 2008, he studied wireless access systems, wireless LAN systems, and wireless systems for Internet services in trains. From 2008 to 2011, he was involved in international standardization efforts in evolved packet core and services using Internet Protocol multimedia subsystems at NTT Service Integration Laboratories. He has been with NTT Access Network Service Systems Laboratories since 2011. Since 2011, he has been contributing to the activities of the Working Parties 5A and 5C in the SG 5 of ITU-R. He received the ITU-AJ International Activity Encouragement Award in 2014. He is a member of IEEE and IEICE.

Event Report: ISNTT2019 at NTT Basic Research Laboratories

Norio Kumada

Abstract

The International School and Symposium on Nanoscale Transport and phoTonics (ISNTT) is held by NTT Basic Research Laboratories once every two years to cover subjects related to electronic and photonic properties in nanostructures. The 2019 event was held at the NTT Atsugi R&D Center from November 18 to 22.

Keywords: NTT Basic Research Laboratories, BRL School, international symposium

1. ISNTT overview and purpose

With the mission of creating new principles and concepts for breaking through the barriers of network technology and developing basic technology for future innovation, NTT Basic Research Laboratories engages in a wide range of joint research activities with universities around the world as well as organizations within the NTT Group, playing the role of a "laboratory open to the world." Since 1998, we have been holding international symposia that focus on the quantum properties of semiconductors and superconductivity with the objectives of disseminating our results to prominent researchers and students from around the world and deepening discussion of these research fields. Since 2009, the symposium has been held every other year under the name the International School and Symposium on Nanoscale Transport and phoTonics (ISNTT). Since ISNTT 2017, the topic of optical properties has been included. In addition, Basic Research Laboratories School (BRL School) has been held as part of the event. The BRL School offers lectures and laboratory tours for Ph.D. students to broaden their knowledge of NTT Basic Research Laboratories and provide growth opportunity for young researchers.

2. ISNTT 2019

2.1 BRL School

About 80 people, mostly Ph.D. students, participated in the lectures and laboratory tours of the BRL School for the day and a half on November 18 and 19 (**Photo 1**). They attended two-hour lectures on "Hybrid Quantum Systems" by Professor Göran Johansson and Professor Per Delsing of the Chalmers University of Technology and by Professor Kouichi Semba of the National Institute of Information and Communications Technology. The students actively participated in the question sessions. The laboratory tours also introduced the students to the research facilities of NTT Basic Research Laboratories. The student participants went on to attend the symposium in the afternoon of the 19th.

2.2 International symposium

The international symposium on electronic and optical properties in nanostructures was held over three and a half days from the afternoon of the 19th to the 22nd. It was attended by 231 people from 15 countries (**Photo 2**). The keynote speech on "Nanoscale Transport and our New International System of Units" by Nobel Laureate in Physics Klaus von Klitzing of Max Plank Institute was followed by 48 oral presentations and 87 poster sessions, including

Photo 1. Participants of BRL School.

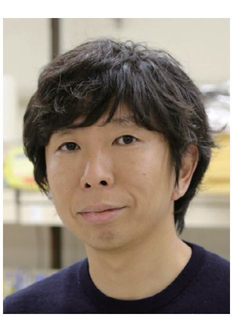
Photo 2. Participants of ISNTT.

19 invited lectures by prominent researchers. The event concluded with a keynote speech on "Superconducting Circuits for Quantum Technologies" by Professor Yasunobu Nakamura of the University of Tokyo and RIKEN. The topics of the symposium were related to the research areas of NTT Basic Research Laboratories such as superconductivity, quantum phenomena in semiconductor nanostructures,

nanomechanics, quantum optics, and their hybrid systems. Discussion sessions on the research were lively. Discussions continued and friendships were deepened during a social reception held on the evening of the 21st. The award for best student poster was presented and five students were awarded diplomas and souvenirs at the reception.

3. After ISNTT 2019

The fine weather and beautiful autumn colors at NTT Atsugi R&D Center created a relaxed atmosphere for pleasant discussions. I was personally inspired by the presentations on the most recent research results and the inquisitive attitude of students, who were very active in asking questions during all the sessions. I hope that this school and symposium will stimulate even greater interest in the topics and in collaborative research, not only for researchers at NTT but for all participants.



Norio Kumada

Distinguished Scientist, Quantum Solid-State Physics Research Group, Physical Science Laboratory, NTT Basic Research Laboratories.

He received a B.S., M.S., and Ph.D. in physics from Tohoku University, Miyagi, in 1998, 2000, and 2003. He joined NTT Basic Research Laboratories in 2003. He has since been engaged in the study of highly correlated electronic states formed in semiconductor heterostructures. He was a visiting researcher at CEA Saclay from 2013 to 2014. He was appointed as a distinguished scientist of NTT in 2010. He received the Young Scientist Award of the Physical Society of Japan in 2008 and the Young Scientists' Prize from the Minister of Education, Culture, Sports, Science and Technology in 2012. He is a member of the Physical Society of Japan.

External Awards

Technical Meeting Encouragement Award
Winner: Hitoshi Wakita, NTT Device Technology Laboratories
Date: February 13, 2020
Organization: The Institute of Electrical Engineers of Japan (IEEJ)

For "Recent Advance in Ultra-high Bandwidth Coherent Driver Modulator."
Published as: H. Wakita, M. Nagatani, H. Yamazaki, T. Fujii, M. Ida, Y. Ogiso, J. Ozaki, Y. Ueda, S. Kanazawa, Y. Hashizume, H. Tanobe, N. Nunoya, M. Ishikawa, M. Nakamura, T. Kobayashi, and Y. Miyamoto, "Recent Advance in Ultra-high Bandwidth Coherent Driver Modulator," Proc. of technical meeting on electron devices, IEEJ, EDD-19-036-044, pp. 7–10, Mar. 2019 (in Japanese).

Specially Selected Paper
Winner: Atsuhiko Maeda, NTT Network Innovation Laboratories (Presently with NTT Service Evolution Laboratories)
Date: February 15, 2020
Organization: The Information Processing Society of Japan (IPSJ)

For "Automatic Generation of a Pedestrian Road Network Using Aerial Photographs and Maps."
Published as: A. Maeda, "Automatic Generation of a Pedestrian Road Network Using Aerial Photographs and Maps," IPSJ Journal, Vol. 61, No. 2, pp. 262–223, Feb. 2020 (in Japanese).

Kenjiro Sakurai Memorial Prize
Winner: Shinji Matsuo, Takaaki Kakitsuka, Tomonari Sato, Koji Takeda, NTT Device Technology Laboratories
Date: February 19, 2020
Organization: Optoelectronics Industry and Technology Development Association (OITDA)

For the development of small-threshold-current and high-operating-speed membrane semiconductor lasers.

2020 PROSE Awards Subject Category Winner in Chemistry and Physics
Winner: Main editors: Kohji Mitsubayashi, Tokyo Medical and Dental University; Osamu Niwa, Saitama Institute of Technology; Yuko Ueno, NTT Basic Research Laboratories
Chapter authors (from NTT): Yuko Ueno, Hiroshi Nakashima, Shingo Tsukada, NTT Basic Research Laboratories; Junichi Kodate, NTT Device Innovation Center; Akihiro Chiba, Kana Eguchi, Hisashi Kurasawa, NTT Service Evolution Laboratories
Date: February 28, 2020
Organization: The Association of American Publishers

For "Chemical, Gas, and Biosensors for Internet of Things and Related Applications."
Published as: "Chemical, Gas, and Biosensors for Internet of Things and Related Applications," edited by K. Mitsubayashi, O. Niwa, and Y. Ueno, Elsevier, June 2019.

Paper Award
Winner: Himma Firdaus, Tokinobu Watanabe, Masahiro Hori, Daniel Moraru, Shizuoka University; Yasuo Takahashi, Hokkaido University; Akira Fujiwara, NTT Basic Research Laboratories; Yukinori Ono, Shizuoka University
Date: March 13, 2020
Organization: Silicon Technology Division, The Japan Society of Applied Physics

For "Electron Aspirator Using Electron–Electron Scattering in Nanoscale Silicon."
Published as: H. Firdaus, T. Watanabe, M. Hori, D. Moraru, Y. Takahashi, A. Fujiwara, and Y. Ono, "Electron Aspirator Using Electron–Electron Scattering in Nanoscale Silicon," Nat. Commun., Vol. 9, 4813, 2018.

Young Researcher's Award
Winner: Kohei Saito, NTT Network Service Systems Laboratories
Date: March 19, 2020
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE)

For "Evaluation of Field Transmission Performance of World's Fastest 600-Gbps per Lambda Signals" and "Long-haul Field Transmission Performance of Real-time 400-Gbit/s/carrier Signals."
Published as: K. Saito, H. Kawahara, T. Kubo, T. Seki, T. Kawasaki, H. Maeda, T. Sekino, N. Sakauchi, M. Shinkai, T. Sakamaki, K. Yamanaka, and T. Kurimoto, "Evaluation of Field Transmission Performance of World's Fastest 600-Gbps per Lambda Signals," Proc. of the 2019 IEICE General Conference, B-10-33, Tokyo, Japan, Mar. 2019.
K. Saito, T. Sasai, F. Hamaoka, H. Kawahara, T. Seki, A. Masuda, H. Date, and H. Maeda, "Long-haul Field Transmission Performance of Real-time 400-Gbit/s/carrier Signals," Proc. of the 2019 IEICE Society Conference, B-10-34, Osaka, Japan, Sept. 2019.

Young Researcher's Award
Winner: Ryo Igarashi, NTT Access Network Service Systems Laboratories
Date: March 19, 2020
Organization: IEICE

For "Reach Extension of 10G-EPON Using Distributed Raman Amplification."
Published as: R. Igarashi, T. Kanai, M. Fujiwara, J. Kani, and J. Terada, "Reach Extension of 10G-EPON Using Distributed Raman Amplification," Proc. of the 2019 IEICE Society Conference, B-8-7, Osaka, Japan, Sept. 2019.

Young Researcher's Award
Winner: Rintaro Harada, NTT Access Network Service Systems Laboratories
Date: March 19, 2020
Organization: IEICE

For "Downstream Frame Forwarding Method Realizing Incremental Upgrade of PON" and "Frame Distributing Method on Incremental Upgrade of PON Using Multiple Wavelengths."
Published as: R. Harada, H. Uzawa, H. Nakamura, and J. Terada, "Downstream Frame Forwarding Method Realizing Incremental Upgrade of PON," Proc. of the 2019 IEICE General Conference, B-8-26, Tokyo, Japan, Mar. 2019.
R. Harada, H. Uzawa, H. Nakamura, and J. Terada, "Frame Distributing Method on Incremental Upgrade of PON Using Multiple Wavelengths," Proc. of the 2019 IEICE Society Conference, B-8-12, Osaka, Japan, Sept. 2019.

Papers Published in Technical Journals and Conference Proceedings

Semantic Segmentation of Sparsely Annotated 3D Point Clouds by Pseudo-labelling

K. Xu, Y. Yao, K. Murasaki, S. Ando, and A. Sagata

Proc. of the 7th International Conference on 3D Vision, pp. 463–471, Quebec City, Canada, September 2019.

Manually labelling point clouds scenes for use as training data in machine learning applications is a time and labor intensive task. In this paper, we aim to reduce the effort associated with learning semantic segmentation tasks by introducing a semi-supervised method that operates on scenes with only a small number of labelled points. For this task, we advocate the use of pseudo-labelling in combination with PointNet, a neural network architecture for point cloud classification and segmentation. We also introduce a method for incorporating information derived from spatial relationships to aid in the pseudo-labelling process. This approach has practical advantages over current methods by working directly on point clouds and not being reliant on predefined features. Moreover, we demonstrate competitive performance on scenes from two publicly available datasets and provide studies on parameter sensitivity.

Evaluation of Dynamic Guidance-sign System for Controlling Pedestrians in Public Facilities

Y. Ichikawa, A. Hayashi, Y. Mihara, K. Shimizu, and H. Mineno

IPSJ Transactions on Consumer Devices & Systems, Vol. 10, No. 1, pp. 50–57, February 2020.

Throughout 2020, the number of foreign visitors to Japan is expected to increase, resulting in congestion of public facilities. Since the congested state impairs the safety of the facility, it is important to introduce a system to alleviate such congestion by guiding facility users and controlling their movements. We measured the congestion situation in a facility the international passenger terminal at Haneda airport, which is constantly changing, and constructed a guidance-sign system to dynamically guide people to vacant routes. We present the results of this evaluation in terms of the degree of congestion.

Sentence-final Prosody Analysis of Japanese Communicative Speech Based on the Command-response Model

K. Takada, H. Nakajima, and Y. Sagisaka

Proc. of the 2020 IEEE Conference on Computer Applications, pp. 235–239, Yangon, Myanmar, February 2020.

Aiming at communicative speech synthesis, we analyzed sentence-final prosody characteristics through subjective impression on constituting lexicons. Since Japanese sentence-final particles and postpositionals are expected to be employed to generate communicative prosody showing speaker's intention and attitudes, we designed 52 single-phrase utterances showing different strength of the speaker's impressions about judgment. These impressions were quantified in Semantic Differential (SD) scales. F0 contour characteristics were analyzed by using the command-response model. To cope with sentence final F0 characteristics, an additional accent command was introduced for F0 rise and drop of sentence-final particles. The analysis showed systematic communicative prosody control by the accent command reflecting effect of judgment impressions which can be obtained from constituting lexicons. These results indicate possibility of sentence-final prosody control using impression obtained from lexicons constituting output sentences.

Understanding Cloaking Techniques of Phishing Websites through Dynamic Analysis

H. Kodera, T. Shibahara, D. Chiba, K. Aoki, K. Hato, and M. Akiyama

IPSJ Journal, Vol. 61, No. 3, pp. 555–566, March 2020.

Phishing attacks have been ever-increasing on the Internet today. One of the promising countermeasures for phishing attacks is filtering by using blacklists. Such blacklists are composed of URLs of phishing websites and have been maintained by accessing/detecting the URLs. However, some phishing websites have implemented a special access control technique in server-side called cloaking to prevent them from accessing/detecting by the provider of such blacklists. In order to improve blacklist-based countermeasures, we need to better understand the cloaking technique and its actual situation on the Internet. To this end, we propose a new method to analyze the cloaking techniques of phishing websites and conduct a large-scale measurement study of them. Specifically, we analyze a specific condition to activate the cloaking techniques by focusing on phishing kits which are commonly used to deploy phishing websites today. We reveal that 10.4% of 4,901 real/active phishing websites implement the cloaking technique relying on User-Agent and Referer which can be configurable by blacklist providers.
