NTT Technical Review

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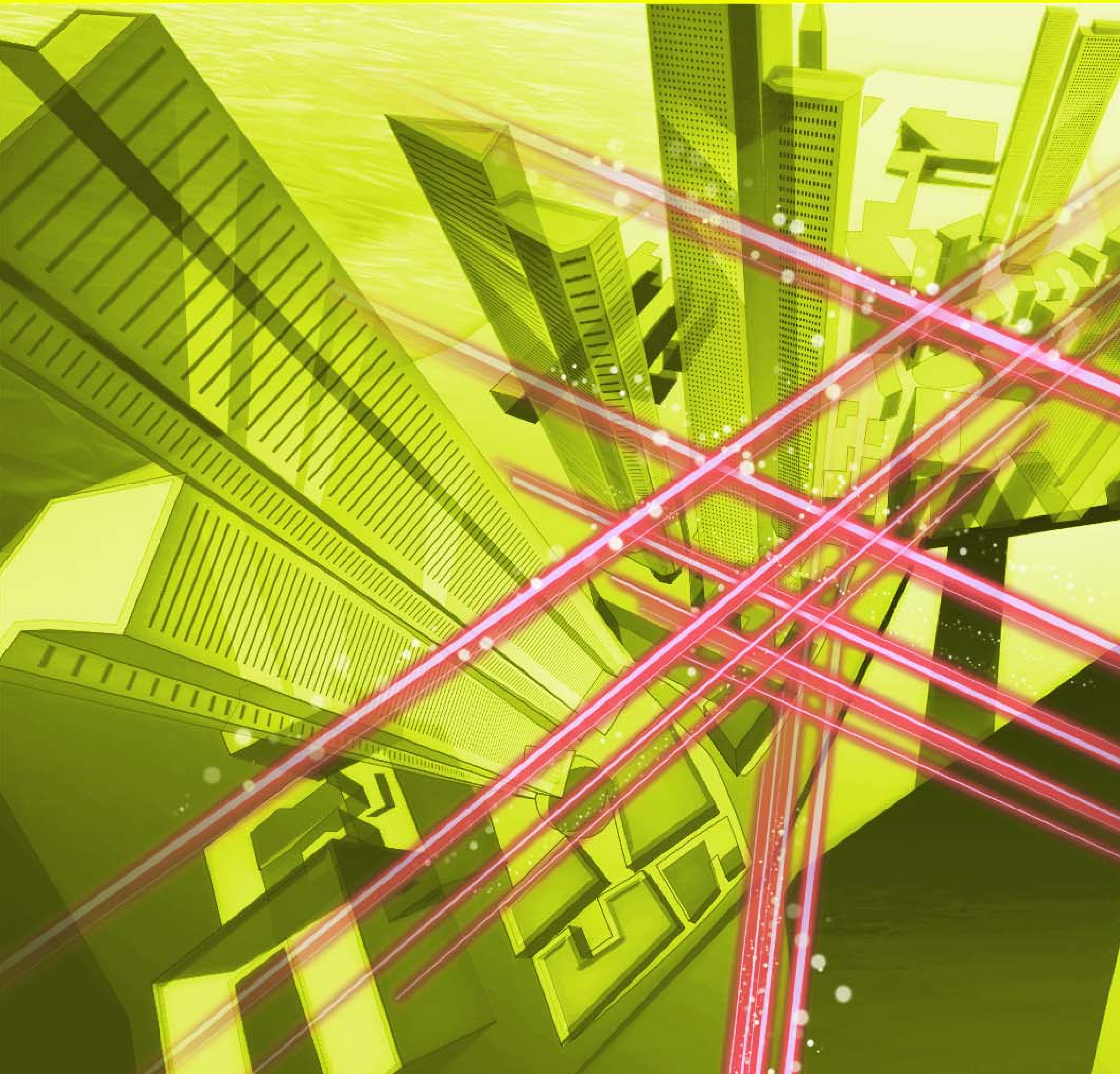

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Let's Open the Door beyond Limits with Hope

Katsuhiko Kawazoe
Senior Executive Vice President, NTT

Abstract

The NTT Group is taking on the challenge of creating a Smart World that enriches the lives of all people around the world through its efforts in a variety of fields. By implementing the Innovative Optical and Wireless Network (IOWN), the group aims to solve social issues and create innovative services. We interviewed Katsuhiko Kawazoe, senior executive vice president of NTT, who coined the term "IOWN," about the development status of IOWN and his approach to his work as a top executive.

Keywords: IOWN, research and development, space datacenter

The target for implementing IOWN is set to be achieved by Expo 2025 Osaka, Kansai, Japan

—Congratulations on your new position. What changes have you seen since assuming your current position?

The change in my position from the head of the Research and Development Planning Department to my current position as senior executive vice president of NTT has changed the sense of time in which I perceive matters. For example, we must predict and create the future during the research process. If we do not proceed while constantly thinking about what lies ahead of current technology, by the time the research results are published, they may be obsolete. When I was head of the Research and Development Planning Department, my main focus was advancing research and development by looking at the results that would be achieved in the near future while considering the direction and importance of the research and technology in question from a medium- to long-term perspective.

On becoming senior executive vice president, I've become responsible for not only research but also technology in general as chief technology officer. My prime mission is to solve the social issues we are currently facing as quickly as possible by using our technologies. This mission also includes improving or developing technologies for securing communications as social infrastructure in times of disaster and other emergencies and technologies for providing high-quality and stable services. Of course, I'm also in charge of research and development, so I'll promote such activities from a medium- to long-term perspective. Another important role of mine is to smoothly introduce the results of advanced research and development into our business in a manner that contributes to society; in that sense, I believe the implementation of IOWN is a symbolic theme.

I also hold the positions of chief information officer (CIO) and chief digital officer (CDO), who must focus on digital transformation (DX). Akira Shimada, the new president and chief executive officer of NTT, has stated that he will "create better CX (customer experience) through better EX (employee experience)." DX is essential for this purpose, so I intend to actively promote DX in cooperation with other CIOs and CDOs of NTT Group companies.

—What initiatives should we pay attention to? First, let's talk about IOWN, the term you coined, which has entered its third year.

Since the announcement of the concept of IOWN in 2019, various social issues have been highlighted, such as the importance of achieving carbon neutrality, the recent shortage of semiconductors, and ensuring Japan's economic security against the backdrop of unstable global situations. In light of the need to respond quickly to these issues, we moved the target set for implementing IOWN forward five years from 2030 to 2025. This change was largely due to the influence of the IOWN Global Forum (IOWN GF) established in 2020. To tackle these social issues, we must collaborate with experts and global partners in a wide range of research and technical fields. IOWN GF, launched with the support of Intel and Sony Group, has grown to include more than 100 participating companies and organizations, including major technology companies such as Ericsson of Sweden and NVIDIA of the US. The number of companies participating in the forum is increasing annually, demonstrating that IOWN is attracting attention worldwide. Thanks to the progress of discussions at IOWN GF and research at NTT, we could move the IOWN implementation target forward. Consequently, we plan to present IOWN-related products to the world at Expo 2025 Osaka, Kansai, Japan, which will draw global attention.

Various innovations are possible with IOWN, and I'd like to talk about one of them, the Space Integrated Computing Network. In July 2022, in collaboration with SKY Perfect JSAT, we established Space Compass Corporation to construct the first *space datacenter* in human history in a manner that overcomes the current limitations on the use of space. As I mentioned in my interview in 2019, when I joined the company in 1987, my research theme was satellite communications, and NTT was developing and operating communication satellites even then. Later, due to the widespread use of terrestrial optical fibers and the enormous cost of developing communication satellites, NTT withdrew from the business. However, recent technological innovations have enabled high-speed communication by using higher frequencies. Because of the potential of these innovations, we can say that the possibility of achieving what we had previously abandoned has increased.

As exemplified by the recent disruption to social life caused by communication failures in Japan, building a solid infrastructure that can cope with uncertainties is NTT's social mission. Communication satellites are playing an increasingly important role in accomplishing that mission. Against this background, we plan to establish the first space datacenter to address this social mission.

The initiative for building the Space Integrated Computing Network consists of two projects: (i) a high-capacity communication and computing infrastructure in space and (ii) a communication infrastructure for beyond fifth- and sixth-generation mobile communication systems (beyond 5G/6G). The former project's aim is to provide a high-capacity communication and computing infrastructure in space, i.e. a space datacenter, by sequentially deploying geostationary orbit satellites equipped with advanced computing capabilities. NTT plans to demonstrate its high-capacity optical transmission technology in space at the aforementioned World Expo and intends to expand this service worldwide.

The latter project's aim is to launch space radio access network businesses, such as image sensing through high-altitude platform stations installed in the stratosphere. By taking up the challenge of building new infrastructures, such as optical wireless communication networks in space and mobile networks in the stratosphere, we hope to contribute to developing the global space industry and creating a sustainable society.

NTT's strengths are its underlying technology and accumulated knowledge

—I'm fascinated by IOWN and other ambitious projects. They are being developed through the research and technological capabilities of NTT, correct?

I believe that one way to hone our foresight in research and development is to continue our research activities while thoroughly pursuing basic research. The current times, issues, and trends tend to drive people to focus on technologies and research results that can be used immediately; for example, GAFA (Google, Apple, Facebook, and Amazon) are heavily investing in artificial intelligence (AI) now. Some say that companies or researchers and developers with such a mindset are using the achievements of others to develop the technology underpinning AI.

NTT laboratories, however, are involved in basic research and fundamental technologies. The basic research on light that supports IOWN has accumulated over more than 60 years since the 1960s. NTT's strengths are its foundational technologies and accumulated knowledge. We can continue our research by generating research funds from the profits from our businesses and can use these hard-earned profits to demonstrate the necessity and importance of basic research. Precisely because our researchers have been fulfilling their responsibility to demonstrate their ideas, we have been able to continue our research activities to this day.

Throughout my career at NTT, I have served as both a researcher and developer. Perhaps more than half of my work has been in business-oriented development. When I joined NTT, research and development were likened to the two wheels of a cart, emphasizing the importance of keeping both wheels running well. In other words, there were roles for people specializing in either research or development and for people responsible for both, turning both wheels, so to speak. I was positioned right in the middle of research and development—turning both wheels.

—It is reassuring that you know about both research and development. Do you have a specific vision for how research and development should be conducted?

The idea that I'm currently developing is to ask employees responsible for research and development to focus on either research or development instead of the two roles that I have played in the past. I understand that this is a difficult request. Research life has its ups and downs, and when things aren't going well, one may work on development, get an idea from it, then resume research to find a way to survive. By taking on both roles, one will be able to take on a certain amount of work in a stable manner and probably get

a sense that they are doing their job and serving a purpose. However, if one is asked to focus on research or development, they must work extremely hard because their escape route is cut off.

Doing what I suggest is tough, and not everyone will be able to overcome this challenge, but I want them to understand how much greatness awaits beyond that pain. As senior executive vice president, it is my job to create a challenging environment that fosters a willingness to work hard. I also strive to secure enough resources for research and development to ensure that our researchers, developers, and employees can enjoy their work and be happy.

Think of work and private life as a combination rather than as separate

—I understand that you are also active as the head of various organizations. How do you balance work and private life?

In addition to being president and chairperson of IOWN GF, I'm also president of the Institute of Electronics, Communications and Information Engineers and, in a different vein, president of the Japan Windsurfing Association.

I'm sometimes asked, "How do you manage your time when you are so busy?" I do not try to distinguish between work and private life; rather, I view my work and private life as a combination.

For example, let me talk about windsurfing. When it was decided that a major international sporting event would be held in Tokyo, Tsuneo Hasegawa, then president of the Japan Windsurfing Association, visited me and said, "Mr. Kawazoe, please make windsurfing a popular sport. Can't we do that by using NTT's technology and ideas?" In response, I said I wondered if it would be possible to use Kirari!, NTT's ultra-realistic viewing technology, to deliver a realistic sensation of watching a competition in a remote venue. We were very excited about the idea. I was told that Mr. Hasegawa said before his death, "I'd like to ask Mr. Kawazoe to be the next president." I decided to accept the offer because I used to windsurf in my student days. When I'm practicing windsurfing while remembering those days, ideas and applications for the next technology or service come to mind, and the conversations with the other windsurfers inspire me to apply the ideas that come to mind for my work.

I'm also involved with cooking, and to improve my cooking skills, I joined the All Japan Food Association. Chefs and cooks who met me at conferences and other events talk about archiving their cooking and food through the technology of NTT. They say, "The food we create is a once-in-a-lifetime work of art, and we want to preserve it." Their words express their wish to record the entire food-preparation process—from the filleting of a fish to preparing the dish—with the power of information and communication technology. My visions and ideas began to expand as I wondered what kind of technology I could use to help them actualize their passion or what IOWN could do for them. This situation illustrates exactly what I mean by thinking of work and private life as a combination rather than separate, in a way that is fun and meaningful. Don't you think that everything is connected and that both work and play stimulate each other in various ways?

—It is important to have a broad perspective and comprehensive view of matters. Finally, please say a few words to researchers and developers.

To researchers, I'd like to see you hone your expertise in either research or development rather than both. Aim to be number one in your field of expertise and accomplish what no one else has done. With the spirit that you are the only one working on this research, you should aim to be the very best. Unlike researchers, developers are constrained by development costs and time and must consider what they can do within those constraints. You should challenge yourself while keeping a strong awareness of what you can do within those constraints of your goals and the conditions. Whether your focus is research or development, sometimes you may feel uneasy; nevertheless, at such times, it is essential to set a starting point based on yourself or to think of yourself as a source of inspiration. If you are a researcher, you'll take great pleasure in achieving results in the form of papers or academic awards and being respected by society; if you are a developer, you'll take great pleasure in seeing your developments implemented in society and in people's daily lives. I hope that you will approach your daily work with that joy in mind.

Although I won't say it's my motto, I always keep the phrase "stress-free" in mind and try not to stress myself too much. Speaking like this may make me seem emotionally detached, but that's not the case. On the contrary, if you force things while trying to break through a metaphoric brick wall, you will be left with feelings of pain and even more stress, just as hitting an actual wall with your hand hurts. Alternatively, when you take on a big challenge, rather than thinking of the process as forcing something to break through a wall, imagine a door. Then, open the door while imagining what could be on the other side. Let's open this door with hope, even if others say we are at our limits.

■ Interviewee profile

Katsuhiko Kawazoe joined NTT in 1987. He became vice president of the Research and Development Planning Department in 2008, head of NTT Service Evolution Laboratories in 2014, head of NTT Service Innovation Laboratory Group in 2016, and executive vice president, head of Research and Development Planning Department in 2020, and assumed his current position in June 2022. He has also served as director of NTT Research, Inc. since April 2019 and president and chairperson of the IOWN Global Forum since January 2020. He received a Ph.D. in engineering.

Intrinsic Motivation Is the Driving Force in Developing a New Methodology

Makio Kashino
NTT Fellow and Director of Kashino Diverse Brain Research Laboratory, NTT Communication Science Laboratories

Abstract

In 2021, the Japanese national team won the gold medal in the women's softball competition at a major international sporting event held in Tokyo. Behind this triumph was a new attempt to clarify the brain mechanisms that enable top athletes to execute their superior techniques and improve such techniques through training using the latest information technology. We interviewed NTT Fellow Makio Kashino, who is exploring the mechanisms of the mind and body by focusing on the implicit brain function, and asked him about his research activities and his approach as a researcher.

Keywords: implicit brain function, cognitive neuroscience, inverse translational science

Uncover and develop the brain function of which you are unaware

—Can you tell us about the research you are currently working on?

What I am consistently interested in is the *implicit brain function*, that is, the brain function that we humans are not aware of. The various activities of daily life, such as understanding situations, making decisions, performing appropriate actions, communicating with others, and feeling various types of emotions, are all the result of an enormous amount of information processing in the brain, and we are unaware of most of those processes. In fact, our mind is supported by our implicit brain function.

The implicit brain function is also deeply connected to our body. For example, athletes achieve superhuman feats by skillfully moving their bodies instantaneously without having to think about it. When we are moved by music, we also have physical reactions such as trembling and shedding tears. Physical discomfort leads to mental discomfort. The research goal of our project is to explore the mechanism of the implicit brain function, namely, the interface between mind and body, and establish a methodology that leads to a more desirable state of mind and body.

This process inevitably involves the issue of diversity. Since each person's brain, body, and accumulated experiences are different, there is no single correct interpretation of the *desirable state*. Therefore, how can we enable people to make the best use

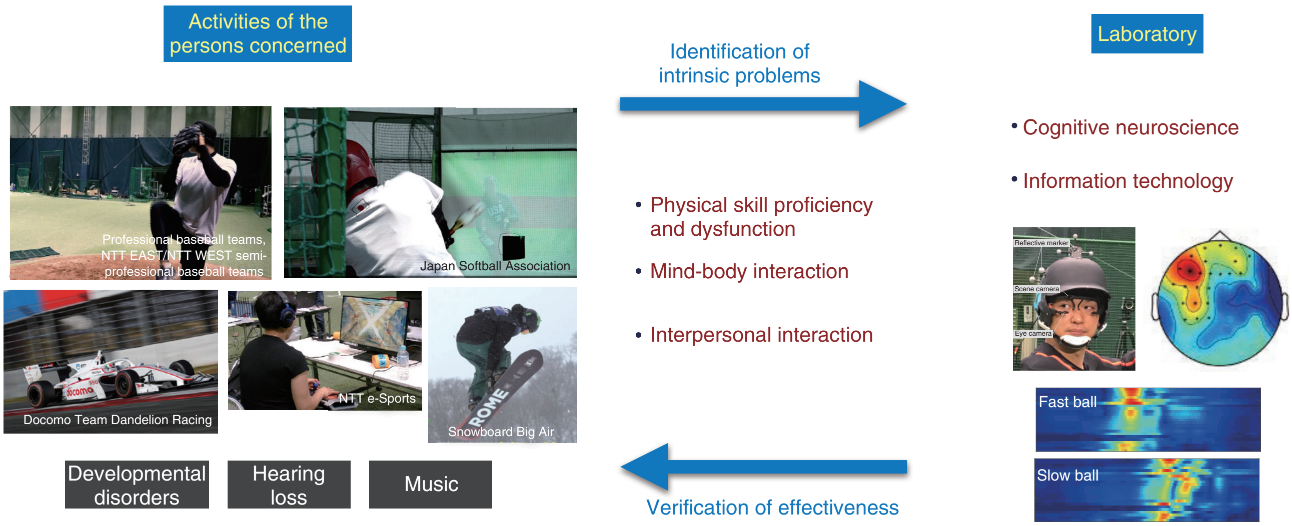


Fig. 1. Exploring the implicit brain function with the approach called inverse translational science.

of their individual characteristics, maximize their abilities, and achieve a sense of well-being? We hope to provide the scientific and technical foundation for answering this question.

—What is your specific approach to research activities?

Over the past few years, I have been emphasizing the approach called *inverse translational science*. Instead of researching in a direction *from basic research to real problems*, research should be conducted in the direction *from real problems to basic research*. This mindset does not simply mean that applied research with a defined purpose and short-range goal is preferable. As Alan Watts said, "If you want to study a river, you don't take out a bucketful of water and stare at it on the shore." I have come to realize that the research on cognitive neuroscience that we, researchers, have been doing is a bit like examining water in a bucket. That is, if we conduct experiments with established methodologies in the research field, the problem setting itself may be unrealistic and off the mark in terms of actual human activities.

With the above-described considerations in mind, first, I decided to go back to looking at the actual *river*. One of the fields characterized by themes such as implicit brain function and diversity was, in my case, sports. We are attempting to do basic research on cognitive neuroscience while keeping in mind the direction of solving real problems faced by the people involved (**Fig. 1**). We will not only publish the results that we obtain as a paper but also feed them back to the field to validate them and their effectiveness. Considering the results, we repeat the feedback loop so that we can delve deeper into the next problem. It has been about five years since we implemented this approach, and, fortunately, with the cooperation of top athletes and various others in the field, we are beginning to produce concrete results.

We are focusing on three main research themes. The first theme is the state of being proficient in certain skills and conversely, the state of being in a slump. The second theme is the mechanism of mind-body interaction, so-called *mentality*. In other words, we want to reveal the mechanism by which an athlete fails when they become nervous or succeed when they are in the zone. The third theme is interpersonal interaction, namely, the mechanism by which the presence of others, teammates, opponents, or spectators, influences an athlete's performance. Since we want to elucidate the implicit brain function, or unconscious processes, involved in these themes, it is pointless to ask the person in question, and it is essential to have an objective method of measuring the function in as natural a situation as possible. Devising such a measurement method is part of the research.

Fig. 2. Initiatives with the Japan women's national softball team.

Contribution to winning a gold medal at the major international sporting event held in 2021

—Your practical work with the Japanese women's softball team, which won the gold medal at the major international sporting event held in Tokyo in 2021, was a great achievement.

That work has certainly become a symbolic example of our approach. Of course, the outcome of a game is partly a matter of luck, so they could have won the gold medal even if we had not been involved. It goes without saying that the team's staff and players are the ones who made the most of their time and effort. Thus, I hesitate to say that we contributed to winning the gold medal; however, it is true that we have had a close relationship with the Japan Softball Association since we launched the Sports Brain Science Project (currently, Kashino Diverse Brain Research Laboratory) in 2017. It was decided in August 2016 that softball would return to the official competitions of the international sporting event to be held in Tokyo. Immediately after that decision, Shinsuke Yabata, deputy training manager (now general training manager) of the Japan Softball Association, Reika Utsugi, head coach of the national softball team, and others showed interest in our research. Perhaps the desire to take on new challenges resonated on both sides. In October 2017, we signed an agreement to conduct a joint experiment and have been working with the national softball team on various initiatives to put into practice the motto "train your brain and win the competition" (**Fig. 2**).

One example of our joint efforts is a pitching machine, which was featured as a "secret weapon" on television and in newspapers after the competition. At first glance, it does not look much different from a pitching machine with a video screen at a batting cage. However, this apparatus is a *pitcher simulator* that reproduces as precisely as possible the pitching form and quality of pitches thrown by pitchers who are expected to compete against each other. The pitching form and pitch quality are based on footage taken by members of our research team at international matches. Provided with that footage, we used a proprietary algorithm to analyze the pitch-rotation information and reproduce it in a programmable pitching machine. This machine can be considered a solution, from the perspective of cognitive neuroscience, to the problem that Mr. Yabata has been talking about since the beginning, namely, "The biggest challenge to winning the gold medal is to counter moving fastballs thrown by US pitchers." Our experiments demonstrated that good batters use information about the pitching form and the trajectory of the ball immediately after it is released by the pitcher to predict the ball's arrival point without being aware of doing so. Even if the batter knows that pitcher A's riseball changes by a certain number of centimeters at a ball speed of over 100 km/h, the batter will not be able to hit the ball. To refine the predictive model in the batter's brain, the batter must repeatedly watch the video of the pitch, "experience" the trajectory of the ball, attempt to hit the ball, then learn the correspondence between these factors. Our pitching machine enabled batters to carry out this task in the absence of actual competition due to the COVID-19 pandemic. Although it is difficult to quantitatively evaluate the effectiveness of this machine, the fact that the players were actively using it at such a crucial time—just before the competition—seemed to us to be the most-positive evaluation of all.

—It is great that you have gained the trust of top athletes. Can you tell us again about the academic and social significance of this initiative?

I think the primary significance lies in the fact that we have practiced the approach of conducting research *from real problems to basic research*. This approach is easy to say but hard to apply properly. There is a reason that until now there has been little interaction between basic research on cognitive neuroscience and an actual practice like sports. Basic researchers simplify a problem, break it down into its elements, and attempt to uncover the mechanism behind the phenomenon causing the problem through rigorously controlled experiments. From this viewpoint, actual sports is too complicated to handle. The complexity of the challenge in the laboratory and in an actual sporting environment vastly differs. Take softball as an example. Pushing a button of an experimental apparatus in response to a simple visual stimulus is completely different from using one's entire body to hit an American pitcher's moving fastballs. Even if we examine the effects of psychological stress, the ethically acceptable level of stress that can be exerted in a laboratory is incomparable with that faced by a batter in a gold-medal game. From the perspective of basic researchers, it is impossible to write a proper paper on a real problem, and from the perspective of sports, scientific findings are impractical.

Therefore, our aim was to bring up real problems for discussion in the realm of basic research without sacrificing reality. This would have been difficult ten years ago. In the late 2010s, wearable-sensor and computer-vision technologies advanced dramatically; thus, it became possible to measure the movements and biological responses of athletes in action in a relatively natural way. We are also actively adopting these technologies as well as developing new ones. For example, when we analyzed the relationship between the state of the autonomic nervous system and performance by measuring the heart rate and body movements of athletes during actual competition, we found phenomena that could not be observed in a conventional laboratory setting.

Advanced information technology can also be used to modulate implicit brain functions and improve unconscious movement. The aforementioned pitcher simulator is one example of such technology, and we are also developing various training systems using technologies such as virtual reality, motion visualization, and motion sonification. These systems are used by top athletes in the field, and we are improving them while listening to the opinions of these athletes.

Naturally, such initiatives will contribute to not only improving performance of athletes but also changing the world of sports. Sports is said to involve a combination of three fundamentals: *mind*, *skill*, and *body*. However, although scientific training for *body* has become widespread, those for *mind* and *skill* has yet to become widespread. It is not uncommon for coaches to force their athletes to do things on the basis of their own successful experiences or to label athletes who do not do well as having no sense or weak mentality. As the implicit brain function that supports *mind* and *skill* becomes more fully understood, systematic and rational methodologies for developing abilities in accordance with the characteristics of each individual athlete should become mainstream.

We are not only focusing on the world of elite sports. We have targeted athletes because, in a sense, their implicit brain function appears in the purest form. We believe that the methodologies and accumulated knowledge developed in this field can be applied to various types of people such as the young, elderly, and those with disabilities with diverse characteristics and in different situations.

The starting point of research is pursuing what is interesting and irresistible

—What is your current attitude toward research activities?

I have become aware of the importance of going back to the basics. On reaching a certain level in your career as a researcher, you'll stop getting so excited about your research or the research of others. You might feel, "OK, I get the picture…" However, when I think back on my childhood, I literally forgot to eat and sleep as I was absorbed in space, castles, music, electronics, and other topics. My passion had nothing to do with schoolwork, and I was acknowledged by no one. In fact, even if I was prohibited from doing something, I wouldn't be stopped. I was motivated purely by intrinsic feelings such as curiosity and fun. I suppose that I'm just inclined that way. As it turns out, that intrinsic feeling is my strongest source of energy. I don't think it's easy to reach a point of expressing one's originality through extrinsic motivation, such as being told to do certain research or choosing a certain research theme, because the topic is currently popular, might produce results, or will allow you to be acknowledged.

Quite often, Nobel-Prize-class research is the result of new entry of researchers into a field that differs from their original specialty. In some respects, since the new entrants do not know the conventional wisdom in that field, they are able to come up with ideas that overturn the conventional wisdom. If you are familiar with a certain field, you may implicitly set a problem that seems to be solvable by using an established methodology in that field. Essentially, you should first decide what you want to know then think of a methodology of acquiring that knowledge accordingly; however, the more you advance along your research-career path, the more you find that this process is somehow reversed. One of my motivations behind starting research in sports brain science was such reflection. It is not easy to come up with new methodology of doing things, but trying to do so is exciting.

However, simply doing what is interesting and what you like to do is hardly enough for research professionals. To secure research funding and recruit team members, you must be able to explain the value of your research effectively from a variety of perspectives. That sounds like opportunism; however, it is also a good opportunity to think about the potential of your research from the perspective of others.

—How do you plan to proceed in the future?

I want to hit the jackpot! In academic terms, that means overturning established theories or proposing new concepts. In social terms, that means changing people's lives or shaking up their view of human nature. However, I haven't accomplished anything on that level yet. Regardless, I've been taking on a new challenge over the past five years, and I feel that this endeavor is expected to produce quite interesting results. We are now entering a phase of more serious exploration and development based on these challenges. Although my focus is on the academic side, I also want to pursue social and business impact at the same time.

This endeavor, of course, cannot be accomplished alone. It is essential to collaborate with researchers from various disciplines as well as athletes, team staff, business people, and others in various capacities. Fortunately, we have already established such a network and are gradually expanding it. I have found that like-minded people naturally come together for interesting projects, even if they have different positions and backgrounds. It is quite common for athletes to be almost exclusively researchers in terms of mentality.

The laboratory that I lead is unique in that many of its members are young and have moved from completely different fields. They voluntarily joined the lab moving from within and outside the company because they each like sports, music, and other things they couldn't get enough of. In that sense, their intrinsic motivation was sufficient, and the fact that they already had a background in another field was also advantageous. I'd like to provide an environment in which they can take on essential themes without fear of taking risks. If each one could create a new methodology for research on humankind, it would be a great asset to society.

■ **Interviewee profile**

Makio Kashino received a B.A., M.A., and Ph.D. in psychophysics from the University of Tokyo in 1987, 1989, and 2000 and joined NTT in 1989. He is currently a visiting professor at the Graduate School of Education, the University of Tokyo. He has been investigating functional and neural mechanisms of human cognition, especially auditory perception, cross-modal and sensorimotor interaction, and interpersonal communication.

Smartphotonics® for High-performance Optical Functional Devices That Are Essential for the Future of IOWN

Kenya Suzuki
Distinguished Researcher, Project Leader, NTT Device Innovation Center

Abstract

Optical functional devices are becoming increasingly widely used and important. There is a need, however, to improve not only their functions and performance, but also development time and manufacturing throughput in order to meet the sophisticated and diverse demand specifications. We interviewed Distinguished Researcher Dr. Kenya Suzuki about smartphotonics® to address these problems in the manufacture of optical devices.

Keywords: smartphotonics®, process feed-forward method, optical device

Smartphotonics® to manufacture optical functional devices

—Tell us about smartphotonics®.

Optical device technology is important in a wide range of areas, including optical communications and optical sensing, such as for the Innovative Optical and Wireless Network (IOWN) All-Photonics Network (APN). There are challenges, however, in terms of performance limitations and manufacturability in their design and manufacturing processes. Smartphotonics® is defined as a technical approach to optimize research and development (R&D) and improve manufacturing through automation and statistical prediction to facilitate the fabrication of high-precision optical functional devices (**Fig. 1**).

Conventionally, errors in the manufacturing processes for optical devices have been manually corrected, but many problems from human errors occur due to the dependence on individual skills. We started research on smartphotonics® for the automation and consistent production of high-performance optical devices.

To explain using architecture as an example, in constructing buildings, tolerance levels are defined for the accuracy of cutting wood and other processes. Any deviation within a certain range is acceptable in constructing a building without any gaps. In general, a building is completed after going through many processes. If tolerance levels are defined for each of those processes, there would be a need to ultimately allow a very large tolerance level. One of the goals of smartphotonics® is to extremely minimize the

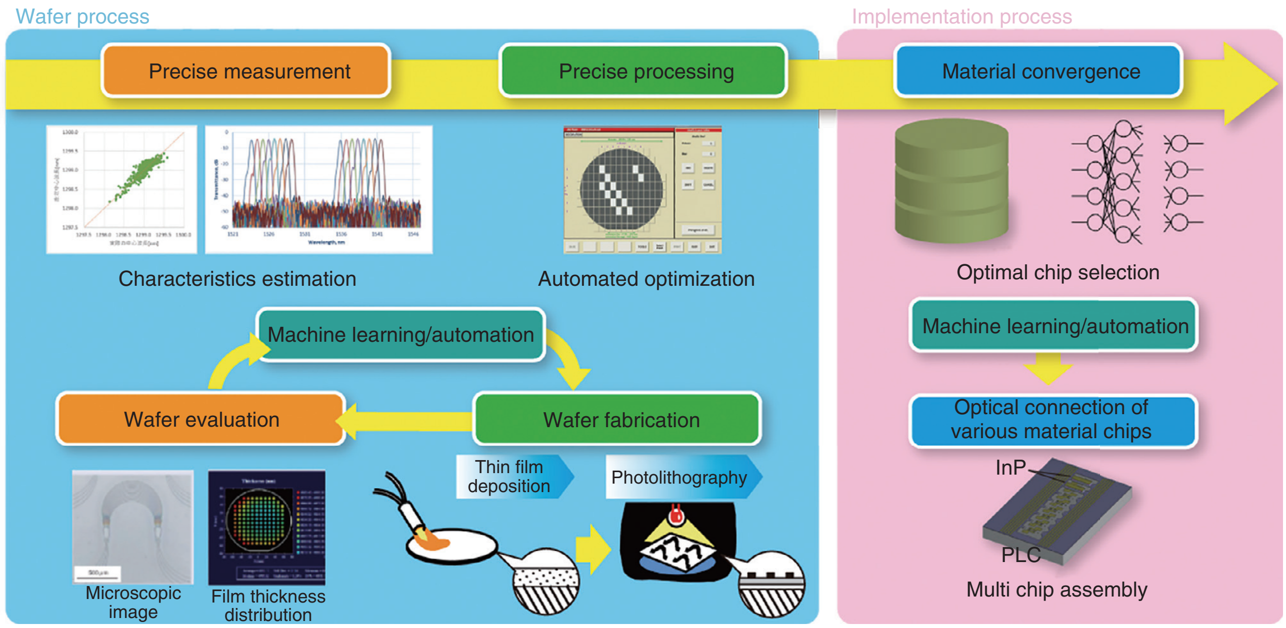


Fig. 1. Overview of smartphotonics®.

tolerance levels and deviations in each process in order to improve the performance of the final product. In other words, research on smartphotonics® is aimed at making sure that we can achieve the desired performance by correcting errors in the previous process at every manufacturing step to eventually achieve stable quality. This may be similar in principle to the smart factory. For example, the issue of automation is a commonly recognized problem, and research is being conducted mainly focusing on achieving smart operations by leveraging the characteristics of optical devices.

The Optical Switch Module Project, where I serve as the project leader, is developing a device called a multicast switch. This is the key device used for routing and switching optical paths to provide an alternative route to ensure communications, for example, in the event of an earthquake or disaster that causes the optical fibers to fail. This switch is fabricated by repurposing the manufacturing technology for the so-called LSIs (large scale integrated circuits), such as central processing units and memory. My group is developing a multicast switch using silica-based planar lightwave circuit (PLC) that uses the same glass material as optical fibers to create an integrated optical circuit on a wafer. Research on smartphotonics® was started as research on fundamental technologies for creating such devices with high performance.

The motivation for this research is to manufacture high-performance optical functional devices required by the APN. We also want to reduce device reworks that occur due to various errors in the manufacturing of optical devices. We believe that smartphotonics® technology will enable the stable and high-volume manufacture of optical functional devices, even in the future when demand for such devices grows due to diversification of applications, such as when optical functional devices come into widespread use in ordinary households.

—How do you specifically manufacture with smartphotonics® technology?

We have proposed a process feed-forward method as the key to the implementation of smartphotonics® technology. The process feed-forward method is based on the idea of creating high-performance optical functional devices by reflecting the error information generated in the manufacturing process into later processes and sequentially compensating for the errors in each process. Although optical device wafers are manufactured through various processes, they are not optimized at each process as described above, but the different processes are coordinated so that they can produce a good product as a whole. In addition to wafer processing, we are also considering

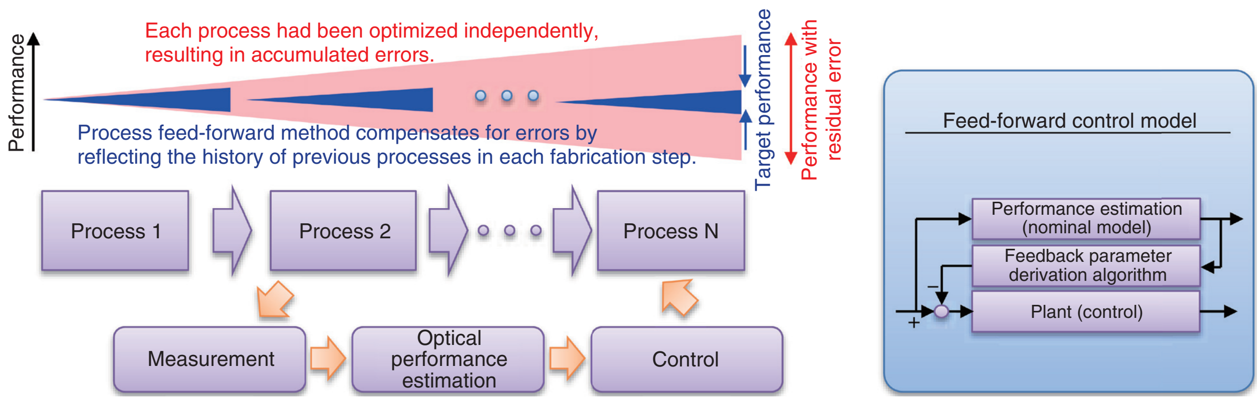


Fig. 2. Outline of the process feed-forward method.

its use in developing devices that combine different materials such as silica-based PLCs and optical semiconductors. While it is normal to yield good performance when you combine products with good performance results, our goal is to create high-performance devices that maximize performance to achieve the target values, even when combining products of moderate performance.

Figure 2 illustrates the process feed-forward method in the manufacturing process of optical functional devices. In optical integrated circuits using wafers as substrates, the index of refraction has a large effect on the optical characteristics of devices. This refractive index value can vary every time the device is manufactured, which causes a major problem. To address this problem, first, we precisely measure the refractive index and thickness of glass and then use statistical techniques to estimate the performance as an optical device. When discrepancy and error are likely to occur, we change the thickness, etc. of the core part that propagates light in the next step and optimize the process so that the equivalent refractive index is the same. Unlike in conventional processes where errors would accumulate and performance would widely vary, the process feed-forward method enables the stable manufacture of high-performance devices with minimal performance variations through repetition of these corrective steps in each process.

Realizing the IOWN concept by creating high-performance optical functional devices

—What are the future prospects for applications of smartphotonics®?

We have just started our research on smartphotonics®. To eventually realize the IOWN concept using this technology, we are aiming to further develop and deploy various devices for wide use. Currently, we are mainly applying smartphotonics® to silica-based PLC technology. We intend to apply the ideas and essence of the technology polished through this application to optical semiconductors and optical devices based on other materials in order to ensure good performance.

Smartphotonics® could be a fundamental technology that underpins research on various optical devices. The field of optical devices has thus far been highly specialized for each material and conversations among engineers beyond their expertise have not always been easy. We want to expand the applications of smartphotonics® across a variety of disciplines and enable sharing of the essence of each area of expertise. One of our goals is to create an unprecedented integrated device that combines the best of each material by deploying smartphotonics® technology in all devices.

The manufacturing of optical devices also has its own unique properties; some devices are being manufactured using equipment with a slightly older design. For areas where old and difficult-to-replace equipment is still used, we believe that smartphotonics® can be applied to the automation technology for the control of those equipment. The digital transformation

market is estimated to reach several hundred billions of yen by 2030. We believe that some of the technologies we have developed in our research can be deployed to a wide range of manufacturing areas where these old equipment remain, such as small businesses and local factories. They can be used as background technologies for automation and the shift to Internet of things.

—Could you give a message to researchers, students, and business partners?

I currently belong to the NTT Device Innovation Center, which I think provides one of the best R&D environments in Japan. In particular, we have access to a wide range of hardware research facilities. I think the NTT's R&D environment, which enables you to test and realize your ideas, is ideal for those who enjoy doing research and are fond of creating new things or taking on different challenges.

Although writing papers is also a part of our activities, the NTT Device Innovation Center is an organization aimed at the practical use of devices, so you are expected to conduct development of devices that give users a value and can actually be used. This entails constantly having conversation with users and identifying their issues, as well as creating industry trends. Because the optical device industry has a global market, meetings with foreign counterparts occupies a great part of our daily activities. In this sense, R&D of devices is characterized by a different kind of rigor from writing papers, but it is interesting to see the techniques and methods you propose become trends in the real world. This is a message to young researchers and students.

Going forward, through R&D, I will work with researchers, students, and business partners to create value that is recognized not only in Japan but also around the world.

■ Interviewee profile

Kenya Suzuki received a B.E. and M.E. in electrical engineering and Dr. Eng. in electronics engineering from the University of Tokyo in 1995, 1997, and 2000. In 2000, he joined NTT. From September 2004 to September 2005, he was a visiting scientist with the Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA, USA. From 2008 to 2010, he was with NTT Electronics Corporation, where he was involved in the development and commercialization of silica-based waveguide devices. In 2014, he was a guest chair professor at the Tokyo Institute of Technology. He served as secretary of the Optoelectronics Research Technical Committee of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan from 2014 to 2016. He was a member of the subcommittee of Passive Optical Devices for Switching and Filtering of the Optical Fiber Communication Conference (OFC) from 2019 to 2021, and served as the chair of the subcommittee in 2022. He is currently a distinguished researcher and project leader at NTT Device Innovation Center. He is also the director of the New Energy and Industrial Technology Development Organization (NEDO) project on the photonic and electronic hybrid switch for future datacenter networking of Photonics Electronics Technology Research Association (PETRA). His research interests include optical functional devices and optical signal processing. He was the recipient of the Young Engineer Award and Electronics Society Activity Testimonial from IEICE in 2003 and 2016. He is a member of the Institute of Electrical and Electronics Engineers (IEEE), Optica, IEICE, and the Physical Society of Japan (JPS).

Access Network Technologies to Implement IOWN

Yuji Aoyagi

Abstract

NTT Access Network Service Systems Laboratories is engaged in research and development (R&D) on access networks that link customers to NTT central offices, supporting the world's communication infrastructure technology with the world's most advanced and cutting-edge R&D. In this article, we introduce our R&D initiatives for the improvement of network functions, smarter operations, and the creation of new value through using our assets to implement the Innovative Optical and Wireless Network (IOWN).

Keywords: access network, IOWN, R&D

1. Introduction

NTT Access Network Service Systems Laboratories (AS Lab) was established in July 1972 as the Construction Technology Development Office. Its current name was adopted in January 1999 after several reorganizations and the merger with departments in Makuhari (Chiba prefecture) and Yokosuka (Kanagawa prefecture). In 2014, a department of AS Lab was set up in Musashino (Tokyo Metropolitan Capital region), and in July 2021, following the reorganization of NTT laboratories in conjunction with the establishment of NTT Innovative Optical and Wireless Network (IOWN) Integrated Innovation Center, AS Lab's development work was transferred to NTT Network Innovation Center. In July 2022, AS Lab marked 50 years since its establishment.

At the time of its establishment, we worked on the research and development (R&D) of outdoor communication facilities and the development and popularization of technologies to construct and maintain them in an efficient, safe, and secure manner. To economically achieve high-speed data-communication services in the period of popularization and expansion of Internet connection services, we have conducted R&D on access networks, including optical access systems, operation systems to support the spread of optical services for quick installation and efficient maintenance, wireless systems for the provision of seamless access, and infrastructure facilities such as underground conduits and tunnels.

Society 5.0 is currently being studied as a sustainable and resilient society that integrates cyberspace and physical space (cyber-physical system). As a means to achieve this, the Beyond fifth-generation/sixth-generation (5G/6G), which is the next-generation mobile communication system, is being studied for launch around 2030, and the R&D of IOWN is being accelerated toward early implementation in 2030. As the need for fixed-line broadband services continues to be strong due to the increase in remote work caused by the COVID-19 pandemic, expectations for access networks have become even greater.

We are working toward the implementation of IOWN on the basis of five access network elemental technologies, namely, access system technology, wireless access technology, optical fiber access technology, infrastructure technology, and operation technology, to achieve its mission of "achieving a natural and smart society by continuing to create and support services through research and development of leading-edge access network technology." The three core R&D policies to implement IOWN are (1) to meet extreme requirements and support diversification of services, (2) dramatically make operations smarter, and (3) use assets for new business areas

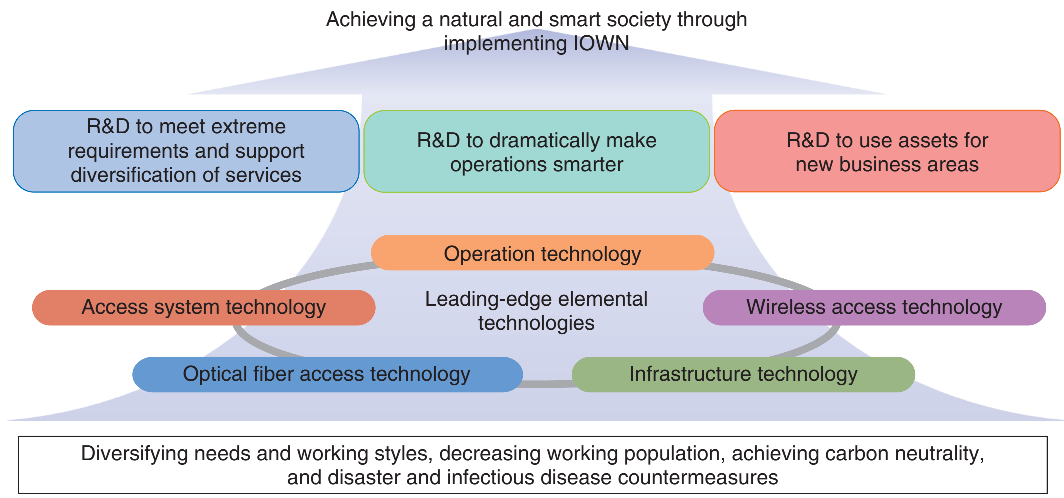


Fig. 1. R&D policies at AS Lab.

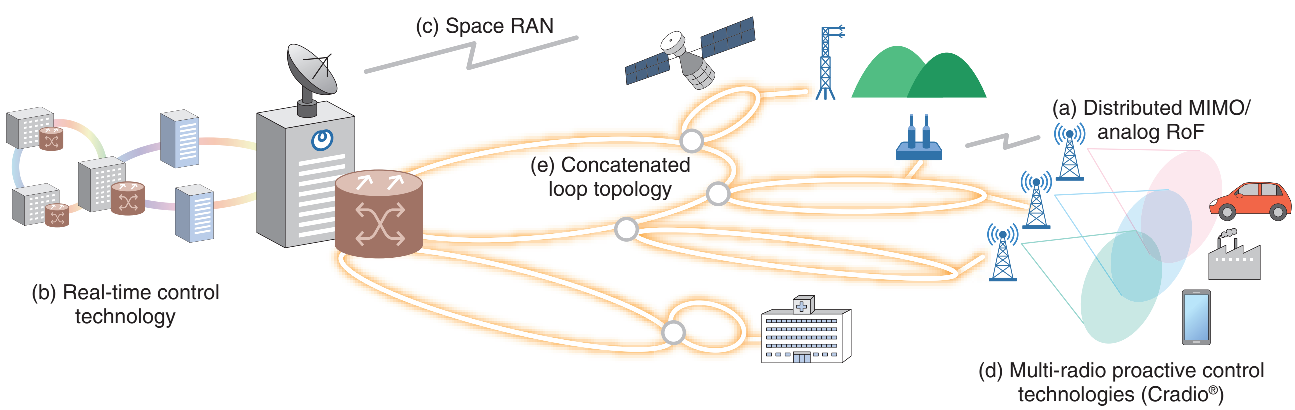


Fig. 2. R&D to meet extreme requirements and support diversification of services.

(**Fig. 1**).

The following sections introduce the main technologies that promote R&D under the above three policies.

2. R&D to meet extreme requirements and support diversification of services

To meet the extreme requirements for the telecom domain and support diversification of services, we are working to innovate communication and infrastructure technologies that will exceed the limits of network performance and innovate flexible network technologies that will meet the needs of users and services (**Fig 2**).

2.1 Innovations in communication and infrastructure technologies to exceed network performance limits

In the area of innovation in communication and infrastructure technologies, we are engaged in R&D on technologies to increase the speed and capacity of wireless and optical communications, reduce the delay of access links, and expand coverage for high-speed access at sea, in mountainous areas, and in the sky.

In the IOWN/6G era, millimeter-wave and sub-terahertz wave bands, which are higher frequencies than those used in current systems, must also be used for higher speed and capacity. However, the higher the frequency band, the smaller the communication area. The distributed multiple-input multiple-output (MIMO) technology achieves stable high-capacity wireless transmission even in a mobile and shielded environment by arranging a large number of antennas (Fig. 2(a)). The area coordination technology with analog radio over fiber (RoF) for the use of high-frequency bands and high-density deployment of remote radio units (RRU) achieves remote beam control by subcarrier multiplexing to send main signals and control signals at one wavelength and reducing signal distortion through level adjustment in multiplexing analog and digital signals. This results in installation and workability improvements through the miniaturization and low power consumption of RRUs and operation and optical fiber cost reductions by reducing the required number of wavelengths.

Both the need for remote operations and demand for performing advanced tasks remotely will increase. Therefore, in addition to end-to-end low latency and low jitter, returning immediately to normal conditions in the event of network congestion or edge overload is required. We are investigating real-time control technology that executes transmission and edge control to switch to optimal optical paths and edge resources, respectively (Fig. 2(b)). By using timely information collection and switching control, it becomes possible to switch immediately even for communication quality change, enabling services to remotely control drones and robots without stress.

To expand coverage, we are studying a space radio access network (RAN) using non-terrestrial network technologies such as geostationary-orbit satellites, low Earth-orbit satellites, and high-altitude platform station (HAPS) (Fig. 2(c)). The provision of a space RAN is expected to support worldwide mobile communications with ultra-wide coverage and improved disaster resistance as well as enhanced 5G and 6G. HAPS platforms can also interconnect to the nearest terrestrial network gateway and extend the reach of existing mobile services directly to end-user devices, providing service options including rural, emergency, and maritime connectivity.

Wireless communication systems will be expanded to use high-frequency radio bands to increase the capacity of communication, but this presents a serious problem in regard to ensuring coverage because radio waves do not extend beyond the line-of-sight range. Therefore, we are researching and developing a technology to control the direction of radio-wave reflection using a reconfigurable intelligent surface. We have confirmed in a demonstration experiment in a world first that the radio-wave-reflection direction from a base station can be dynamically changed in accordance with the movement of a terminal to always form a radio communicable area.

2.2 Innovations in flexible network technologies to suit users and services

As a wireless technology to develop a network that matches user services, we are investigating multi-radio proactive control technologies (Cradio®) that can continuously provide a natural communication environment without users having to be aware of how they are using the wireless network through cooperation with diverse systems and applications (Fig. 2(d)). Cradio® is broadly composed of the following three technology groups: Understanding (wireless sensing/visualization), Prediction (wireless-network-quality prediction and estimation), and Control (wireless-network dynamic design/control). It provides an optimal wireless environment for users by creating a wireless access network suitable for various application requirements amid ever-changing communication quality in wireless channels by implementing these three technology groups in a highly advanced manner, interlocking them, and cooperating with various applications.

To develop an inclusive optical fiber network for diversified services, we are investigating new optical access network designs based on a concatenated loop topology (Fig. 2(e)). The demand for optical fiber communication will change, and the business model will change to B2B2X (business-to-business-to-X). Therefore, the optical access network that supports IOWN must respond to the change in the business model. The concatenated loop topology achieves three goals for the optical access network: reliability (optical path duplexing for supporting ultra-reliable services), tolerance for demand variation (fiber reassignment for meeting uncertain demands), and path selectivity (optional cable routes for directly connecting decentralized base stations) and provides the optical fiber communication services that meet the various needs of service providers.

3. R&D to dramatically make operations smarter

We are conducting R&D on smart engineering and maintenance as an effort to achieve the ultimate smart access network by digitizing facilities and operations (**Fig. 3**).

Smart engineering uses remote-operated optical fiber switching nodes and optical coupling technology

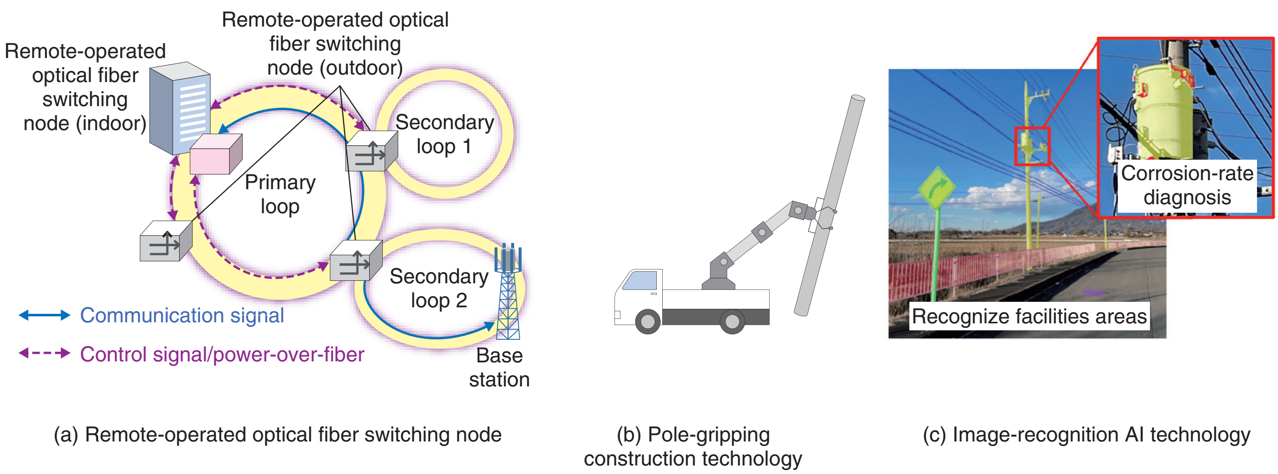


Fig. 3. R&D to dramatically make operations smarter.

(Fig. 3(a)). Optical access networks offering rapid and flexible services will be required to predict the service area and communication capacity, which is challenging. To respond to such demand fluctuations, we are promoting R&D on node technology that remotely switches the outside nodes installed at the connection points between the upper and lower loops of the concatenated loop topology previously introduced and optical coupling technology that arbitrarily branches from existing optical fiber cores.

We are also investigating pole-gripping construction technology to reduce construction burdens and significantly improve safety for on-site contractors (Fig. 3(b)). We aim to achieve this by replacing the traditional role of a human with a machine that controls the gripping force and grip structure without slippage, damage, or breakage, regardless of pole materials and installation conditions.

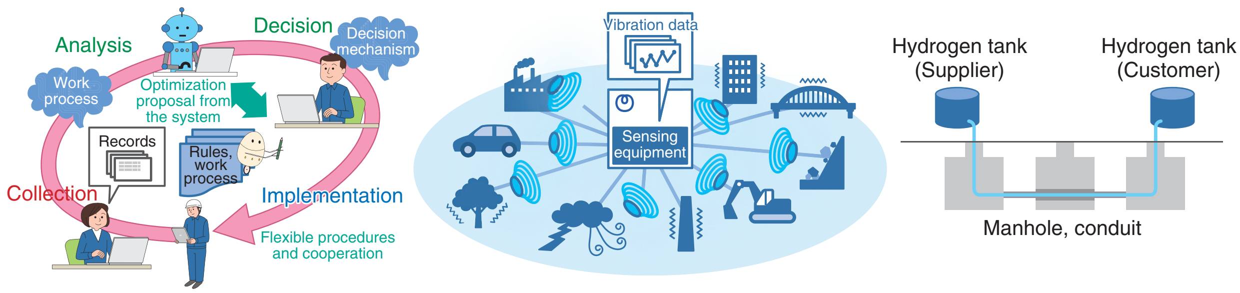
In smart maintenance, we are researching on image-recognition artificial intelligence (AI) technology that can distinguish multiple types of infrastructure facilities from images of roadside facilities taken using a mobile mapping system (MMS) to detect rust that has formed on the facilities (roadside facilities and utility pole-mounted facilities) (Fig. 3(c)). This makes it possible for separate field inspections currently carried out by each infrastructure manager to be consolidated into one MMS run. This is expected to reduce the operational costs of inspections. We are aiming to achieve efficient maintenance of all social infrastructure by using digital information.

4. R&D to use assets for new business areas

We are engaged in R&D to develop new business areas that will become new sources of revenue for NTT, using the assets it has cultivated in the fields of access systems, wireless access, optical fiber access, infrastructure, and operations: operation expertise, communication facilities, and communication technologies (**Fig. 4**).

In operation technologies using operation expertise, we are investigating business design support technology to improve business processes through robotic process automation (RPA) (Fig. 4(a)). Although digital transformation requires an understanding of the current situation based on a highly objective business analysis, analyzing complex business processes requires specialized skills and a significant amount of time, making it difficult to achieve. This technology focuses on the co-occurrence of operation logs and automatically classifies similar operations while absorbing fluctuations in operation procedures. It also extracts frequent operation flows automatically by using sequence alignment. By analyzing and visualizing operation logs, it simplifies the business-process design without requiring any special skills. Users can also edit and output RPA scenario files for automating operations from visualized operation flows, resulting in the continuous evolution of business operations.

In optical fiber environmental monitoring using communication facilities, a deployed optical fiber network is used as a sensor to obtain high-value-added information that can provide various social



(a) Business design support technology to improve business process

(b) Optical fiber environmental monitoring

(c) Hydrogen transportation using communication facilities

Fig. 4. R&D to use assets for new business areas.

services (Fig. 4(b)). Vibrations in the optical fiber network are recorded in real time using highly sensitive measurement technology. IOWN's All-Photonics Network transmits large amounts of high-precision vibration data, and the data-centric infrastructure converts it into environmental information. New business can thus be created with optical fiber networks. As increasing the use of hydrogen energy is expected to achieve carbon neutrality, the challenge is to reduce the transportation cost of hydrogen from the supply areas to demand areas. We are also studying hydrogen-transportation technology using existing communication facilities (Fig. 4(c)).

5. Conclusion

This article presented the direction of R&D on access networks toward IOWN and the main technologies in R&D on the three core policies. We will promote R&D of access network technologies and achieve further sophistication of social systems and the development of new business fields by implementing IOWN in view of the changing circumstances and progress toward a smart world.

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R&D Challenges in Solving Social-infrastructure Problems

Teruhisa Awata

Abstract

To solve problems surrounding social-infrastructure projects, such as a declining workforce, proliferation of aging facilities, increasing maintenance and renewal costs, and frequent disasters, and to create a "smart world," NTT Access Network Service Systems Laboratories is engaged in research and development centered on three pillars: (i) digital transformation of maintenance and operations, (ii) construction of safe and secure social-infrastructure facilities, and (iii) use of assets such as facilities and operations. In this article, the technologies related to these three pillars are introduced.

Keywords: safe and secure social infrastructure, digital transformation (DX) of maintenance, use of communication infrastructure

1. Initiatives of the Civil Engineering Project

As well as facing a declining workforce, a rapid increase in aging facilities, and rising maintenance and renewal costs, the social-infrastructure industry must accommodate growing disaster risks due to climate change and seismic motion. To operate social-infrastructure facilities under these circumstances, it is urgent to address the following key issues: maintenance and operation that requires less manpower, renewal that optimizes the life-cycle cost (LCC), disaster prevention and mitigation, and reduction in environmental impact. The Civil Engineering Project of NTT Access Network Service Systems Laboratories will contribute to the creation of a "smart world" through their research and development (R&D) on the basis of three pillars: (i) digital transformation (DX) of maintenance and operations, (ii) construction of safe and secure social-infrastructure facilities, and (iii) use of assets such as facilities and operations (**Fig. 1**). In this article, the technologies that the Civil Engineering Project is developing—while aiming to create a smart world—are introduced.

2. Technologies for creating a smart world

2.1 DX of maintenance and operations

NTT uses a mobile mapping system (MMS) and drones to photograph outdoor communication facilities and uses the acquired images to check facility conditions and diagnose facility deterioration. We at the Civil Engineering Project have been researching and developing inspection and diagnosis technology for communication infrastructure and facilities using image recognition. Specifically, we have developed technologies using image-feature analysis and deep learning to automatically detect deterioration of manhole covers (i.e., surface wear and the gap between a manhole cover and the surrounding road) and rust on communication conduits attached to bridges. Although these technologies are used for diagnosing the condition of NTT's facilities, the image-recognition technology must be further improved.

We are currently researching and developing image-recognition technology that will contribute to the collaborative inspection of social infrastructure along roadsides. The goal with this technology is to (i) identify pixel areas of roadside structures, such as guardrails, and pole-mounted facilities, such as cables and metal fixtures, from multiple images of such roadside infrastructure facilities taken using

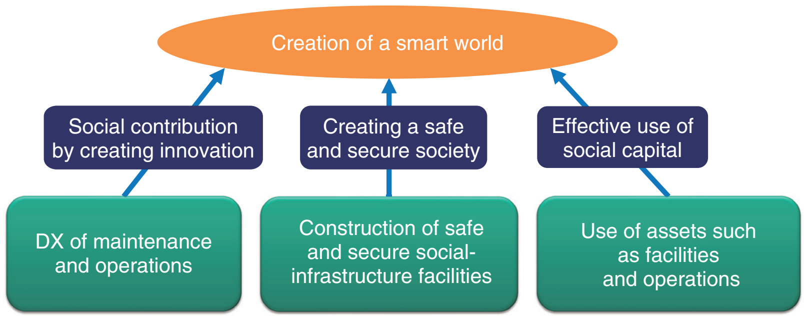

Fig. 1. Three initiatives of the Civil Engineering Project.

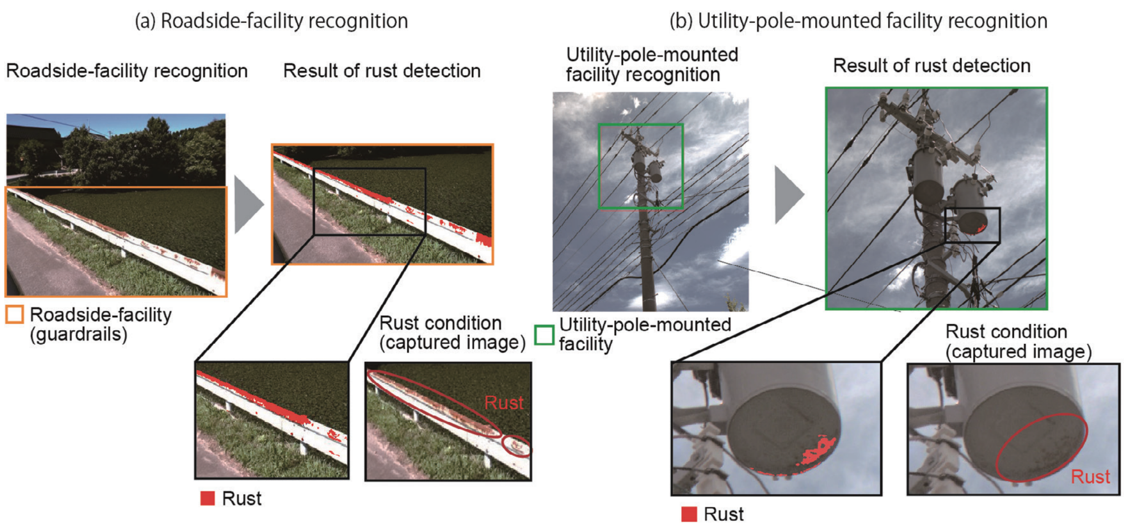

Fig. 2. Results of infrastructure-facility recognition and rust detection.

MMS with image-recognition artificial intelligence (AI) and (ii) detect the pixel areas containing rust formed on the facilities (**Fig. 2**). To achieve this goal, the image-recognition AI incorporates multiple functions (**Fig. 3**). One function is facility-recognition AI, which can identify roadside infrastructure facilities with high accuracy by sufficiently learning the types of facilities that appear in various forms and compositions. Another function is rust-detection AI, which uses ensemble learning* [1] to detect minute amounts of rust in pixel areas on a pole-mounted facility and rust in pixel areas in dark areas of images taken under backlit conditions. Facility-recognition efficiency with this technology will be approximately 94% and rust-detection efficiency will be approximately 98%, which are sufficiently high for practical use.

Implementation of the above image-recognition technology for collaborative inspections of roadside social infrastructure is expected to promote the centralization of on-site inspection work (which has conventionally been conducted by separate infrastructure operators) and improve the accuracy of facility diagnosis using AI. We now aim to improve the efficiency of the maintenance and management of social infrastructure by centrally managing facility information acquired during such inspections on a common platform.

* Ensemble learning: A method of generating a single training model by fusing multiple models (“learners”).

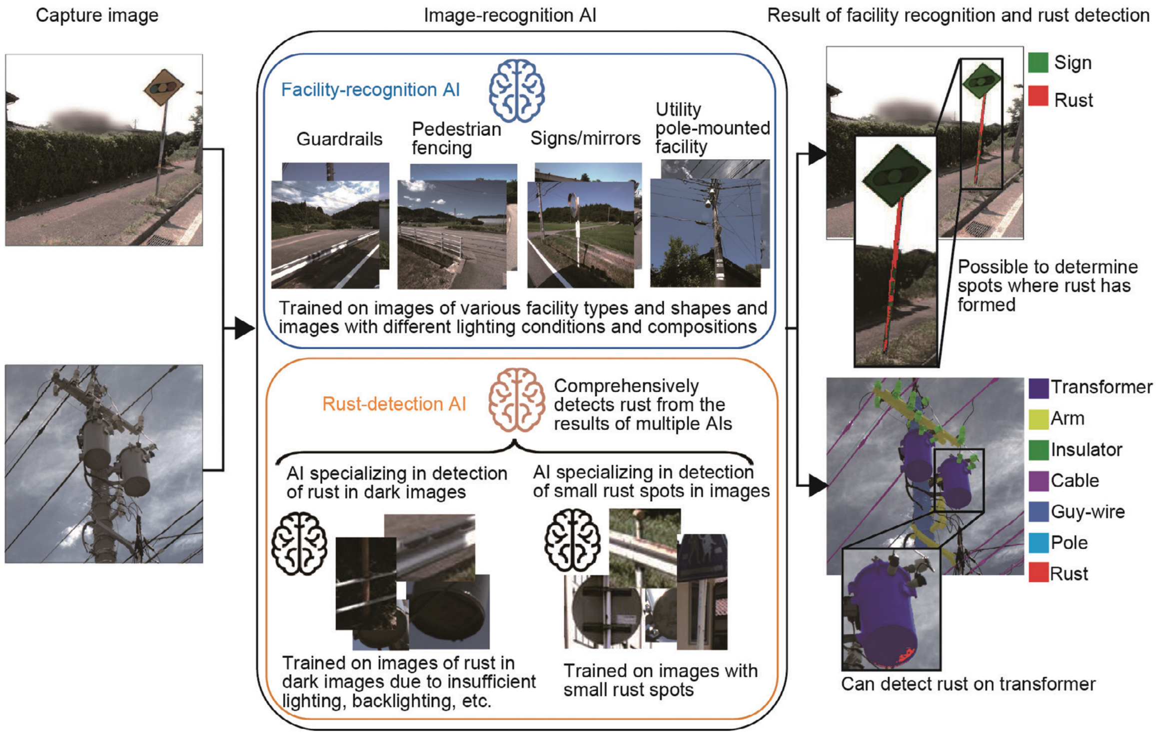

Fig. 3. Features of image-recognition AI.

2.2 Construction of safe and secure social-infrastructure facilities

2.2.1 Technology for extending service life of structures

NTT maintains facilities in a variety of environments throughout Japan. We aim to establish technology for operating facilities to the load-bearing-capacity limit while ensuring safety by maintaining quality and optimizing operational resources, that is, maintaining the safety and reliability of a vast amount of facilities without using a large amount of manpower. Current inspections of infrastructure facilities and equipment are conducted at regular intervals while the inspection cycle is being optimized. To further improve the efficiency of inspection operation, we plan to establish a deterioration-prediction technology that can predict the future condition of facilities on the basis of deterioration phenomena and individual environments. This prediction is based on elucidating three factors: the materials that make up the facility, mechanism of deterioration in each installation environment, and rate of deterioration. The optimal inspection period for each facility will be determined using this deterioration-prediction technology; in other words, it will become possible to eliminate the need for periodic inspections.

In the current infrastructure-facility repair process, when deterioration is confirmed during inspection, whether to repair is determined in accordance with the state of deterioration, any deterioration determined to be in need of repair is then repaired appropriately. To further reduce repair costs, it is necessary to shift from the current partial repair of deterioration to reinforcement based on an evaluation of the load-bearing capacity of the deteriorated structure. We plan to establish a structural-analysis technology for determining the future load-bearing-capacity limit of a structure by reflecting the future deterioration state of each facility through structural analysis and evaluating its load-bearing capacity. This structural-analysis technology will clarify the optimal reinforcement timing for the structure, enabling the facility to operate safely for a long period while optimizing the LCC (**Fig. 4**).

2.2.2 Damage prediction for infrastructure facilities due to seismic motion

During the 2011 Great East Japan Earthquake in the Tohoku region of Japan and other major earthquakes, communication facilities were severely damaged by

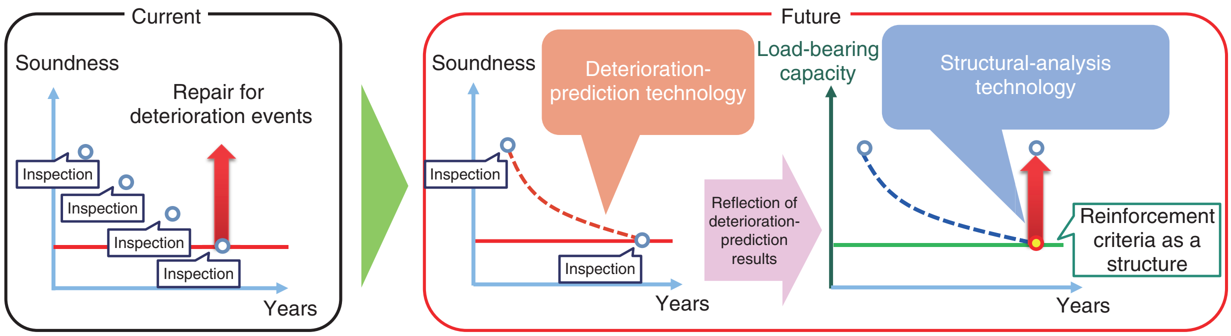

Fig. 4. Optimizing LCC.

seismic motion and tsunamis. The Japanese government has announced assumptions concerning large-scale damage by possible earthquakes, such as a massive earthquake along the Nankai Trough or an earthquake directly under the Tokyo metropolitan area, and these assumptions will further increase the demand for the safety of facilities against earthquake damage.

Communication-infrastructure facilities, such as service tunnels, manholes, and conduits, have been made highly resistant to earthquakes, including the Great East Japan Earthquake, thanks to the addition of seismic countermeasures (such as flexible joints) in the facilities. We have been researching and developing technologies that enable old-specification conduits to be seismically reinforced, without having to excavate roads and remove the cables, by using the new pipe-insertion type conduit system.

We are currently researching and developing technology for predicting damage to individual conduits in the event of an earthquake. These predictions will enable us to identify conduits that require seismic reinforcement among the vast number of conduits that we maintain. We created a database for comparing a large number of parameters (such as facility information, topography and ground information, and seismic-motion information) regarding the damage caused by past large-scale earthquakes, identified the effective parameters for estimating damage through machine learning and variable-contribution analysis, and built an easy-to-use prediction model. The prediction model enables us to identify the locations of damage to individual conduits, which will enable us to take proactive measures such as planned countermeasures, prompt emergency inspections, and emergency repairs (**Fig. 5**).

Through the above efforts, we confirmed that a prediction model that is machine-learned using information on facilities and the surrounding environment is an effective tool for predicting disaster damage. Although the content of the database used for machine learning will vary depending on the type of disaster, we believe that the technological approach (i.e., the developed prediction model based on machine learning) can be applied to various types of disaster prediction, and we will attempt to construct disaster-prediction models for disasters involving severe wind and flooding. We also believe that the model and technology can be extended to businesses operating “lifeline” facilities such as electricity, gas, and water and sewage systems.

2.3 Use of assets such as communication facilities and operations

Since the start of optical-communication services to general households in 2001, such services have rapidly spread, and current access networks are shifting from metal cables to optical-fiber cables. Compared with metal cables, optical-fiber ones are lighter and thinner, so they can be accommodated more efficiently, thus increase the space available in communication-infrastructure facilities. One example of effectively using this space is transportation of hydrogen via communication conduits, and we are verifying technologies related to this application.

As a carbon-free energy that contributes to reducing energy-supply and procurement risks, hydrogen can be produced by electrolysis of water or reforming of biomass by using renewable energy. It is thus attracting attention as one of the next-generation energies for building a decarbonized society. Tanker trucks are currently the main means of transporting hydrogen; however, the challenge is to lower the cost of transportation and reduce emissions of carbon

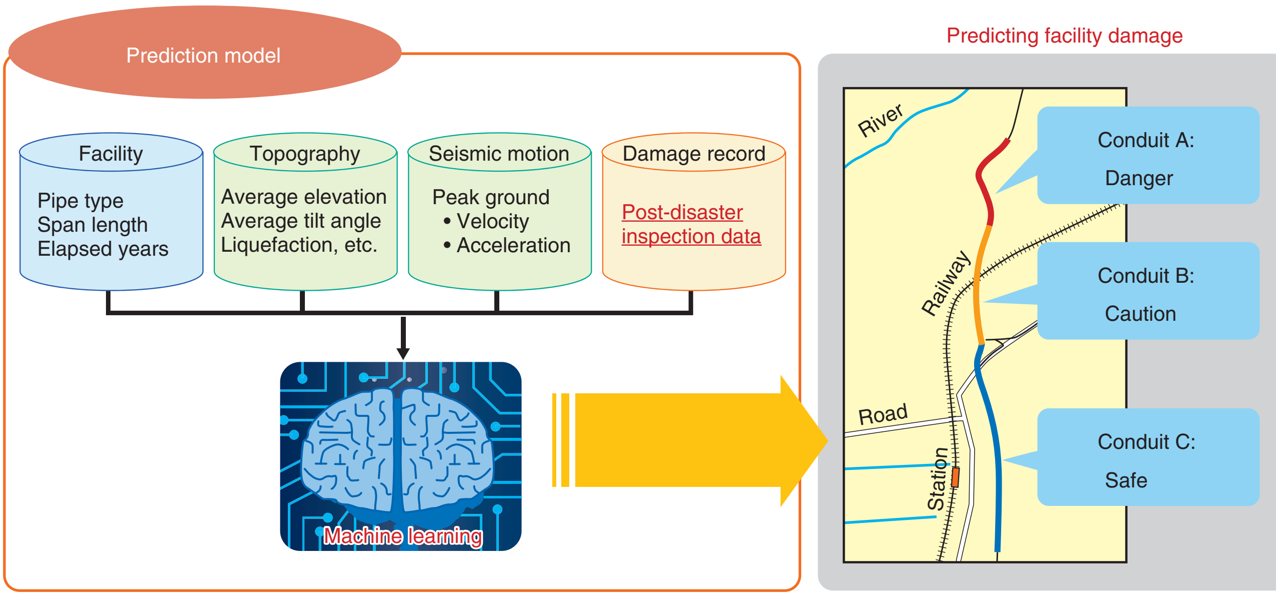

Fig. 5. Technology for predicting facility damage due to seismic motion.

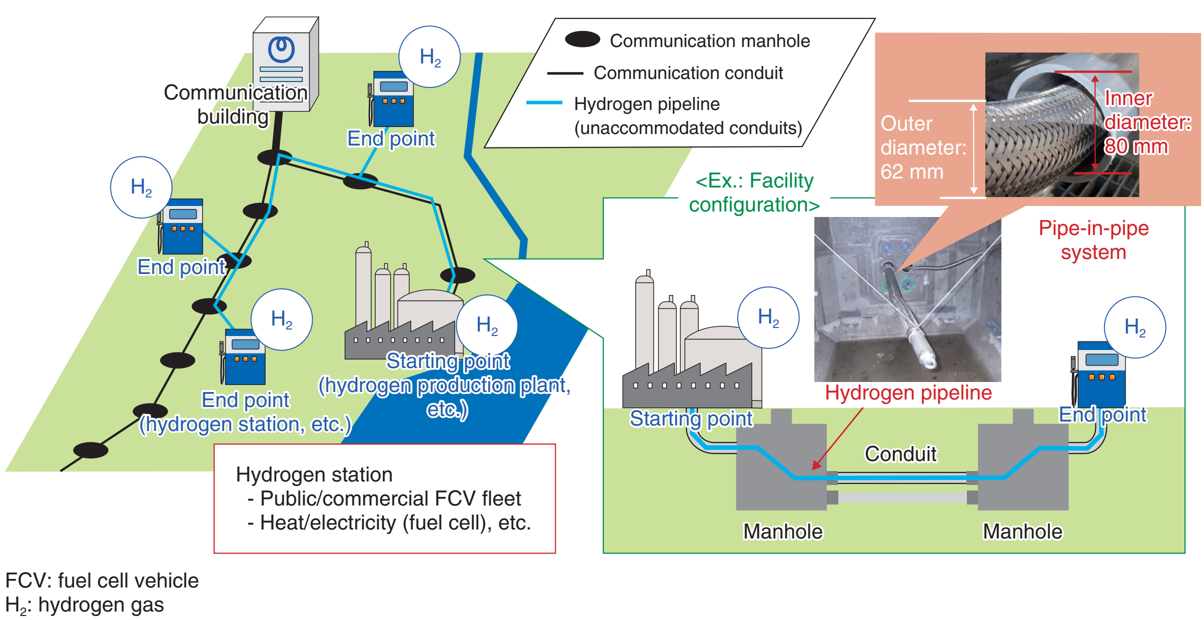

Fig. 6. Transportation of hydrogen via communication facilities.

dioxide. One way to face this challenge is to use pipelines that use existing infrastructure.

Transporting hydrogen by pipeline requires airtight transportation because the gas needs to be pumped under high pressure. Therefore, we are considering a pipe-in-pipe system in which an airtight pipeline for hydrogen transportation is accommodated in the existing communication conduit (**Fig. 6**). This system requires a flexible structure that enables the hydrogen-transportation pipeline to be laid within existing communication conduits and manholes. We are also evaluating safety in terms of hydrogen leakage and its impact on communication facilities as well as studying countermeasure technologies against such leakage.

3. Concluding remarks

The Civil Engineering Project is committed to developing technologies—including the initiatives described in this report—to create new social value by leveraging our assets: operational expertise, communication facilities, and communication technology. We will further promote the above R&D activities and contribute to solving issues faced by society as a whole by sharing our technology and expertise with facility-management companies facing similar challenges.

Reference

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Wireless Technologies for Future Network Services Tailored to the Requirements of Various Users and Applications

Yasushi Takatori

Abstract

For the IOWN (Innovative Optical and Wireless Network)/6G (6th-generation mobile communication system) era, wireless systems and use cases, applications, and terminals will evolve, and users and service requirements will diversify. Therefore, drastic innovation is needed, especially for wireless access, which is sensitive to the environment. This article introduces technologies for expanding the potential of wireless-access performance, control technologies that make the most of the expanded potential, and wireless-environment-verification technologies that support the development of various services.

Keywords: wireless, Extreme NaaS, Cradio®

1. Introduction

Wireless communication began with its use as a communication infrastructure that connects distant points. With the practical application of satellite communication, it then played a role in delivering communication to all locations. Car phones, mobile phones, and PHS (personal handy-phone system) have become more common as access methods that enable voice communication anytime. From around 2000, when data communication and wireless local area networks (LANs) using mobile phones became common, Internet connection by wireless access became widespread, speeding up and diversifying devices such as mobile terminals/smartphones, notebook personal computers, and intelligent machines. The use cases have greatly expanded due to this synergistic effect. As shown in **Fig. 1**, wireless access is now a means for everyone to access the Internet and is an indispensable means of communication in people's lives.

Wireless access has been developed mainly through cellular systems that address public wireless access and wireless LANs that address private wireless access. A local (private) fifth-generation mobile communication system (5G), which provides wireless access in a local area with a cellular system, has also appeared, and wireless access is diversifying. For the 6G era, new technologies should open up various use cases by using public and private wireless access systems to create new value that exceeds that of connecting to the mobile Internet.

The total amount of wireless-access traffic is predicted to triple in 2026 compared with that in 2021 [1]. There will also be a significant change in the content of the traffic. From around 2020, various organizations began to work on technological development related to 6G cellular and next-generation wireless LANs (Wi-Fi 6E, Wi-Fi 7). These technologies enable building a new wireless environment that can withstand such an increase in traffic. The Innovative Optical and Wireless Network (IOWN) Global Forum members announced IOWN in May 2019, and innovations are about to begin in the network. IOWN will make it possible to connect all people and things to the network and link everything happening in the

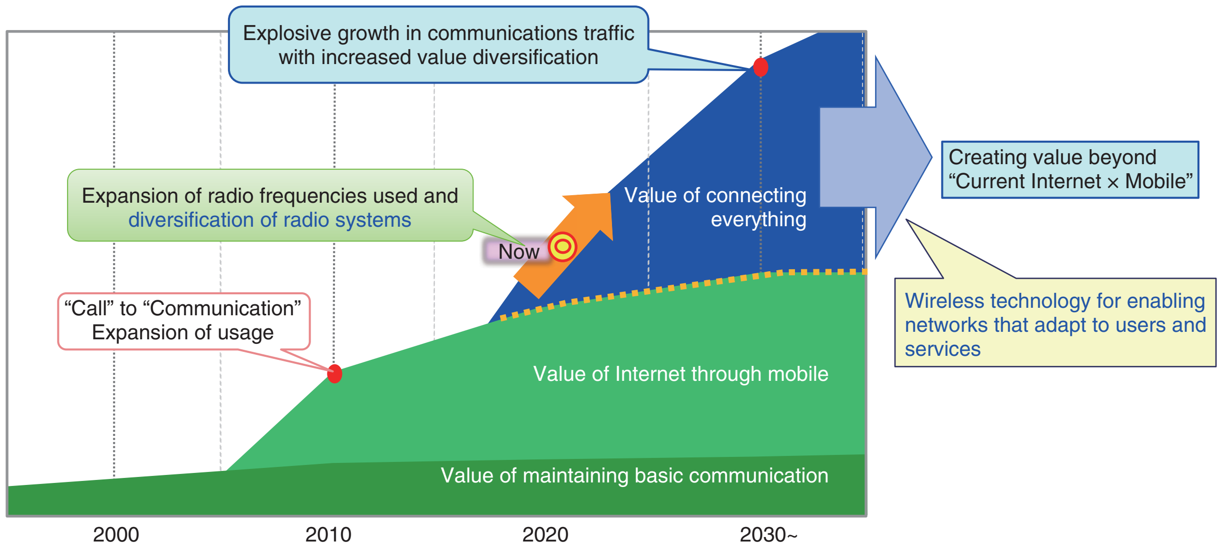
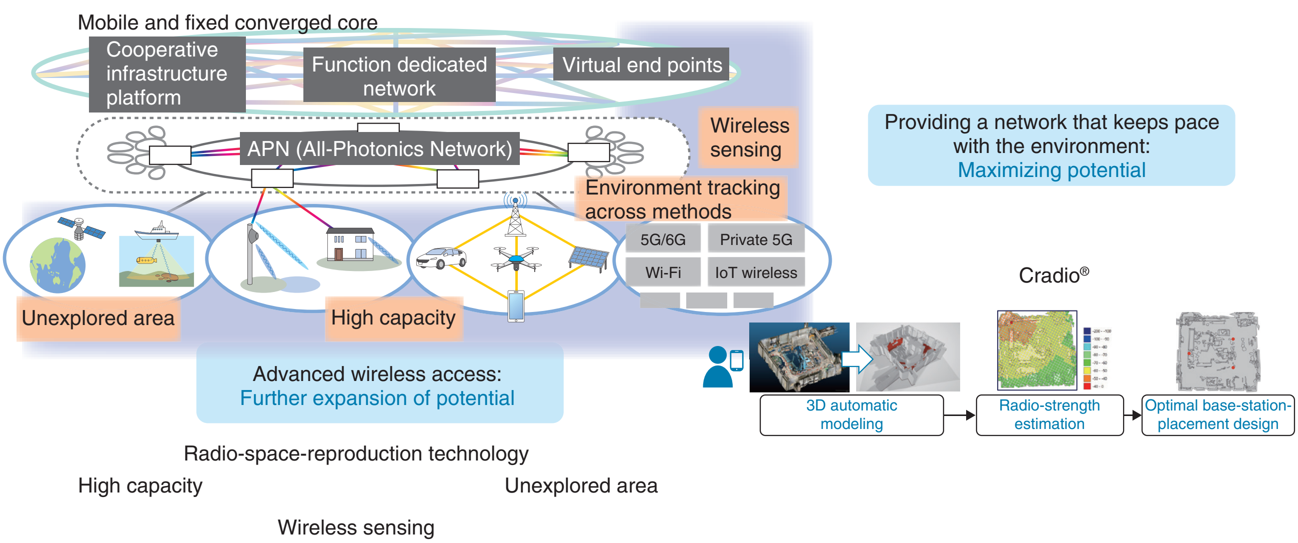


Fig. 1. Transition of value created through wireless communication in society.



IoT: Internet of Things
3D: three dimensional

Fig. 2. Extension of the network to the wireless access area to meet extreme requirements.

world, such as human experiences and various physical phenomena, and wireless access will be responsible for creating new value. At NTT laboratories, network services that maintain end-to-end and extreme service requirements, including wireless access, are called Extreme Network as a Service (Extreme NaaS). We are researching and developing Extreme NaaS, as shown in **Fig. 2**.

To further develop wireless access, technologies that expand the potential of wireless access and those that draw out the expanded potential are required. Increasing the potential of wireless access requires two approaches: expanding the available frequencies and improving frequency-utilization efficiency. To fully draw out the expanded potential, technology to follow the changes in the wireless environment and meet the required wireless quality is necessary.

NTT Access Network Service Systems Laboratories conducts research and development on increasing this potential by using two approaches. One involves developing frequencies by sharing frequencies with different systems [2, 3], and the other involves creating new high-frequency bands that had not been used to expand the available frequency resources. To improve frequency-utilization efficiency, we are focusing on developing spatial areas that use new wireless devices.

To follow the changes in the wireless environment, we are researching and developing Cradio®—a set of multi-radio proactive control technologies that consists of three advanced and coordinated technology groups: wireless sensing/visualization, wireless-network-quality prediction/estimation, and wireless-network dynamic design/control.

Toward the development of such new wireless access, we are actively contributing to the development of core technologies, standardization of new wireless systems, and establishment of laws and regulations that enable the effective use of new frequencies. We are promoting research and development in collaboration with various partner companies, universities, research institutes, and NTT Group operating companies, to create new value.

This article introduces advanced wireless access technologies to expand the potential of wireless access. It also introduces tracking technology for changes in the wireless environment and radio-space-reproduction technology that supports various wireless-access verifications to expand network services that meet the extreme requirements of the wireless domain.

2. Advanced wireless access technologies to expand the potential of wireless access

Technology areas that expand the potential of wireless access include those for increasing capacity, developing into unexplored regions, and integrating non-communication areas. Potential expansion plays a central role. Frequency bandwidth × frequency-utilization efficiency expresses the capacity of wireless access. The following explains efforts to expand the available frequency bandwidth. In the low-frequency band where many systems already exist, an overlay approach is suitable in which different wireless systems share frequencies. The high-frequency range of 100 GHz or higher is suitable for developing new use cases.

For frequencies below the 1-GHz band, IEEE (Institute of Electrical and Electronics Engineers) 802.11ah (11ah), a new wireless LAN for Internet-of-Things (IoT), will be available in Japan [2]. The 11ah enables a wireless LAN at a frequency of 1 GHz or less with low radio-wave attenuation and low penetration loss, which drastically decreases the coverage holes and transmits high value-added information such as video transmission over a wide range. To develop wireless LANs for IoT, more stable operation will be achieved by considering new factors such as battery operation and optimizing in accordance with the 920-MHz-band radio-wave law that stipulates many rules for operation. We are making efforts to make this possible, as shown in **Fig. 3**.

We are also working on developing a frequency band that exceeds 100 GHz. For the 6G era, the use of frequencies above 100 GHz, which makes it possible to secure a vast bandwidth, is promising. As shown in **Fig. 4**, we were the first to start modeling propagation characteristics up to 300 GHz in an outdoor urban environment and contribute to the development of frequency bands by contributing to the Beyond 5G Promotion Consortium and the international standardization organization ITU-R (International Telecommunication Union - Radiocommunication Sector).

It is time for significant changes in the radio systems throughout all frequency bands. The potential of future wireless access will significantly grow by combining the frequency expansion with frequency-utilization technologies that focus on the spatial axis, such as distributed multiple-input multiple-output technology.

3. Tracking technology for changes in the wireless environment

The wireless environment will be highly complex as various wireless systems have been implemented. The wireless terminals and use cases will become more diverse and multi-layered. The selection, design, and control of optimal wireless access according to user requirements and location is complicated. Considering the changes in the environment and conditions over time, it is challenging to fully use the potential of multiple wireless-access-system environments.

NTT laboratories are researching and developing Cradio® to solve this complicated problem and achieve a broader range of optimization by linking with various industries and applications other than

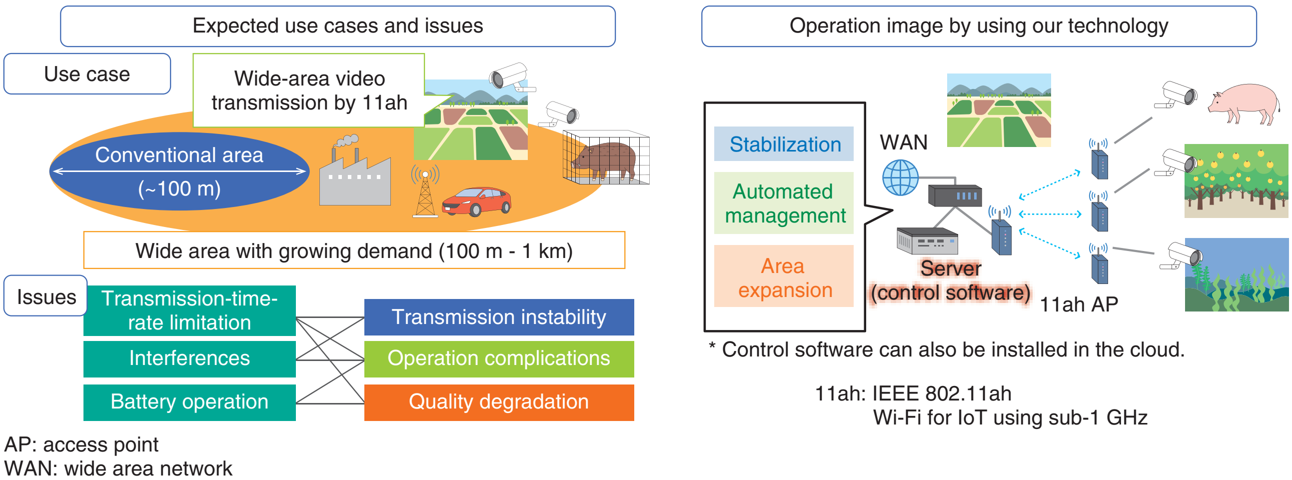


Fig. 3. Wide-area wireless-LAN-management technology.

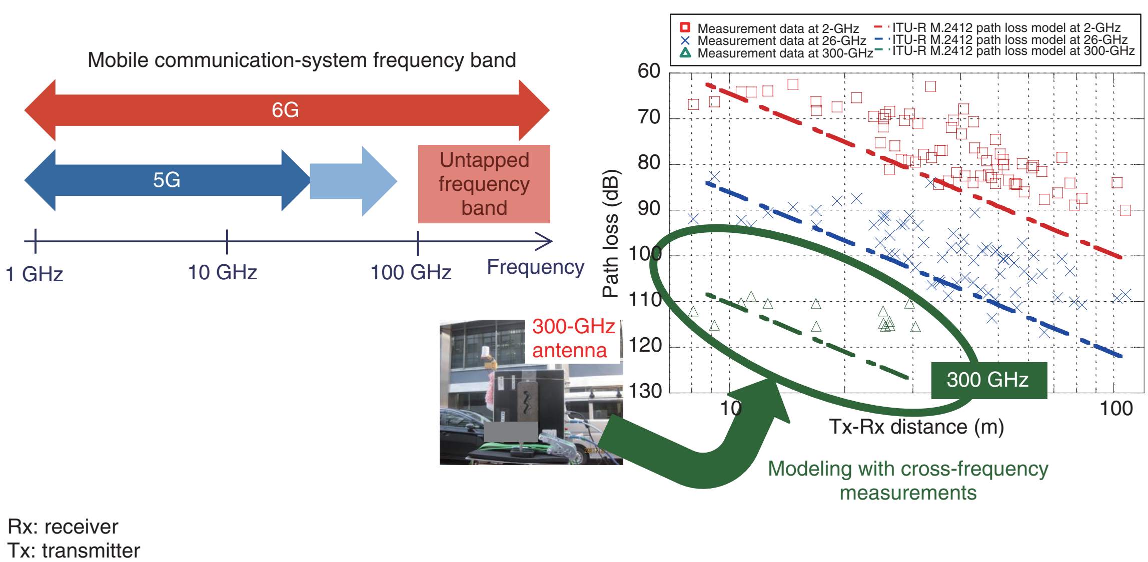


Fig. 4. Efforts to develop frequencies above 100 GHz.

wireless [4, 5]. Cradio® is shown in **Fig. 5**, which, as mentioned above, consists of wireless sensing/visualization technology, wireless-network-quality prediction/estimation technology, and wireless-network-dynamic design/control technology. The wireless network follows changes in the environment and demands by repeating understanding, prediction, and control. We aim to continue to meet the requirements of users and services.

Figure 6 shows an example of achieving the optimization of wireless access in conjunction with the database information of a distribution warehouse. Cradio® can optimally design and control the wireless system for the warehouse environment by obtaining the information on the planned change of the environment in the warehouse from the database. It takes the data for multiple functions for radio-environment control, e.g., three-dimensional (3D) modeling, automatic optimal design, wireless-network redesign, and management. Therefore, if IOWN makes it possible to link in real time with information and functions possessed by various industries,

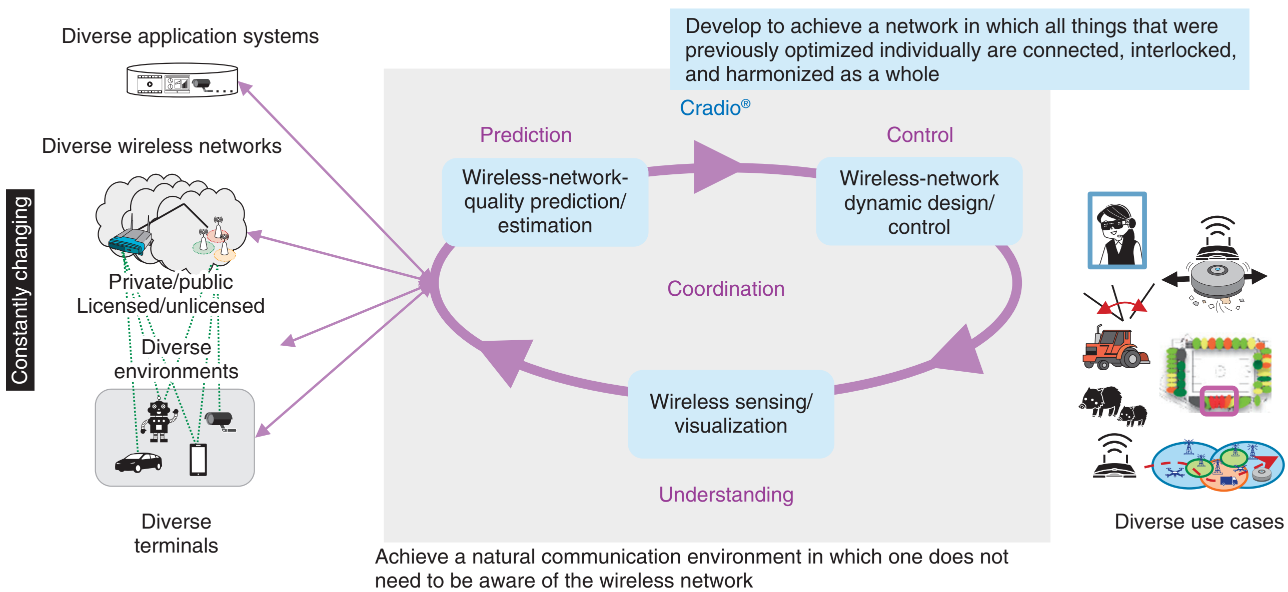
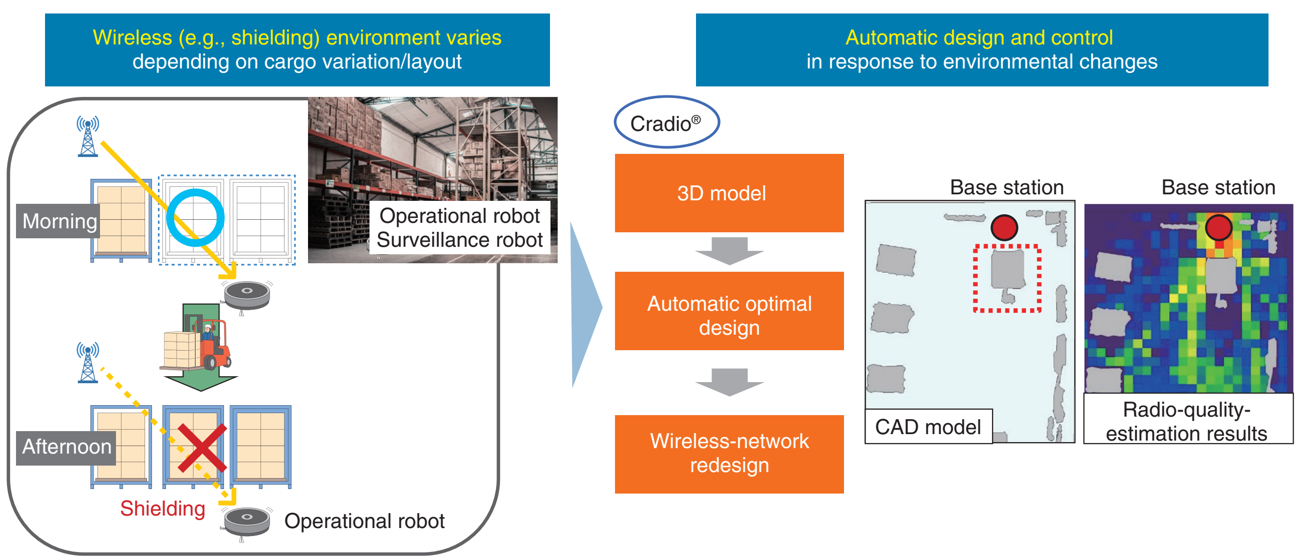


Fig. 5. Cradio®.



CAD: computer-aided design

Fig. 6. Examples of how Cradio® is applied to logistics solutions.

Cradio® will harmonize the entire wireless network including applications. We believe this will lead to the creation of new value.

4. Radio-space-reproduction technology

Through the sophistication mentioned above, we aim to expand the potential of wireless access, maximize the expanded potential, and ultimately form an intelligent wireless space around the wireless terminal in advance of the required wireless environment. It is an entirely new approach to creating an actual wireless environment, not optimizing for a given environment [6]. The critical technology supporting

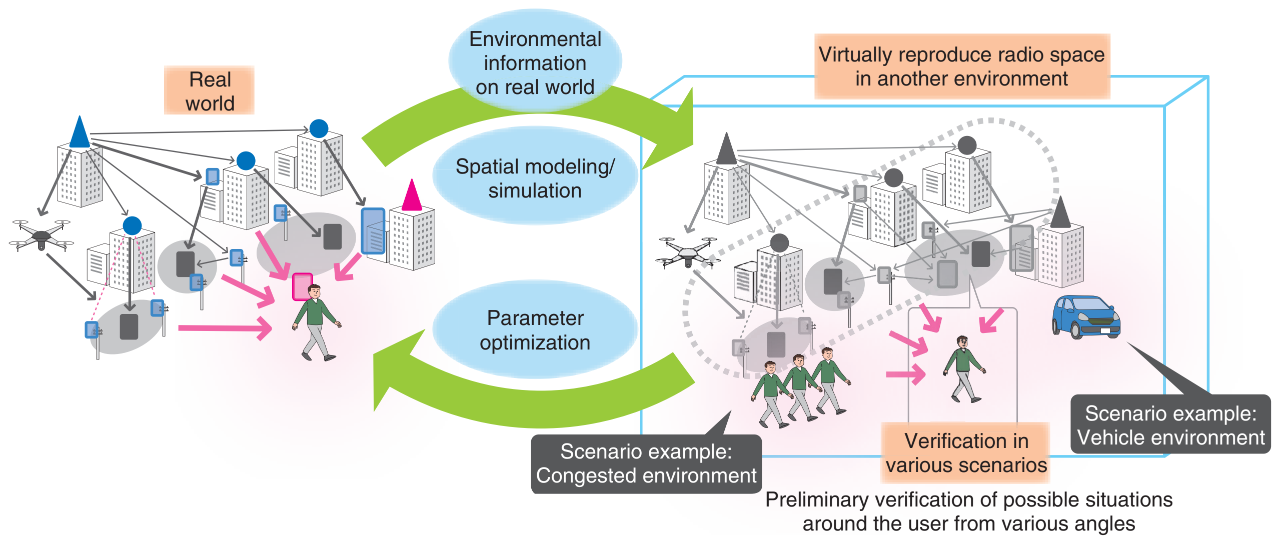


Fig. 7. Radio-space-reproduction technology.

this approach is the radio-space-reproduction technology shown in **Fig. 7**. This technology reproduces radio space in another space using the wireless-environment information acquired from real space and highly accurate modeling/simulation technology. By accurately producing the modeled wireless environment, we aim to improve the spatial-reproduction accuracy for providing wireless space tailored to users and services.

5. Conclusion

As an initiative to create new value that exceeds that of connecting to the Internet using mobile phones, which has brought about the explosive spread of wireless access, we introduced wireless technologies to develop a network that matches users and services. Wireless access will evolve in various ways, e.g., integrating non-communication areas such as wireless sensing and the expansion of coverage areas to unexplored regions, both of which were omitted in this article due to space limitation. NTT Access Network Service Systems Laboratories will contribute to the innovation of wireless access for the IOWN/6G era.

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Technical Approaches for Operations to Accelerate Digital Transformation

Tomoko Shibata

Abstract

NTT Access Network Service Systems Laboratories is undertaking research and development into operations technology to enable smart operations and explore new business areas through such operations. We believe that collaborative business operations involving multiple players will be both deeper and more common in the future. Therefore, we are focusing on the promotion and expansion of digital transformation involving multiple players. This article introduces our recent efforts in self-evolving zero-touch operations technology and business design support technology based on operation-process classification.

Keywords: digital transformation, network operation, business design

1. Characteristics, trends, and desired directions of access network operations

Access networks are widespread across Japan. Since they directly interface with service users and maintenance staff at indoor and outdoor telecommunications facilities, access operations are deeply linked with these various players' and users' businesses. There have been growing expectations for digital transformation (DX) across various infrastructure companies to address social issues, such as the shrinking working-age population [1] and aging infrastructure [2]. Demand for new services, such as private fifth-generation mobile communication (5G)/6G and mobility as a service (MaaS) using automated driving, is expected to grow. Triggered by measures taken against infectious diseases, lifestyles and work styles have become increasingly diversified. These trends will increase our sharing and mutual use of facilities and services with players other than telecommunications carriers, as well as collaboration in their operations. Thus, it is important to develop a mechanism that breaks through business boundaries and enhances productivity.

In view of the above, the Access Network Operation Project at NTT Access Network Service Systems Laboratories is developing smart operations that accompany the progress of the Innovative Optical and Wireless Network (IOWN). Specifically, we are aiming to actualize an ecosystem in which various players can easily collaborate with each other using their respective business operations, systems, and data, and cause a chain reaction of value creation (DX acceleration) within this ecosystem. The form of collaboration can vary depending on the business structure of each player. The targets for collaboration can also differ, ranging from information to systems and organizations. We are conducting research and development (R&D) into operations technologies from these various perspectives and working with NTT Group companies to prepare for their commercial introduction. This article introduces our latest efforts to enable collaborative end-to-end operations across multiple network layers and domains. Specifically, it introduces *self-evolving zero-touch operations technology*, which features versatile network-information management with autonomous analysis and decision on the basis of this management, and *business design support technology* based on operation-process classification, which improves work efficiency by enabling business-support and business-execution organizations in the field to develop a common understanding.

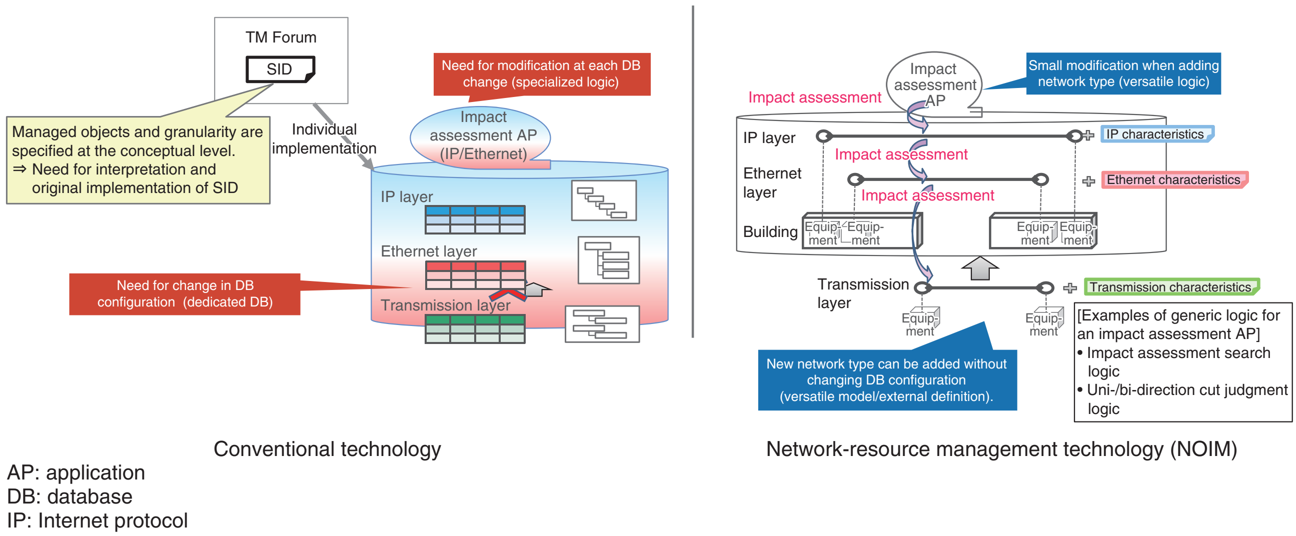

Fig. 1. Network-information management.

2. Self-evolving zero-touch operations technology

NTT Access Network Service Systems Laboratories is undertaking R&D into making network operations dramatically smarter. We believe that one of the keys to self-evolving smart operations is end-to-end operations coordination that manages network resources across multiple domains and carriers. We are developing technologies for end-to-end operations coordination from the following perspectives:

(1) *Network-information management* for handling end-to-end resources across multiple layers and domains;

(2) *Analysis and decision* for the provision of network services on the basis of the network information made available in (1).

Figure 1 shows the network-information management referred to in perspective (1). A network-information database is traditionally built for each service provider, for each service, and for each network type. This hinders operations and maintenance across multiple network layers and poses a barrier to enabling operations coordination. A solution to these problems is a generic versatile network-information model. For example, TM Forum has standardized one such model as the Shared Information and Data Model (SID) [3]. However, since the SID specifies managed objects and granularity only at the requirement or conceptual level, service providers need to interpret the SID in accordance with the type of networks they manage and develop their own implementations. Since the time and cost service providers can expend in developing their implementations are usually restricted, it is difficult for them to take generality and future extensibility into account when studying the details of the data model. Thus, their implementations tend to be specific to the network type to be added at the time. The result is that each time a new network type to be managed is added, it is necessary to change both the network-information database and logic.

NTT Access Network Service Systems Laboratories has developed the Network Operation Injected Model (NOIM), which is now in commercial use [4]. NOIM is a technology for handling network information using a versatile unified model. NOIM does not stop at the conceptual level but specifies a versatile, extensible, network-type independent mechanism, which reduces both the need for modifying databases and logic and the cost that is incurred each time a new network type is to be added. NOIM makes it easy to specify a versatile model that focuses on network-type independent properties, such as point and connectivity, specified in the SID. It uses a mechanism by which network-type dependent attributes and inter-layer relationships can be defined and held externally, thus ensuring high extensibility. As a result, even if network types change or new network types emerge, there is no need to change the databases, and the changes needed in processing logic are also greatly reduced. Network information from multiple domains can also be handled uniformly at the data-format

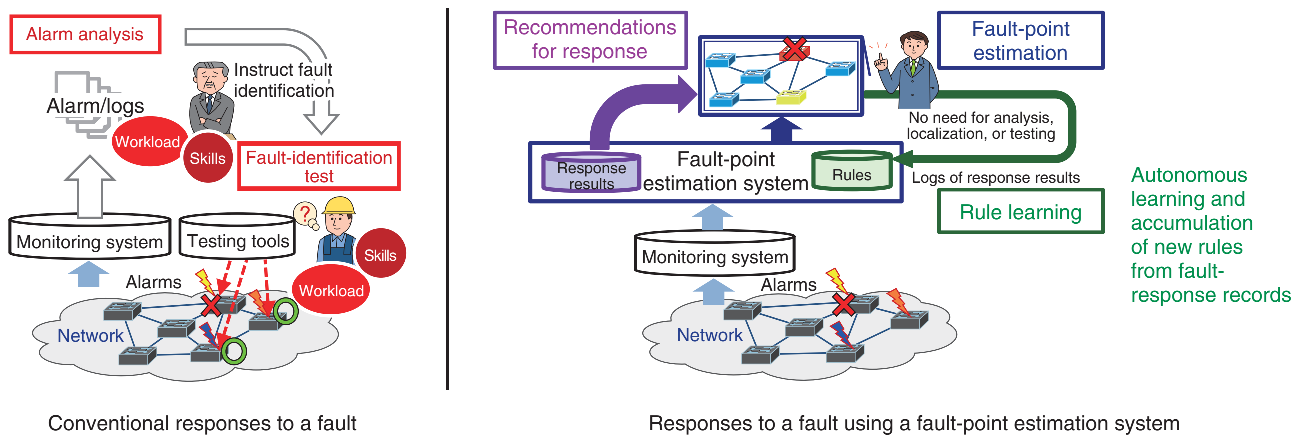

Fig. 2. Estimation of fault-point and selection of response actions.

level, enabling interoperability, and making it easy for service providers and services to make mutual use of each other's network information and rules.

The analysis and decision referred to in perspective (2) are regularly applied to various tasks for the provision of network services such as facility planning, responses to service orders, and fault monitoring and handling. Such analysis and decision is highly dependent on operators' skills and imposes a considerable workload. To solve this problem and enable optimal analysis and decision—which is not possible with human operators—there have been initiatives in the field of network operations to use network-artificial intelligence (AI) such as autonomous network and AI operations (AI Ops).

The R&D efforts of NTT Access Network Service Systems Laboratories are aimed at further expanding the positive effects of network-AI by combining optimal analysis and decision made possible by network-AI with the versatility, extensibility, and interoperability provided by NOIM. The following technologies for fault-point estimation and fault response are introduced as examples of our efforts.

When a network failure occurs, it is necessary to identify its fault point from a large amount of event information that has complex causal relationships across multiple layers and select response actions appropriate to the cause of the fault. Such identification and selection are heavily dependent on the skills of the operators and impose a considerable workload. To solve these problems, NTT Access Network Service Systems Laboratories has developed a technology that automates fault-point estimation and response-action selection. The technology is now in commercial use [5]. **Figure 2** illustrates the process of network fault-point estimation and response-action selection. In this technology, a network-AI learns the relationships (rules) between fault information and fault points across multiple network layers from alarms, analysis, and identification results related to previously occurring faults. When a network failure occurs subsequently, the network-AI estimates the fault point on the basis of these learned rules. It also recommends a method for minimizing the recovery time or recovery actions on the basis of the actions taken in the past for each type of cause of fault.

The network-AI requires a large amount of past data to learn how to identify faults and deal with them. Therefore, the network-AI cannot adequately respond in cases where it was only introduced recently and the volume of accumulated data is still small, or where a particular type of event occurs so rarely that the network-AI is not likely to be able to learn about it from the accumulated data. The training stage of the network-AI currently requires the skills and work of experts for the preparation of appropriate training data. A solution to these problems is to use data generated in actual network operations as training data. Therefore, NTT Access Network Service Systems Laboratories is developing an autonomous learning technology that automatically extracts the causes of faults and response actions from logs and trouble tickets that have been created in actual network operations and feeds them back into the network-AI. We are also aiming to enable training data, rules, and AI models that are generated in a network environment or derived from each network-AI

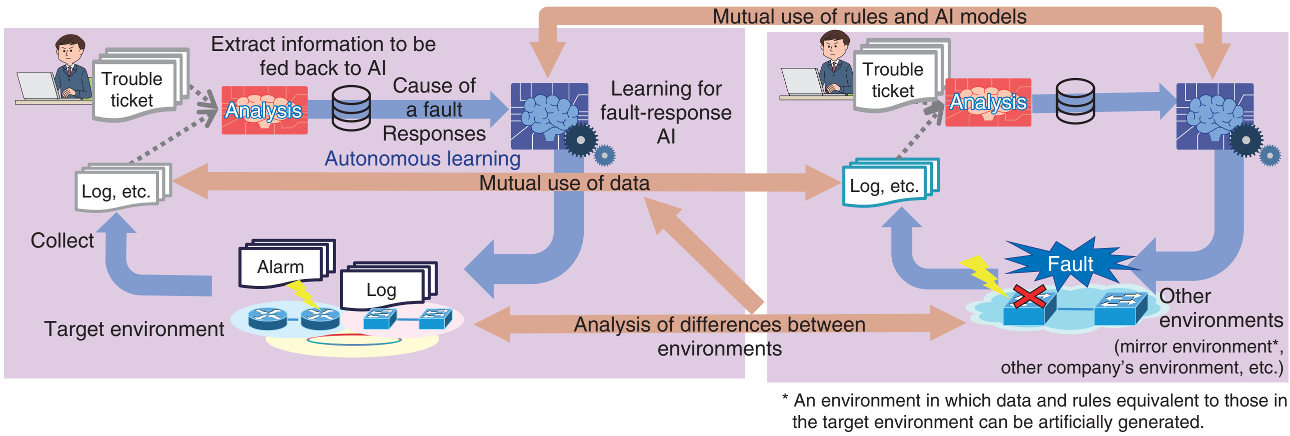

Fig. 3. Data and rule transfers between environments.

applied to the environment to be used in other environments. For this purpose, we are developing an inter-environment transfer technology, which analyzes the differences between different network environments using the interoperability of NOIM, and converts training data, rules, and AI models for application in other environments [6]. **Figure 3** illustrates the transfer of data, rules, and AI models between different environments.

3. Business design support technology based on operation-process classification

Business reforms had been led by business-support organizations. Based on its bird's-eye view of a company's business operations and the insights it had gained from business trends, a business-support organization makes reform proposals that it thought had high potential for creating substantial improvements in productivity. However, such reforms sometimes lost touch with actual business conditions and required much time and cost to implement. Due to the spread of robotics process automation (RPA) and low-code/no-code automation, DX has been led by business-execution organizations. Such an organization implements its reform proposals that are based on detailed perspectives and insights closely related to actual business operations. While such reforms are highly compatible with business reality and bring about immediate effects, there are growing concerns about only achieving the individualized optimization from this approach. We believe that, if we are to further enhance the effectiveness of DX in the coming years, it is important to ensure *paraconsistency* between the above two approaches on the basis of a common understanding between business-support and business-execution organizations. This common understanding should be founded in turn on a shared perception of how the actual business is run (business reality). The operations of a business-execution organization (actual operations) vary depending on the differences or changes in the business environment, such as business needs and trends relating to other companies. Consequently, there is a gap between *actual operations* and either *designed operations*, which provide the basis for the formulation of standard operational flows and operations manuals, or *assumed operations*, which are derived from the observation of a selective sample of operations and interviews with business-execution staff. This gap makes it difficult to develop a common understanding of the reality of actual operations.

At NTT Access Network Service Systems Laboratories, we are developing a technology intended to deepen common understanding between business-support and business-execution organizations by enabling accurate and easy understanding of actual operations on the basis of objective data. Since the success of business reform is highly dependent on an accurate understanding of actual operations, we developed a *business design support technology* that is based on operation-process classification. It focuses on actual operations on terminals, which are among the operational tasks that a business-support organization has difficulty in understanding accurately [7]. This technology offers a comprehensive mechanism for obtaining operation logs, which provide powerful objective data about operations on

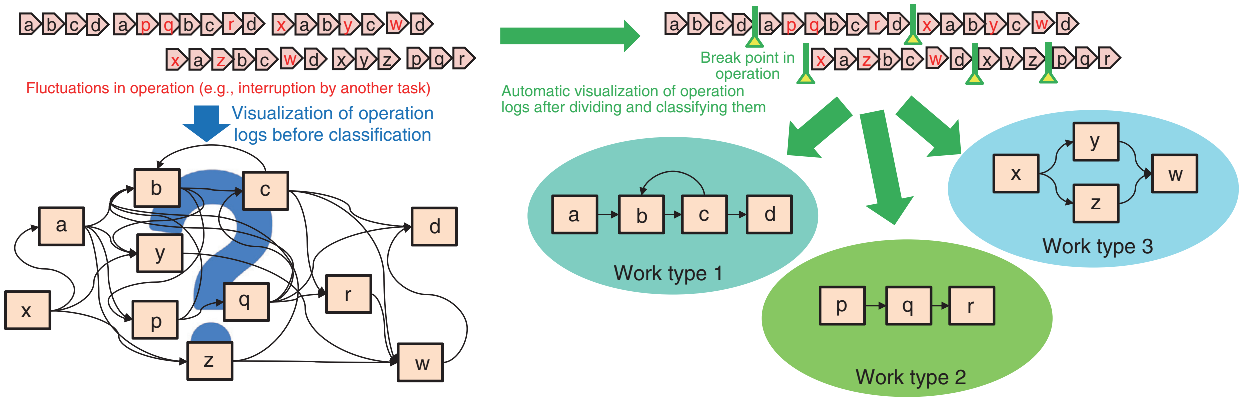

Fig. 4. Classification of operation logs into work types.

terminals and, on the basis of them, for visualizing, editing operational flows, and generating an operation automation scenario for RPA. The technology provides the following features, which are keys to understanding the gap between designed/assumed operations and the actual situation.

(1) Classification of operation logs into work types

When operations are designed or assumed, the process of service order reception, for example, is broken down into several work types, such as order-information registration and operational-task reservation, and it is assumed that several service orders are handled one by one and these work types are executed sequentially. However, in actual operations, it is not uncommon that different work types for several service orders are executed in parallel. Individual operation logs are also obtained without differentiation by operation type. Therefore, it is difficult to identify the gap between designed/assumed operations and the actual situation simply by arranging operation logs in chronological order. Our technology automatically detects the points in a series of operation logs where the operation type changes and visualizes the operation logs after dividing and classifying them. This makes it possible to understand actual operations by operation type [8]. **Figure 4** shows the classification of operation logs into work types.

(2) Extraction of frequent operation patterns

Among the operations that occur in the course of work, designed/assumed operations only cover typical operations, such as entering a value in an input field or pressing a button. In contrast, fully logged operations are more comprehensive and include those operations that are normally ignored in designing or assuming operations but are necessary to the process of entering a value in an input field such as making keystrokes to change selections in a list box or scrolling a screen. This means that there are various operations that are not included in designed/assumed operations, and these vary depending on the task being performed at the time. Even if a series of consecutive operations that occur frequently are extracted from the operation logs, it is not possible to compare them with the operation patterns that occur frequently in designed/assumed operations. Our technology is used to examine not only the consecutive operations in the operation logs but also the relationships between distant operations in the logs and automatically extract the most frequently occurring relationships, enabling actual operations to be compared with frequently occurring operation patterns in design/assumed operations. **Figure 5** shows the extraction of frequently occurring operation patterns.

To enable the design of highly productive and feasible operations and prompt incorporation of these into actual operations that can be implemented continuously, we will refine and expand the technologies mentioned above to promote and deepen common understanding and develop a mechanism that facilitates the use of not only RPA but also various information and communication technologies in business operations.

4. Outlook

We are aiming to develop a mechanism that makes it possible to increase productivity across diverse players and explore new business areas through collaboration of these players in a manner that takes advantage of their respective assets. For this purpose,

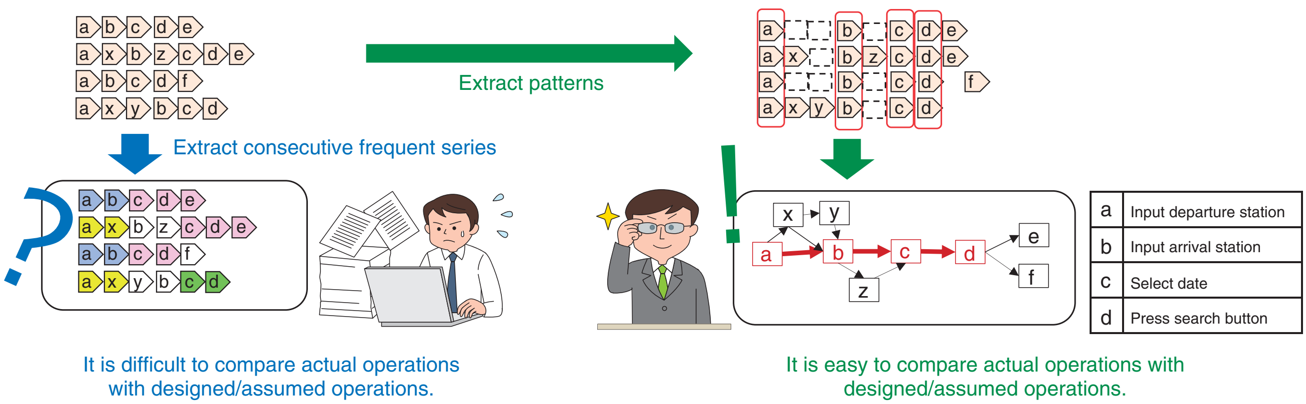

Fig. 5. Extraction of frequently occurring operation patterns.

we will develop technologies that facilitate collaboration among players and achieve self-evolution of analysis and decision. Through this R&D, we will strive to deepen collaboration with our partners and produce results in a timely manner.

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50 Years at Tsukuba R&D Center

Hiroshi Takahashi, Hideo Kawata, Ryo Koyama, Ryo Tanaka, Shinya Otsuki, Kazuto Goto, and Masashi Tadokoro

Abstract

NTT Access Network Service Systems Laboratories was established in Tsukuba City on July 20, 1972 as Tsukuba Telecommunication Construction Engineering Development Center. Since then, it has been renamed several times during the era of the Nippon Telegraph and Telephone Public Corporation and the Nippon Telegraph and Telephone Corporation (NTT). In July 2022, the Laboratories' Tsukuba Research and Development (R&D) Center celebrated its 50th anniversary. This article introduces the 50-year history of the Tsukuba R&D Center, focusing on the large-scale experimental facilities that supported R&D activities in Tsukuba.

Keywords: access network, infrastructure, optical fiber

1. Introduction

Tsukuba Telecommunication Construction Engineering Development Center of the Nippon Telegraph and Telephone Public Corporation, the predecessor of NTT Access Network Service Systems Laboratories, was established in July 1972 as a member of the 43 research and educational institutions planned for the Tsukuba Science City, a national project promoted by Cabinet approval in September 1963 [1]. As shown in **Fig. 1**, Tsukuba Telecommunication Construction Engineering Development Center was reorganized into Tsukuba Engineering Development Center (1985), Tsukuba Field Engineering Development Center (1987), NTT Telecommunication Field Systems Research and Development (R&D) Center (1991), and NTT Access Network Systems Laboratories (1994) and took its current name of NTT Access Network Service Systems Laboratories in January 1999. The Tsukuba R&D Center was established as the organization's experimental facilities in 1972, and the Makuhari Building and Yokosuka R&D Center were added to the organization in 1997, and the Musashino R&D Center was added in 2014. In July 2022, NTT Access Network Service Systems Laboratories and its Tsukuba R&D Center celebrated their 50th anniversary.

When it was first established as Tsukuba Telecommunication Construction Engineering Development Center, R&D activities on metal access technology and infrastructure technology were conducted in Tsukuba to improve the efficiency, safety, and work environment of outdoor construction work due to the increase in telephone service demand at that time. NTT Access Network Service Systems Laboratories is currently conducting R&D in the five fields of optical-fiber access technology, infrastructure technology, access system technology, wireless access technology, and operation technology. At the Tsukuba R&D Center, our R&D has been focused on communication lines and civil engineering facilities since the establishment of Tsukuba Telecommunication Construction Engineering Development Center.

The Tsukuba R&D Center was designed to conduct various experiments under conditions equivalent to those in the field to create communication facilities that can work in various environments. Therefore, it has large-scale and unique experimental equipment and facilities for communication lines and civil engineering facilities. This article describes the large-scale experimental equipment and facilities that support the R&D in Tsukuba.

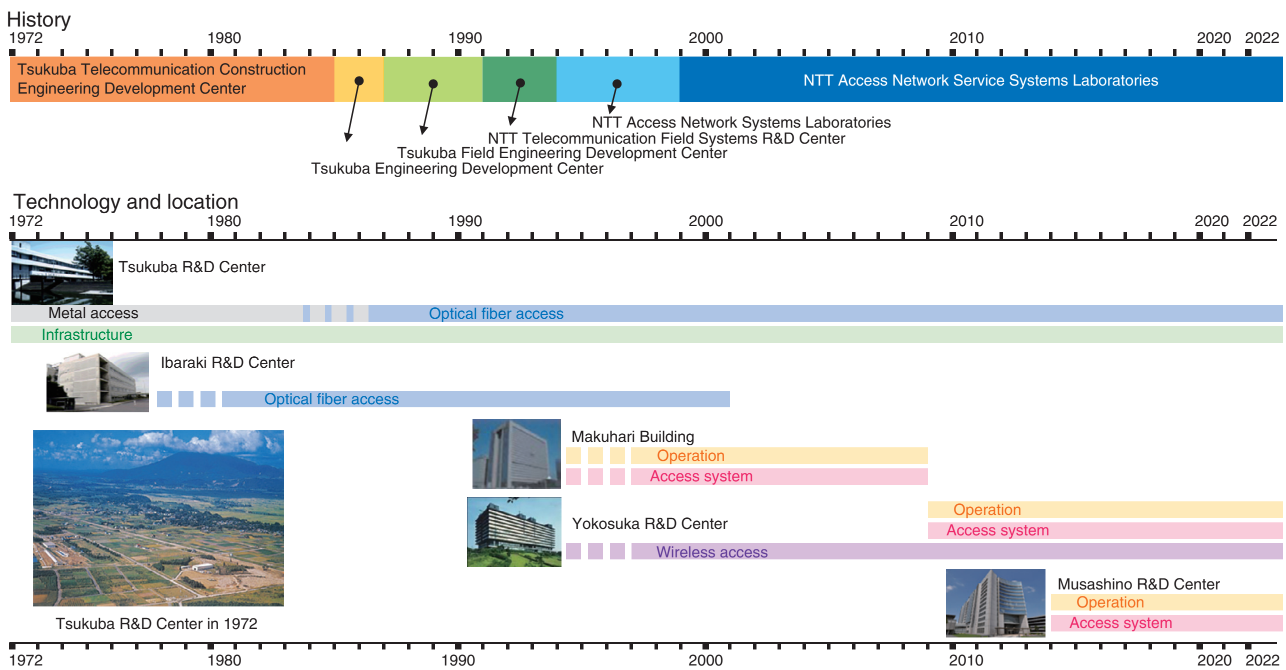


Fig. 1. History of NTT Access Network Service Systems Laboratories.

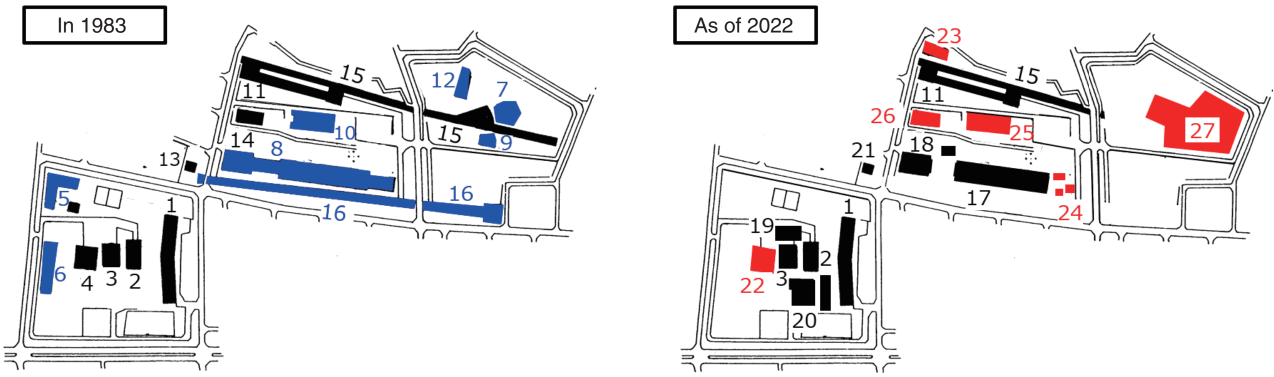
2. Large-scale experimental equipment and facilities at Tsukuba R&D Center

The Tsukuba R&D Center has mainly been carrying out R&D on infrastructure technology, metal access technology, and optical-fiber access technology. This article focuses on the facilities that were constructed during the Tsukuba Telecommunication Construction Engineering Development Center era but have now completed their intended purposes.

Figure 2 shows the facilities of the Tsukuba R&D Center in 1983 and the current ones on the vast site of about 22 hectares. Many of the facilities were designed to accurately reproduce installation environments such as the high-rise laboratory building (a vertical wiring experiment facility and was the highest in the world), buried object experiment facility by soil type, shield propulsion experimental facility, underwater experimental equipment, cable weather conditioning experiment facility, and vibration fatigue experiment equipment.

Figure 3 shows photographs of the high-rise laboratory building at the time of its completion (1983). With the increase in high-rise buildings, such as skyscrapers and large bridges, it was constructed for the purpose of improving vertical cable-laying methods and elucidating temperature changes in high-rise facilities and seismic behavior of high-rise facilities during earthquakes. Inside the building, there was a 75-m-high, 1.8-m-long, and 2.5-m-wide shaft (A) (from the 3rd story below ground to 12th story above ground) for cable laying experiments, static load tests, and vibration tests, and a 60-m-high, 1.0-m-long, and 1.0-m-wide shaft (B) (from the 1st story above ground to 12th story above ground) for vertical cable heat cycle tests (–40 to +80°C). It was used to verify the vertical installation of various cables. Today, vertically optical wiring installations are common in high-rise buildings, and their reliability is widely recognized and unshakable. The purpose of this experimental facility was accomplished, thus it was dismantled.

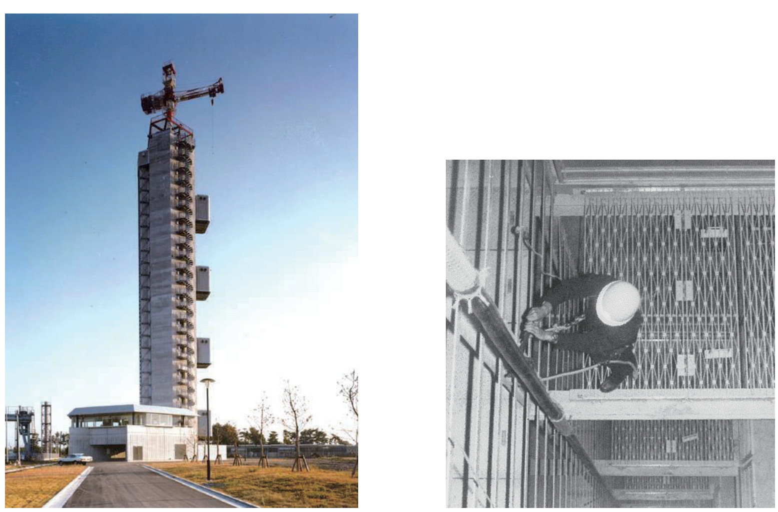
Figure 4 shows the large-scale experimental facilities used for verification of underground facilities and underwater communication lines and civil engineering facilities. Figure 4(a) shows photographs of the buried object experiment facility by soil type at the time of completion (1977). This facility was constructed to replicate installation under roads for the purpose of examining issues such as design, construction, and maintenance, because ground properties are diverse and difficult to predict accurately. The facility made it possible to alter soil quality, groundwater level, etc., and run a load car reproducing



1: The main building
2: Outside plant experiment building
3: Civil engineering experiment building
4: Large structure experiment building
5: Trainee hostel
6: Cable abrasion test equipment
7: High-rise laboratory building
8: Buried object experiment facility by soil type
9: Shield propulsion experimental facility
10: Underwater experimental equipment
11: Cable weather conditioning experiment facility
12: Vibration fatigue experiment equipment
13: Underground wiring experiment equipment
14: In-house experimental building
15: Conduits experiment facility
16: Transmission line experiment facility
17: Civil engineering comprehensive experiment facilities
18: Wireless experiment building
19: Optical access experimental building
20: Access building A, B
21: In-house experimental facility
22: Large structure experiment building (Wheel load/manhole equipment)
23: Fiber manufacturing equipment
24: System for analysis using wall and pole keeping equipment
25: Vibration fatigue experiment equipment
26: Access network museum
27: Outdoor experiment area

Blue: Equipment that is no longer used
Red: Equipment newly installed or renewed in recent years
Bold: Facilities introduced in this article

Fig. 2. Large-scale experimental equipment and facilities at Tsukuba R&D Center.

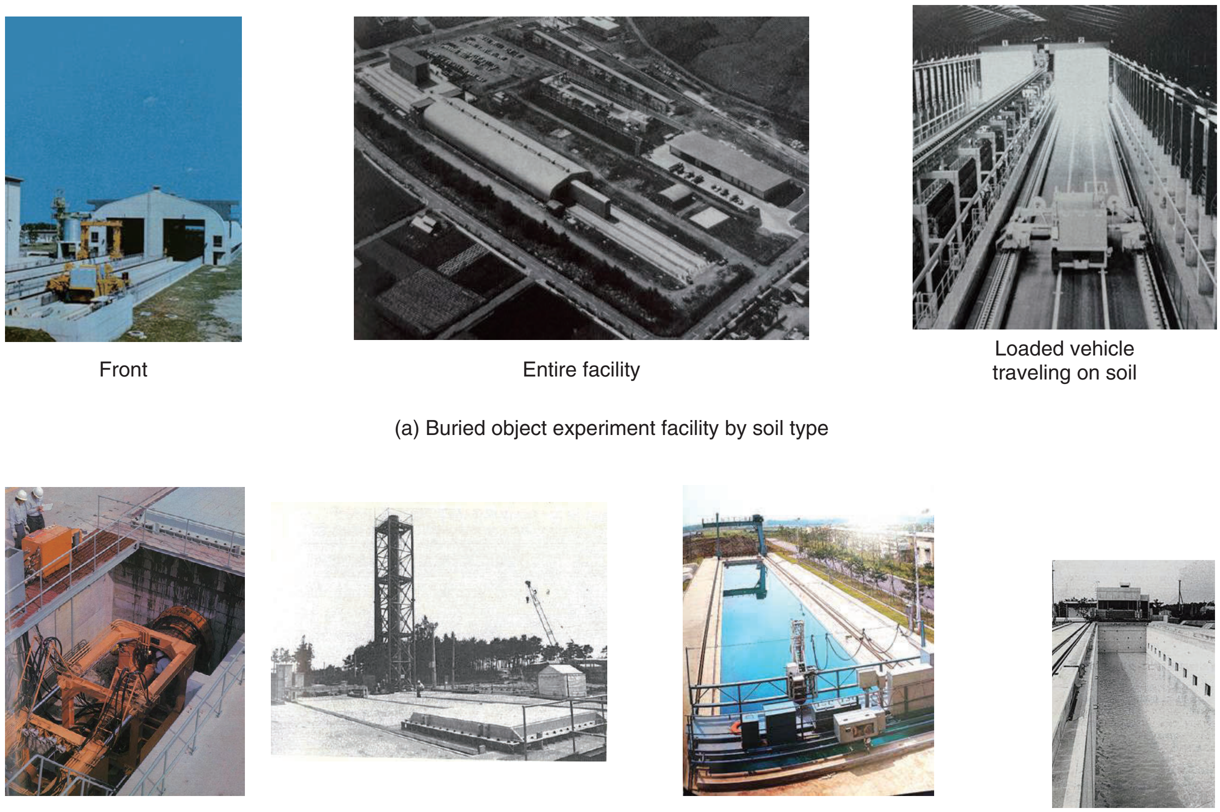


(a) Exterior view at completion (1983)

(b) Inside shaft A

Fig. 3. High-rise laboratory building.

automobile loads over it. It was useful in various verification tests, such as the investigation of the effect of burying a full-scale manhole, and the investigation of the movement of optical fiber cable in the pipeline by burying a pipeline in the soil layer close to the actual site and driving a load car over it. Underground facilities for communication services have been installed all over Japan, thus this facility



Front / Entire facility / Loaded vehicle traveling on soil

(a) Buried object experiment facility by soil type

Experimental pit / Entire facility / Full of water / Drained

(b) Shield propulsion experimental facility

(c) Underwater experimental equipment

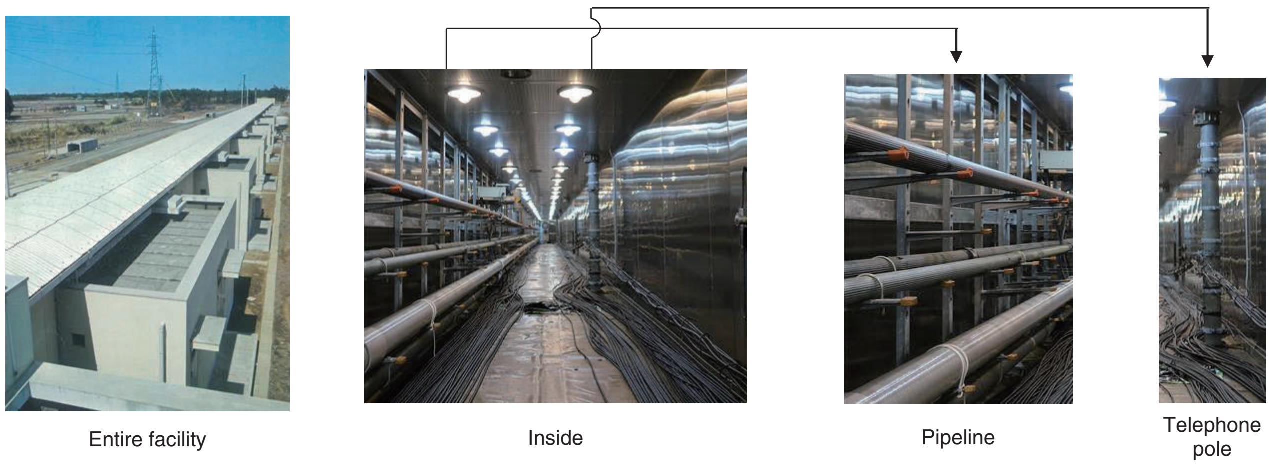
Fig. 4. Large-scale experimental facilities used for verification of underground and underwater facilities.

completed its intended purpose.

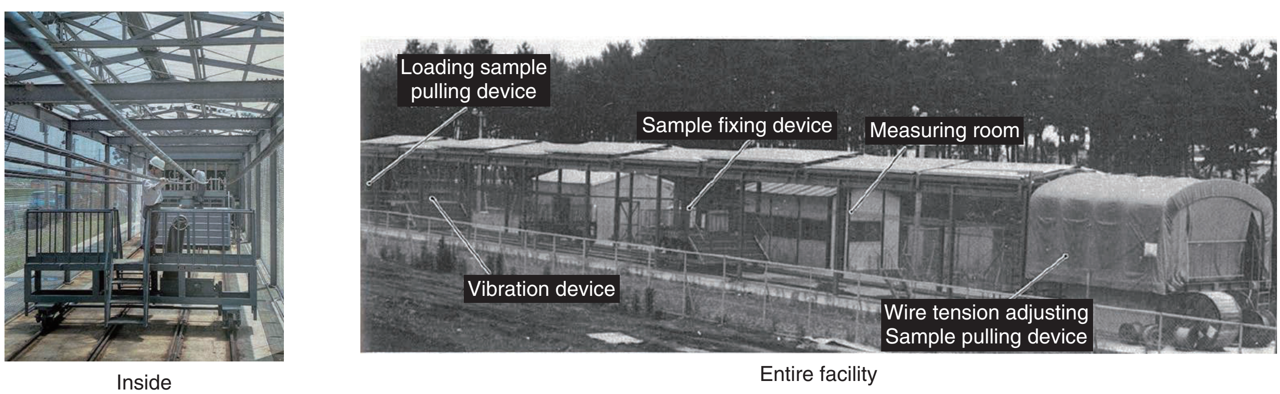
Figure 4(b) shows the test pit and panoramic view of the shield propulsion experimental facility. To apply the shield-tunneling method developed for road construction without using open pit methods, this facility was constructed to verify the adaptability and safety of the method, considering various construction conditions expected at different sites. By putting a sample of the soil layer under test into the pressure soil tank and using a water-pressure generator to apply arbitrary water pressures to the layer, predetermined ground conditions could be created. Therefore, a small model shield machine installed in the experimental pit was propelled into the soil layer, and experiments on excavation, soil removal, etc. were conducted. As the shield-tunneling method for various types of ground has become widely used, and the construction of new roads has been reduced, the shield propulsion experimental facility was dismantled upon completion of its purpose.

Figure 4(c) shows an exterior view of the underwater experimental equipment at the time of completion (1974). It was constructed to test the laying of submarine cables and water-resistance tests of underground structures. It consisted of a water tank 50 m long, 6 m wide, and 5 m deep, underwater observation tunnel, moving bridge, bridge crane, and measurement room. The mobile bridge was self-propelled with a running speed of 10–50 m/min and used as a simulated submarine-cable laying device for conducting simulation experiments on submarine cables. Test methods for submarine cables and underground facilities were established, therefore this equipment has been removed.

Figure 5 shows the large-scale experimental facilities used for the verification of aerial communication cables and civil engineering facilities in the open. Figure 5(a) shows the cable weather conditioning experiment facility at the time of completion (1973). Since most communication lines and civil engineering



(a) Cable weather conditioning experiment facility



(b) Vibration fatigue experiment equipment

Fig. 5. Large-scale experimental facilities used for verification of aerial communication cables and civil engineering facilities in the open.

facilities are installed outdoors, this facility was constructed to reproduce actual cable installation environments and conduct weatherability tests and temperature-characteristic tests. Having a totally stainless steel roof and being 150 m long, 2.45 m wide, and 2.25 m high, it made it possible to reproduce in a test room the state of installation in a conduit, pipeline, and on a telephone pole. At the time of construction, the temperature could be changed from –20 to +60°C, but now it can be changed from –30 to +70°C. In optical cables, small bends in the cable affect various transmission characteristics, so we will continue to use the facility through various tests for the practical application of new fiber and cable structures.

Figure 5(b) shows the vibration fatigue experiment equipment when it was completed (1977). It was constructed for the purpose of clarifying the response characteristics, such as the increase in optical loss and fracture of cables, passive optical components, closures, and hardware, used in overhead lines by the imposition of vibration to replicate the effect of wind on aerial cables, etc. By providing feedback to the design, development, and verification of new cables and components, we have been able to enable safe long-term use of overhead equipment and facilities. This equipment can forcibly excite cables and suspended wires with actually installed aerial cables. At the time of completion, the maximum installation length was 35 m, but the maximum installation length has been extended to 65 m, and it will continue to be used for various experiments.

As of 2022, we also have large-scale experimental facilities intended to support the Innovative Optical and Wireless Network (IOWN) and smart facilities, as shown in red in Fig. 2.

3. Summary

This article introduced the R&D history of the Tsukuba R&D Center over the last 50 years, focusing on the large experimental equipment and facilities created to support the R&D of communication lines and civil engineering facilities. We will continue to conduct R&D activities toward the development of smart facilities that support IOWN, with the aim of achieving technologies that can be used to support both the most advanced in the world and easy-to-use in the field.

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Intent AI Mediator (Mintent) for High-satisfaction-level Services

Kazuhisa Yamagishi, Masahiro Kobayashi, Shingo Horiuchi, and Kenichi Tayama

Abstract

This article introduces the intent AI (artificial intelligence) mediator called Mintent that coordinates and cooperatively controls networks, cloud servers, and applications on the basis of the respective requirements (intents) of service providers and users. This technology can be used to provide services on the basis of such intents.

Keywords: intent, Mintent, cooperative control

1. Introduction

Advances in communication network, cloud-server, and application technologies have made it possible to provide a higher satisfaction level of communication services. However, the resources of networks, cloud servers, and user terminals are limited, so the increase in the number of service users can cause network congestion and server resource constraints. When these situations occur, the throughput degrades and latency increases, and users cannot receive data properly at their terminals. As a result, users cannot experience a high satisfaction level of service. To avoid these quality degradations, service providers are deploying network, cloud-server, and application control technologies to overcome temporary resource constraints. However, improvements in these single-domain control techniques are limited. Therefore, it is important to coordinate and cooperatively control network, cloud-server, and application information.

The requirements (i.e., intents) that service providers and users demand of services generally differ for each service type. For example, a video-streaming service provider monitors the number of video users and the viewing time to encourage continuous use of the service. Thus, the service provider has an intent, i.e., a demand to increase the number of viewings or lengthen the viewing time. Similarly, the service provider of a connected vehicle has an intent to deliver video to the monitoring center without interruption to monitor what is happening inside and outside the vehicle. However, since it is not possible to provide services with an excessive amount of network, cloud-server, and application resources, these intents are converted into resource information for networks, cloud servers, and applications, which are coordinated to provide appropriate quality of service (QoS). Therefore, networks, cloud servers, and applications need to be controlled in a coordinated manner to provide appropriate QoS.

The intent artificial intelligence (AI) mediator called Mintent is introduced as a technology that coordinates and cooperatively controls networks, cloud servers, and applications on the basis of intents of service providers and users, as shown in **Fig. 1**.

2. Recent activities regarding intent-related technology in standardization

The Industry Specification Group on Experiential Networked Intelligence (ENI) of the European Telecommunications Standards Institute is developing a method for specifying the goals and requirements of operations that operators want to achieve as intents, which are described in restricted natural language. ENI 008 Intent Aware Network Automaticity released in March 2021 defines the architecture and functional blocks required to process an intent and discusses the

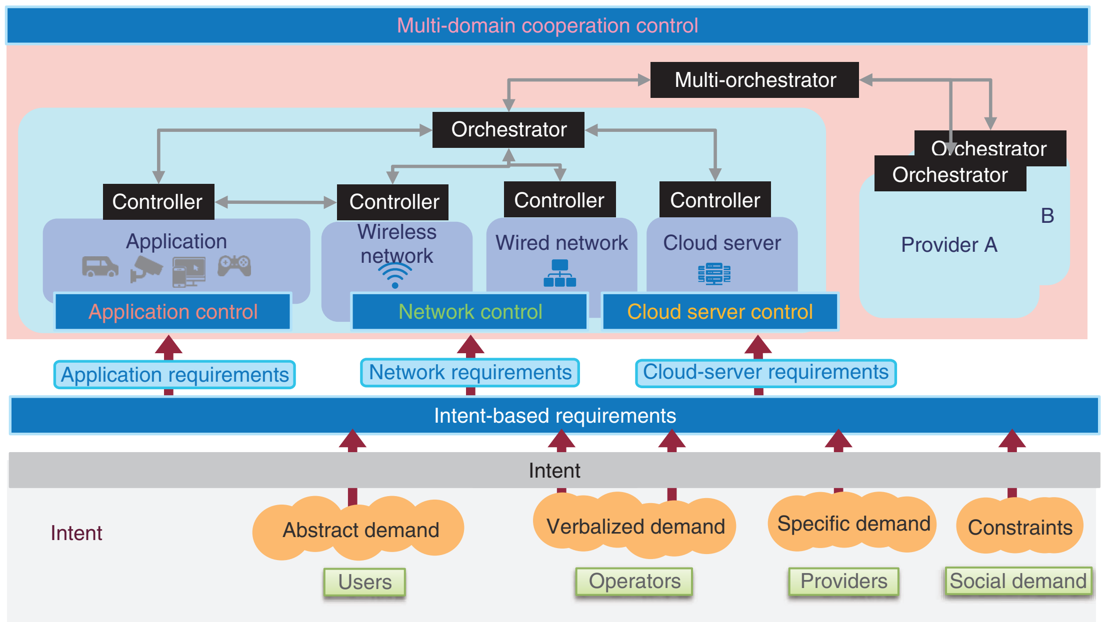


Fig. 1. Concept of intent AI mediator (Mintent).

lifecycle management of intent operations and elements such as external interface requirements. Proofs of concept applying intent management methods to the cloud and wireless networks are also being actively carried out.

TM Forum, an industry association for communication service providers and their suppliers, advocates a closed loop architecture to achieve autonomous network operations by taking into account the business, service, and network-resource layers, and the interworking of loops between each of these layers is defined as shown in **Fig. 2**. In this architecture, the autonomous network is achieved using the intents defined by the users and operators as the goal. This architecture has been discussed to study how to minimize the total operation cost.

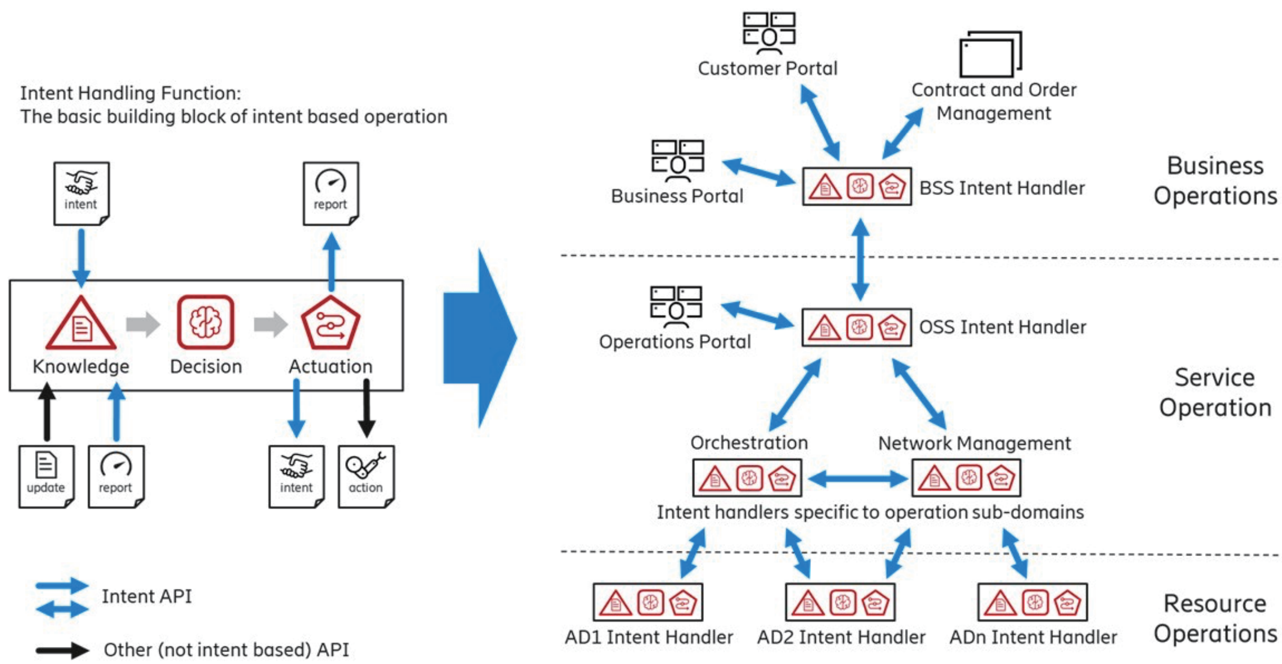
3. Mintent

To provide services that satisfy intents of service providers and users, it is not enough just to use respective control technologies in the network, cloud-server, and application domains. Therefore, Mintent was developed as a technology for sharing and coordinating information obtained from each domain to provide a higher satisfaction level of services by taking into account the intents of service providers and users (Fig. 1). An overview of the elemental technologies of Mintent is described below.

3.1 Application control technologies

Application control technologies to obtain video data with different video coding bitrates (i.e., adaptive bitrate streaming) or control video coding bitrates (i.e., Google Congestion Control) on the basis of network throughput, packet loss, and/or fluctuations in the amount of received data have become common for video streaming and web conferencing. These technologies provide a service without stalling by requesting video data with a lower coding bitrate when QoS (i.e., throughput, packet loss, and delay) degrades. However, such technologies cannot control on the basis of the service provider's or user's intent because the control is based only on QoS.

For example, service providers have an intent to avoid increasing content-delivery-network and network costs by providing services with excessive quality if they can maintain a certain level of suitable quality. Similarly, users have an intent to avoid excessive data consumption by receiving high-quality video. To satisfy these intents, we proposed technologies that do not transmit excessive data while maintaining a suitable quality level [1, 2]. These technologies consist of a quality-estimation model that estimates quality of experience (QoE) and request video data so that the QoE satisfies the suitable quality



Excerpt from IG1230 "Autonomous Networks Technical Architecture" v1.0.0 in TM Forum

AD: autonomous domain
API: application programming interface
BSS: business support system

Fig. 2. Autonomous network architecture using intent in TM Forum.

level. This prevents excessive quality and excessive data transmission, thus satisfying the intents of service providers and users.

3.2 Cloud-server control technology

As the environment surrounding the service changes, to maintain optimal resource allocation while satisfying QoE requirements, server resources need to be designed on the basis of various situations and requirements. With the diversification of services and increasing complexity of resource control, however, resource design and control based on the experience of service engineers or system performance-based methods are no longer adequate. Such a conventional approach has issues, such as service engineers are required to have much experience and high skill levels, the difficulty in providing services in accordance with user quality requirements and usage conditions, and the need to allocate extra resources to satisfy quality requirements.

To address these issues, we proposed a cloud-service-resource optimal-control technology that proactively and automatically calculates the amount of resources [3]. This technology handles user-experience quality requirements and service-provider performance requirements as intents, then the optimal cloud resource that satisfies the intent is calculated on the basis of the system environment, usage status, and planned usage information. The optimal cloud resource that satisfies the intent can be proactively controlled using an AI model that can predict performance on the basis of the system environment, usage status, and planned usage information.

3.3 Network control technology

Network control technology optimizes communication paths to maximize the efficiency of network equipment utilization while satisfying QoS requirements on the basis of the intents of users and network operators.

With the advancements in virtualization technologies such as software-defined networking and network functions virtualization, networks can be dynamically and flexibly controlled by software operations. As the services and terminals used become more diverse regarding user intent, QoS expected for the network is also becoming more diverse. In addition, network operators have an intent to use equipment efficiently and reduce equipment expansion.

To satisfy the intents of users and network operators, we proposed an optimal-route-allocation method to accommodate as many users as possible while satisfying QoS requirements calculated on the basis of users' QoE requirements by using network virtualization technology [4]. Since the optimum route allocation at a certain point in time is not always the optimum allocation in the future, this method improves the utilization efficiency of equipment by optimizing the resource allocation in consideration of future demand.

4. Multi-domain cooperative control technology

Multi-domain cooperative control coordinates the control for each domain (e.g., application, network, cloud server, and resource of other operators) to optimize the entire resource across domains while satisfying QoS requirements on the basis of the intent.

In future networks, such as IOWN (Innovative Optical and Wireless Network) and 6G (6th-generation mobile communication systems), controllers and orchestrators will be deployed in each domain and control the resources of the domain autonomously on the basis of the elemental technologies mentioned above. In this environment, individual optimization within a domain does not necessarily translate into optimization across domains. Therefore, the end-to-end intent may not be satisfied and resource utilization may be inefficient.

For optimal control across domains, we are developing *sharing of communication quality among domains* and *optimization of control order considering control execution time* as mechanisms to coordinate autonomous control by controllers in each domain. When communication quality in a certain domain degrades due to resource congestion or other reasons, resources will be over-allocated in other domains if the same amount of resources as in the normal case is reserved. Therefore, *sharing of communication quality among domains* prevents over-allocation of resources in other domains by sharing the communication quality achieved in each domain. As the types of control in each domain become more diverse, the execution time also varies. For example, rerouting in a network domain may take less than 1 minute, and cloud-server resource expansion may take 5–10 minutes. When congestion avoidance control is executed in multiple domains during resource congestion, the end-to-end communication quality deteriorates until the control with the longest execution time is completed. Therefore, *optimization of control order considering control execution time* shortens communication-quality deterioration by optimizing the content and order of control in consideration of the difference in execution time for each control.

5. Use cases of Mintent

Mintent enables multi-domain cooperative control such as the cooperation between wireless networks and applications, wired networks and applications, cloud servers and applications, and wired networks and cloud servers. The following sections describe the use cases and benefits of the coordination between wireless networks and applications and between wired networks and cloud servers.

5.1 Monitoring of in-vehicle camera videos

Studies for automated driving are rapidly advancing. However, fully automated driving will not be achieved immediately, and for the time being, driver assistance is the initial target. Specifically, images captured with an in-vehicle camera are sent to a monitoring center, where an observer monitors the images to assist the driver. In this case, the service provider has an intent to enable the non-stop delivery of surveillance video. Since wireless-network quality generally fluctuates, a high video-coding rate relative to the throughput causes packet loss, which distorts the video and prevents proper video monitoring. Therefore, current technologies either deliver video at a fixed coding rate designed to be safe with respect to wireless-network quality or deliver video at a low coding rate that does not reliably cause packet loss by capturing dynamic changes in the past wireless-network quality. Therefore, surveillance video with sufficient video quality cannot be provided to the observer, and there is a concern that the observer may fail to detect hazards both inside and outside the vehicle. Therefore, as shown in **Fig. 3**, Mintent dynamically controls the encoding rate by sharing the throughput value predicted as the future wireless-network quality with the encoder that encodes the in-vehicle camera video. This enables video transmission in accordance with the wireless-network quality and aims to transmit high-quality video in accordance with the wireless-network quality.

5.2 Robot control in smart factories

Automation of robot control is being studied for

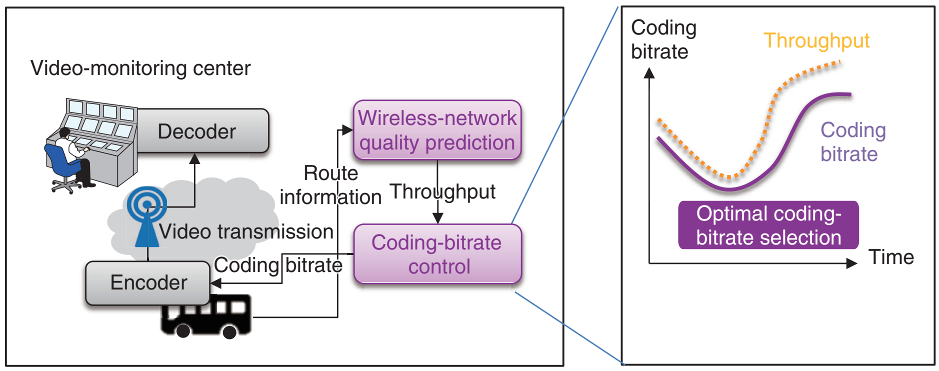


Fig. 3. Monitoring of in-vehicle camera videos.

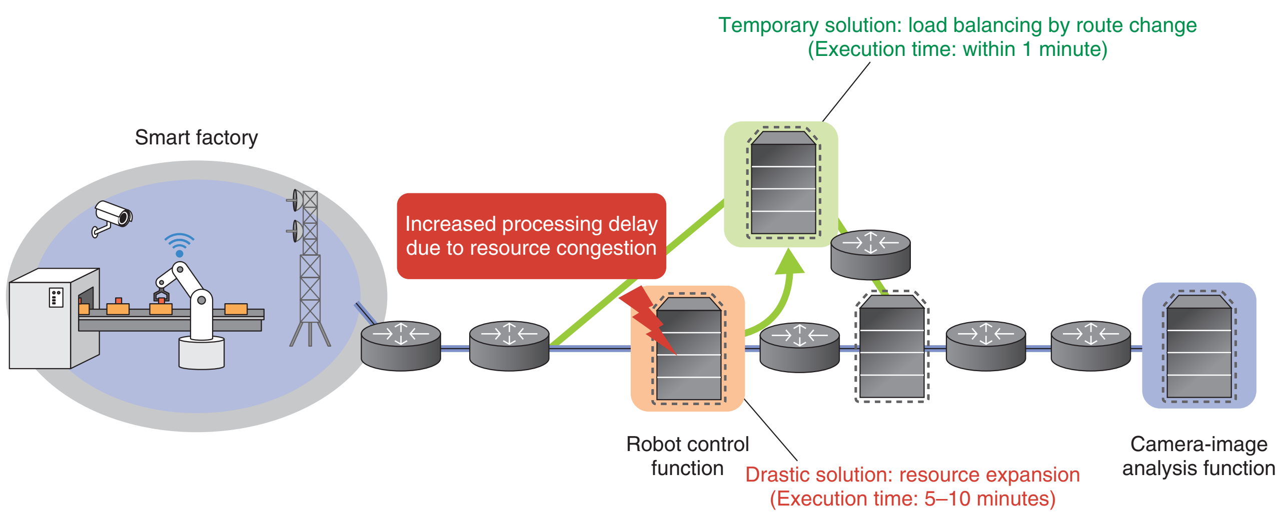


Fig. 4. Robot control in smart factory.

smart factories. Factory managers have an intent to keep robots running without stopping. To achieve this intent, communication-quality degradation that affects robot control must be minimized. Mintent coordinates the control of multiple domains and optimizes the control content and sequence by taking into account the control-execution time to shorten the quality-degradation period.

Consider the environment with a network domain and cloud-sever domain shown in **Fig. 4**. The robot-control function is deployed on the server close to the factory, and the camera-image analysis function is deployed on the server far from the factory. Consider the case in which processing delays increase due to temporary resource congestion on the server where the robot-control function is deployed. As a fundamental solution, the cloud-server-domain control needs to expand the resources of the server. However, since server-resource expansion takes about 5–10 minutes to execute, the processing delay continues to increase during this period. As a result, robot control is affected, and the factory manager's intent is not satisfied. Mintent can shorten the period of quality degradation by distributing the load to servers with sufficient resources by changing routes in network domains with control times of 1 minute or less as a temporary solution until the control of resource enhancement is completed.

6. Conclusion

In this article, the need for an intent AI mediator

(Mintent) was described. Subsequent articles will introduce the latest research and development of individual technologies at NTT laboratories.

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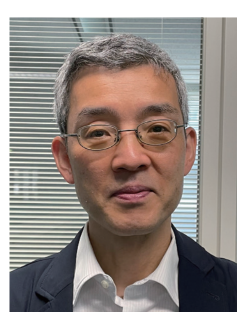

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Technology for Extracting and Converting Various and Ambiguous Intents to Implement Mintent

Noritsugu Egi and Shingo Horiuchi

Abstract

In this article, we introduce an intent-extraction technology to extract intents of service providers and users in a next-generation communication service and a resource-requirement-conversion technology to convert these intents into resource requirements that can be used for resource control in the intent artificial-intelligence mediator (Mintent) that enables operations by taking into account various intents.

Keywords: intent, intent extraction, resource requirements conversion

1. Introduction

Attention has been focused on intents, which are various demands for services, to create beneficial services for service providers and users. By accurately extracting these demands (intents) of service providers and users and enabling a cooperative resource control using network, cloud-server, and application information on the basis of these intents, i.e., the intent artificial-intelligence mediator (Mintent), it is possible not only to provide services in response to these demands but also to achieve efficiency of operation without decreasing the satisfaction of service providers and users by optimally designing and controlling resources on the basis of these intents. To implement Mintent, it is important to accurately understand the intents of service providers and users for services and convert these intents into requirements of adjustable indicators for operations. We introduce intents and related technologies in the following sections.

2. What is intent?

Service providers and users have various demands for various services over a network. For example, virtual reality (VR) video-service users want to have an audiovisual experience as if they were in a real space, e-sports-service users want to have smooth operation without performance being affected, and users of an automatic operation or working robot want to achieve necessary tasks such as transportation and object detection more accurately and quickly than a human. While meeting user's demands, service providers want to minimize the amount of data transmission to reduce operating costs or respond quickly to complaints for maintaining user satisfaction. We define these demands as intents and aim to enable service operation on the basis of these intents.

Figure 1 shows the elemental technologies for achieving intent-based operation. Intents are not always given as specific requirements by service users or service providers. For example, ambiguous demands related to functional requirements, such as "enjoying watching sports" or "detecting suspicious persons," or ambiguous demands that are not a specific index or required values related to the quality or performance of certain functions, such as "feeling of being there" or "achieving high accuracy," can be assumed.

Because these ambiguous intents in service operation are difficult to use, we need to break them into specific requirements and define indices for these requirements (intent definition in **Fig. 2**). To express quantitative values of non-functional requirements related to quality or performance, we are studying the

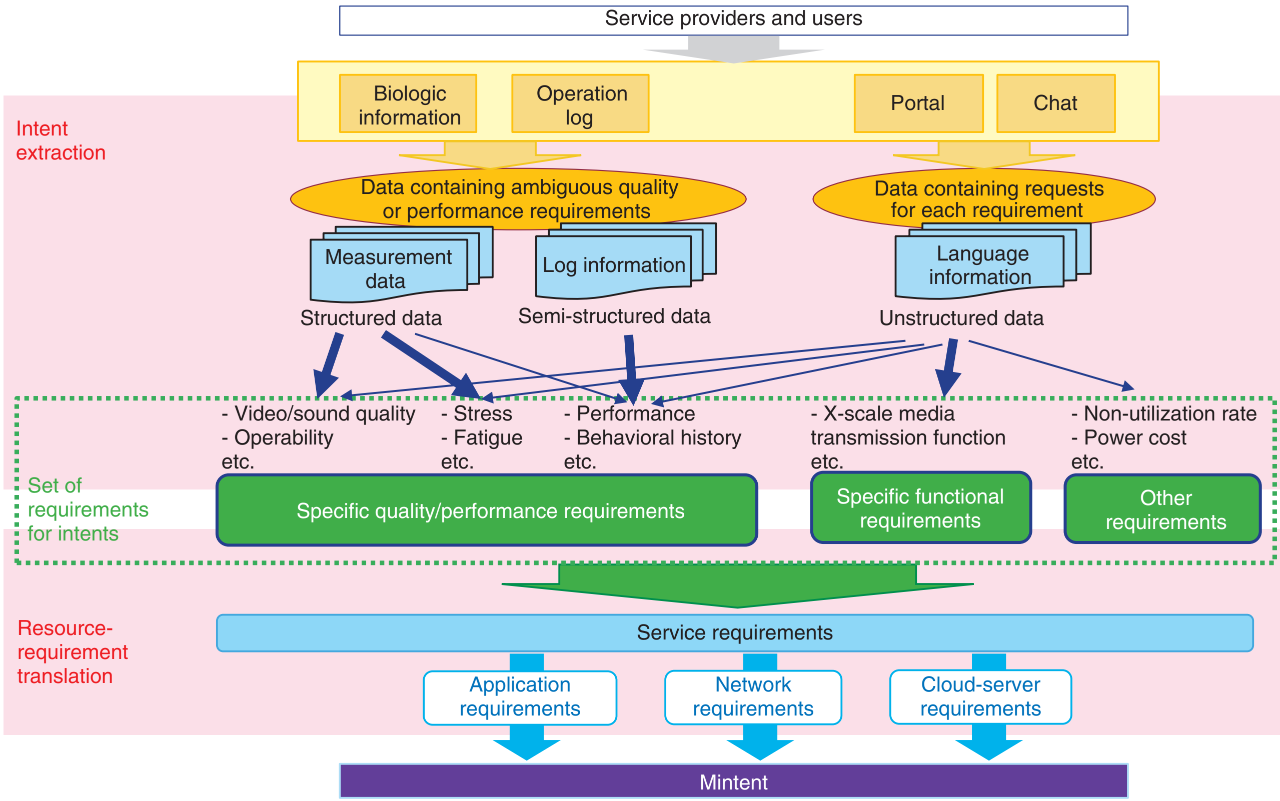


Fig. 1. Fundamental technologies of intent-based operation.

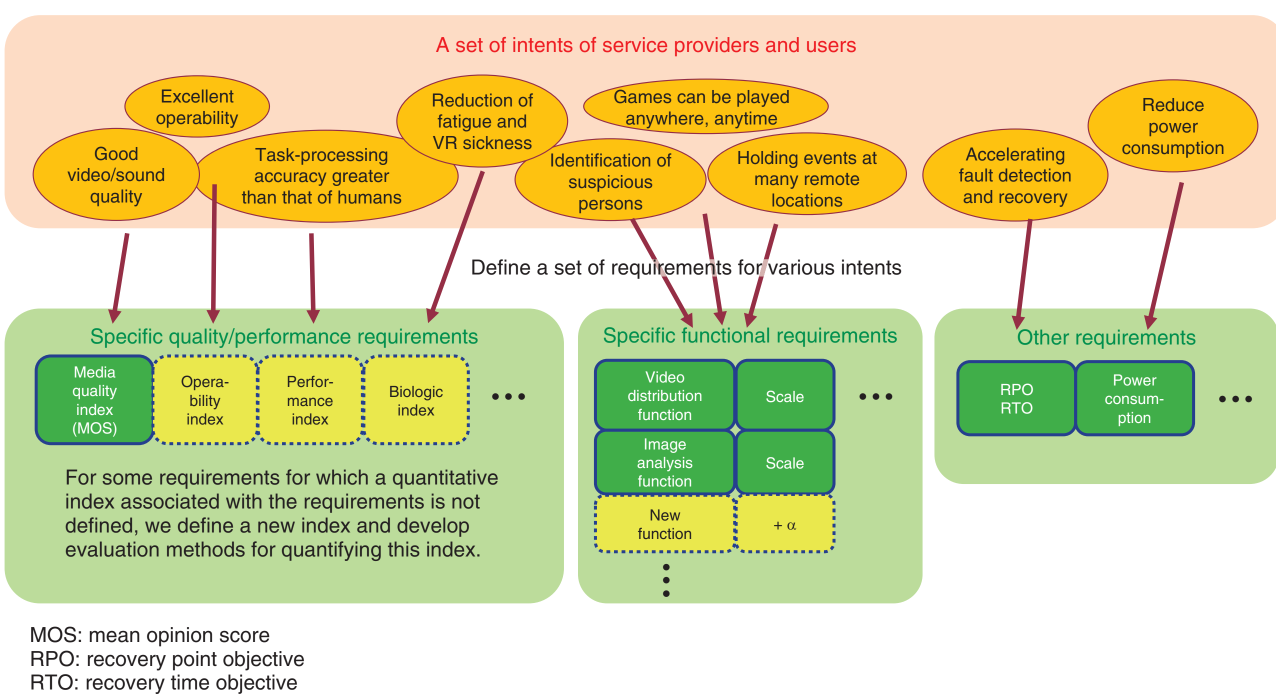


Fig. 2. Intent definition.

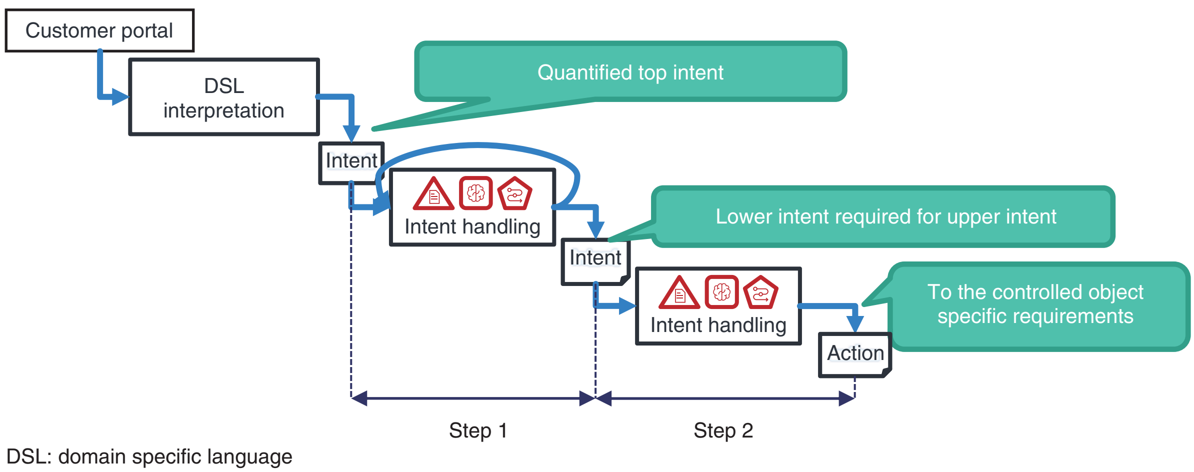


Fig. 3. Intent analysis method in the standardization.

definition of general indices for various requirements and quantitative values for each index. Thus, we aim to implement Mintent by extracting a set of specific requirements of service users and service providers (intent extraction) and converting these requirements into adjustable indicators for operations in Mintent (resource-requirement conversion). The following sections introduce intent-extraction technology and resource-requirement-conversion technology.

3. Intent-extraction technology

Intent-extraction technology collects information related to the intents of service providers and users and extracts a set of specific requirements from this information. As intent-related information, we use (1) language information obtained through the input interface for service providers or users and (2) information related to these users that can be obtained in-service.

An example of (1) is the language information received through a user portal or chat function. By using language-processing technology for this information, we extract the intents for specific demands or concerns. For example, when the service provider of a service that delivers real-time high-quality video of a professional sports competition gives language information such as “There is a suspicious person in the audience” or “A player is injured,” intents such as “detection of suspicious persons from images in corresponding area” or “remote diagnosis for the player” are extracted, and the required functions are extracted from these intents. We extract the quality and performance requirements necessary for each function (e.g., detection accuracy rate is 90% or more). We also aim to provide a flexible service that can automatically switch to the appropriate service plan from a pre-set one on the basis of the intents of service providers or users.

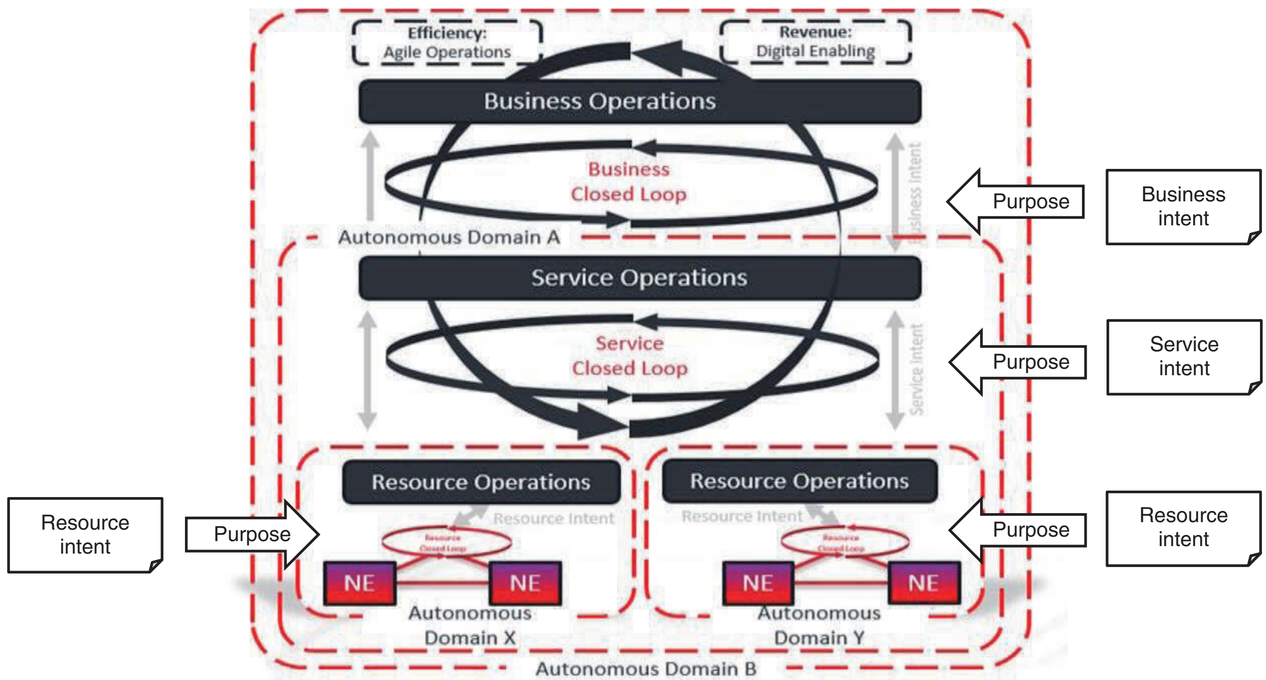
An example of (2) is operation-log information. We extract intents of service users from changes in the behavior patterns obtained by analyzing the operation-log information. For example, in a service related to remote control, service interruption and time spent on each task are extracted from the operation log. If it is found that service users tend to stop using the service when the time required for the last specific task is long, intent related to performance is obtained. Specific quality or performance requirements (e.g., within 10% of the average time required for the task) is determined on the basis of the correspondence between the time and the user’s behavior.

We aim to extract a set of specific requirements that service users and service providers have by using various types of information.

4. Resource-requirement-conversion technology

To use Mintent for resource control, specific requirements extracted using intent-extraction technology need to be converted into indicators that can be controlled by the resource controller. In addition to intent extraction, we believe that a two-step function is necessary on the basis of discussions on standardization (**Fig. 3**).

Step 1 may include several steps of transformation



Excerpt from "Autonomous Networks Technical Architecture," v 1.0.0, IG 1230

NE: network element

Fig. 4. Relationship between intent and autonomous network.

from the business layer to a controlled target in a specific network domain. As specified in the standard, an architecture in which the management target and business are separated by several layers is the basis for developing systems such as a business support system and operation support system. Key performance indicators (KPIs), which represent the performance of the management target, exist for each operation-management layer and have relationships (structures) across layers. We believe that the technology to extract qualitative intents and achieve Step 1 can be developed not only by conventional machine learning but also by taking into account the hierarchical KPI structure and implications of KPIs for intents.

The intent discussion in the standardization is treated as the purpose of the closed loop mechanism in each layer that enables an autonomous network for automating the operation (**Fig. 4**). Intent based on understanding the abstract requirements of the users that we aim to achieve not only automates the operation but also contributes to enhancing customer management by increasing user satisfaction [1].

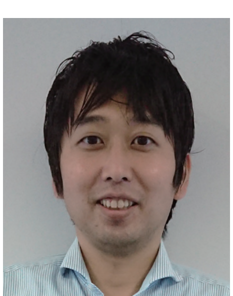
We are not only targeting services such as CaaS (Connectivity as a Service) services, e.g., network slices of 5G (5th-generation mobile communication systems), but also aiming to establish technologies to extract user requirements for end-to-end services including application functions provided on those services.

5. Conclusion

We introduced technologies to be studied to enable operations corresponding to various intents of service providers and users. In addition to the development of these technologies, we will participate in the proof of concept (Catalyst Project) at the TM Forum, an industry association for communication service providers and their suppliers, to increase awareness of these technologies, discover applicable business scenarios, and promote research and development so that the technologies can be used for a wide range of business requirements. We will also standardize the intent model and API (application programming interface) requirements and quantification of intent metrics as needed.

Reference

[1] TM Forum, "IG1230 Autonomous Networks Technical Architecture v1.1.0," https://www.tmforum.org/resources/how-to-guide/ig1230-autonomous-networks-technical-architecture-v1-1-0/



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Optimize Cloud-server Resources for Comfortable Web Conferencing

Hiroaki Kikushima and Chao Wu

Abstract

This article introduces an application example of the cloud-server resource-optimization technology, which is one of the technologies comprising the intent artificial intelligence (AI) mediator called Mintent, to a web-conferencing service. This technology recommends the minimum amount of resources necessary to meet the requirements (intents) of each service provider and user, reducing resource costs while ensuring quality of experience, by using AI that predicts performance in accordance with various service usage conditions. This helps to meet a variety of requirements, such as improving user engagement with services, reducing service providers' operating and resource costs, and reducing carbon dioxide emissions through more efficient energy use.

Keywords: intent, resource control, web-conferencing service

1. Introduction

Changes in social conditions, such as the rapid increase in remote work and the promotion of digital transformation, have accelerated the rapid change in demand for services and the diversification of user needs.

To keep up with changes and the diversity in these environments, various systems are becoming cloud-native, and various services and network functions are being provided on cloud servers with a shorter lead time. Therefore, server-resource control is becoming increasingly important; however, it is difficult to provide services that meet quality of experience (QoE) requirements and usage conditions with resource design based on experience and resource control based on system performance. Therefore, NTT Access Network Service Systems Laboratories developed a novel cloud-server resource-optimization technology that takes into account various user's QoE in addition to system-performance requirements.

The cloud-server resource-optimization technology automatically calculates optimal resources under various service-usage conditions while maintaining QoE, leading to reductions in resource design and operation and resource costs.

To show the effectiveness of this technology, this article introduces its application to a web-conferencing service.

2. Cloud-server resource-optimization technology overview

2.1 Technological superiority

The cloud-server resource-optimization technology uses an artificial intelligence (AI) model that predicts various types of performance on the basis of system load and service-usage conditions and calculates the minimum amount of resources that satisfy the requirements (intents) of service providers and users (**Fig. 1**).

It has the following advantages over conventional resource-control technology that focus only on system performance.

By combining multiple AI models that predict various types of performance, this technology can calculate the optimum amount of resources not only for system-performance requirements but also for intents including QoE requirements. The AI models used are trained to use different log data to predict different types of performance. Basically, a regression analysis

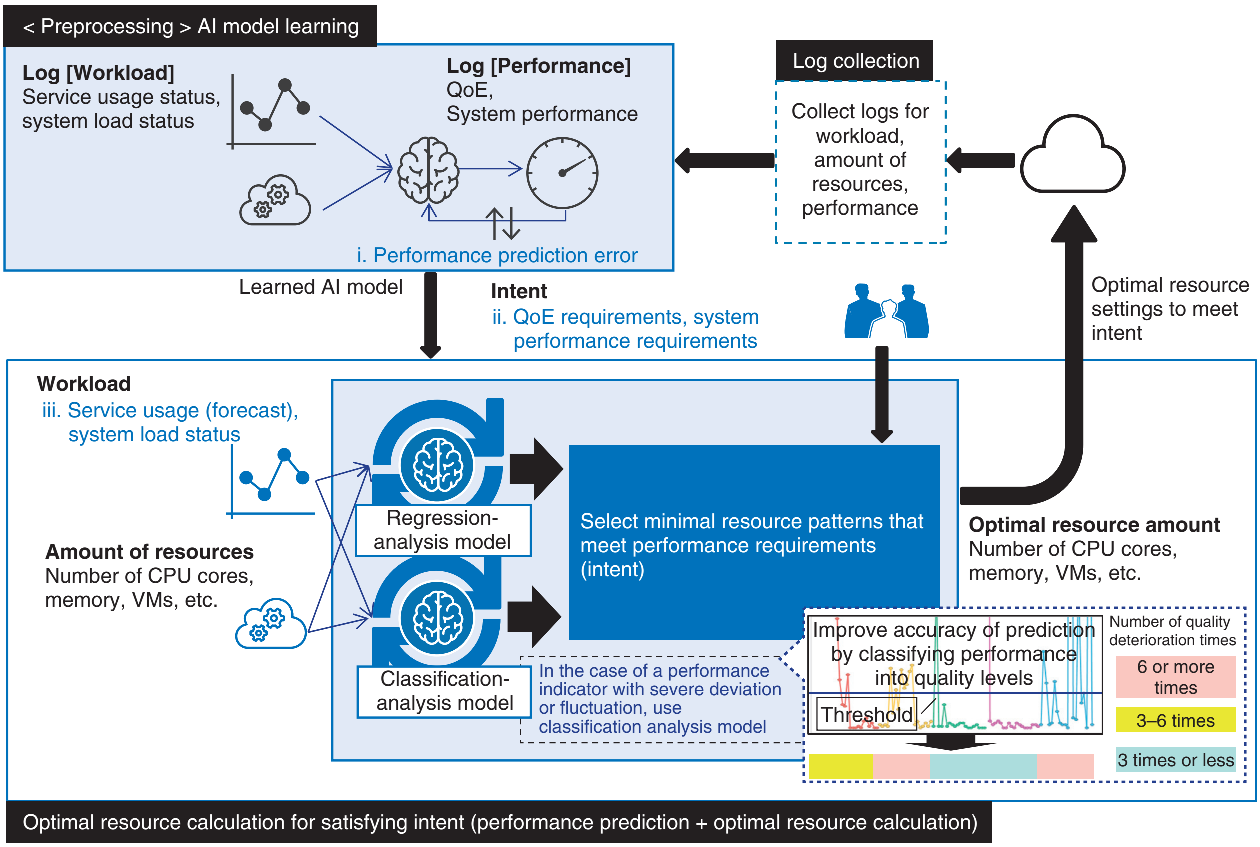


Fig. 1. Technical overview.

model is used. However, some QoE indicators are difficult to predict numerically through regression analysis. In this case, by using a classification analysis model, the technology is able to predict the performance level with high precision (Fig. 1). These features make it possible not only to avoid quality failures and improve resource efficiency but also to provide services tailored to users' usage conditions and objectives.

Various efforts have also been made to train AI models to more reliably meet QoE requirements. The loss function is unique, for example, with modifications to lower intent violation risk (**Fig. 2**). The loss function is also defined separately not only for the degree of violation but also for the period and number of violations, which are important for performance management in network operation.

By using both the service (application) and system (infrastructure) workloads (iii. in Fig. 1) as input to the AI, it is possible to calculate resources in accordance with the service usage status (including predictions) in addition to the system load status. This makes it possible to proactively control the service in accordance with the demand forecast of the service provider. This advantage is especially effective in cases such as a web-conference service, where it is not easy to scale up the host server (virtual machine instance) of a conference or change the host server while providing the service once the meeting started. By calculating the optimal resource in advance on the basis of the meeting-reservation information, the system can scale out in advance when the meeting starts.

2.2 Application of cloud-server resource-optimization technology

This technology can be used not only in the resource-design phase when a service is introduced but also for dynamic resource control in the service-operation phase. This technology can be used not only for SaaS (Software as a Service) but also for

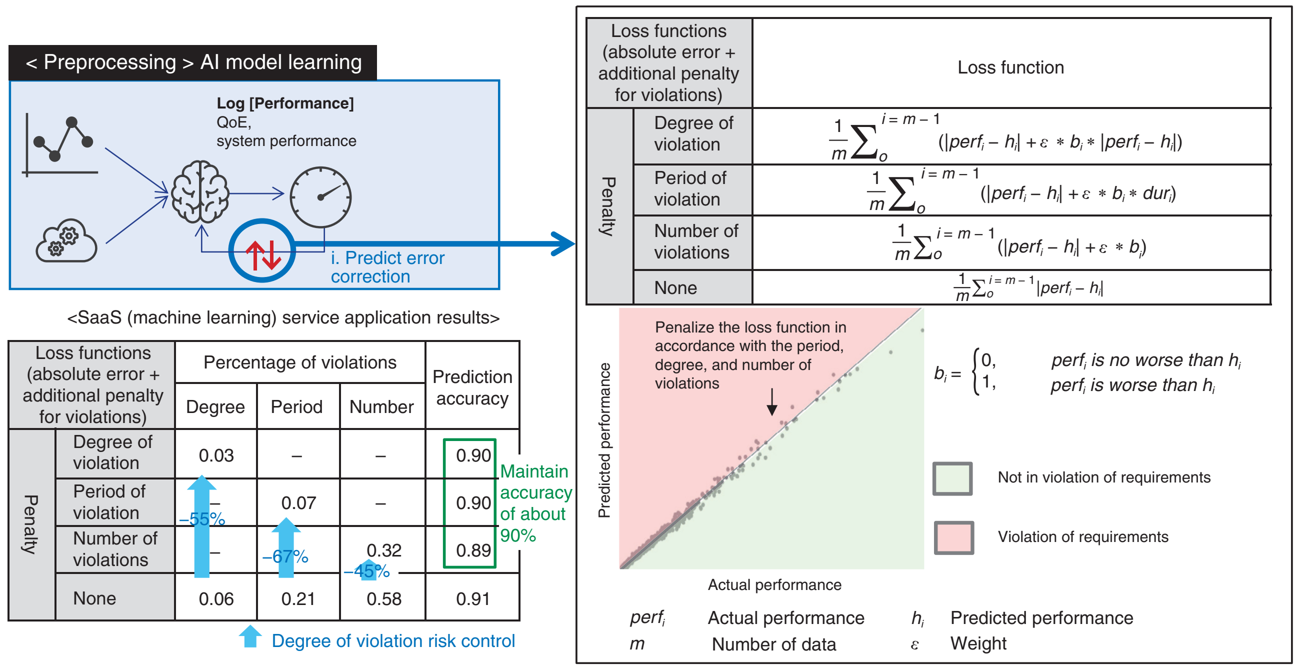


Fig. 2. Requirement-violation risk-control function.

IaaS (Infrastructure as a Service) infrastructure. In the future, we plan to expand the scope of application scenarios to virtual network services.

3. Application of cloud-server resource-optimization technology for web-conferencing services

For the application of this technology to web-conferencing services, we devised AI models and developed new functions on the basis of the issues and features of web-conferencing services.

3.1 Requirements with web-conferencing services and their solutions

Web-conferencing services have the following requirements due to the changes in social conditions described above.

(1) A web-conferencing service provider wants to optimize server resources and cost by allocating servers in accordance with server resource conditions and the amount of meetings.

(2) By clarifying that it has the technology for QoE maintenance, a web-conferencing service provider wants to improve the brand value for the service.

We can satisfy these requirements by applying this technology, as shown in **Fig. 3**.

With the conventional resource operation, it is common to prepare sufficient server resources in advance for the expected maximum service usage (number of users, etc.) on the basis of the experience of engineers and verifications. In this case, when there are only a few users, unnecessary resources are allocated, and when more users access than expected, QoE degradation occurs. It is also difficult to increase the number of central processing unit (CPU) cores while running a service such as web conferencing, which can lead to a fatal situation.

By combining this technology with the control functions of cloud services, it is possible to solve this problem by operating services with the minimum amount of resources when the number of users is small and scaling out in advance servers as the number of users increases.

3.2 Constructing a performance-prediction AI model for web conferencing

QoE indicators that are important for web-conferencing services are generally throughput and jitter, which are indicators of the cleanliness and stability of video and audio. Because these values fluctuate constantly, they are difficult to predict with high accuracy (**Fig. 4(a)**). Therefore, we focus on the fact that these

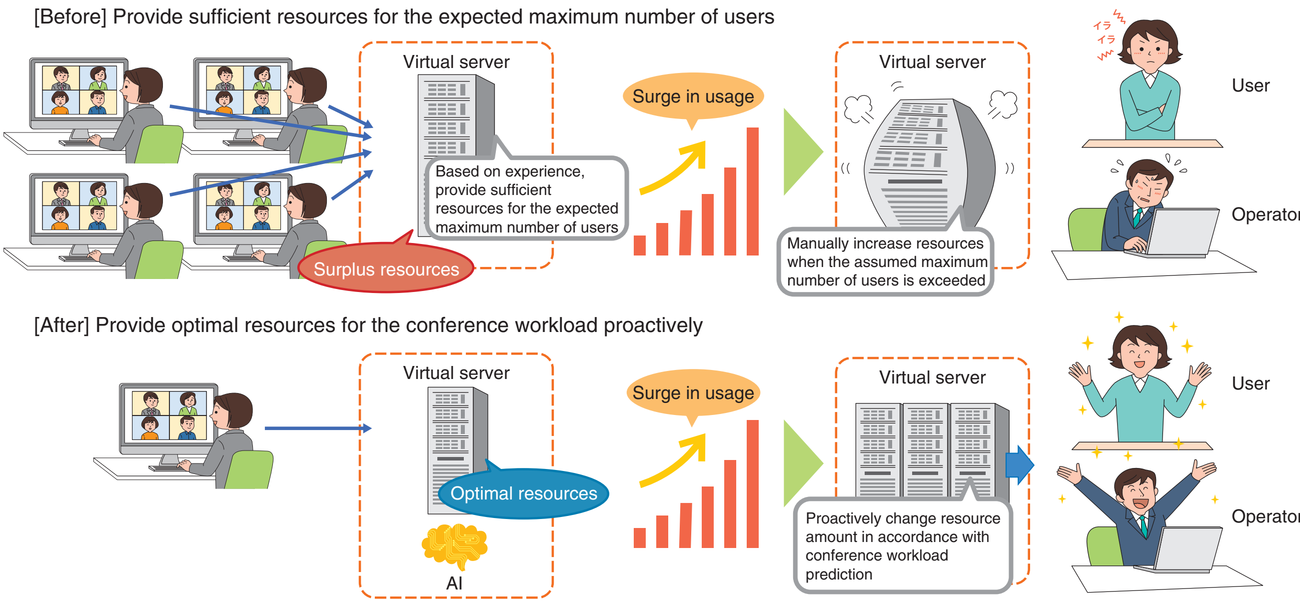


Fig. 3. Image of problem solving.

values do not deteriorate when the CPU usage is below a certain level, and we can derive the optimal resource amount to maintain QoE by using an AI model (**Fig. 4(b)**) that predicts the CPU usage from the workload and resource amount.

3.3 Peripheral function

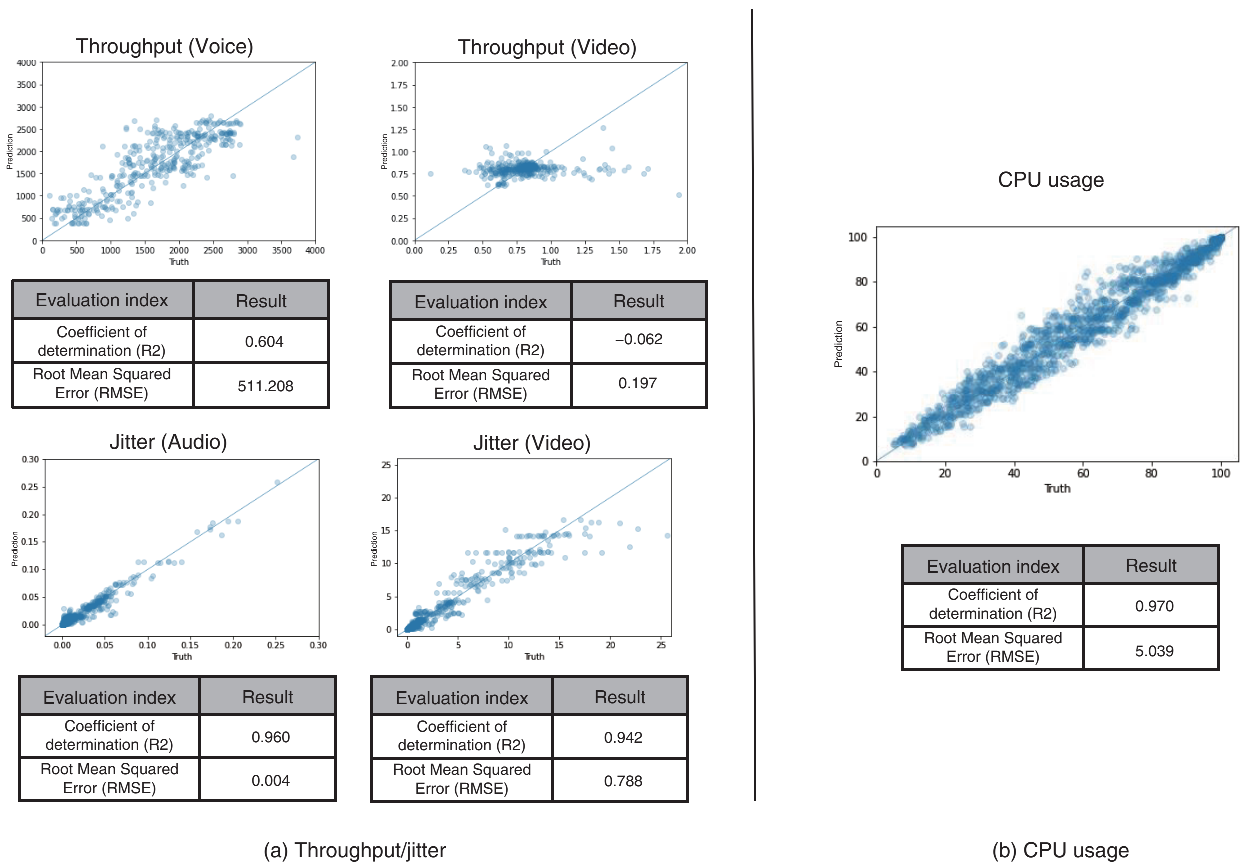
As mentioned above, to provide this technology to a web-conferencing service, it is necessary to have the function of determining the amount of resources required and the allocation of the conference among various server instances before the conference starts. Therefore, it is necessary to provide a function to supplement the workload information (the number of video and audio streams) from the meeting-reservation information before an actual meeting occurs (**Fig. 5(a)**). A function is also required to predict the QoE indicator of each meeting combination in accordance with the supplemented workload and determine whether it can be accommodated in the existing instances with predetermined instance type (number of CPU cores) and execute scale-out in advance (**Fig. 5(b)**). By operating this resource-calculation function on the basis of these usage conditions (predictions) periodically (from a few minutes to a few hours), proactive and automatic resource control can always be achieved during service operation, and the maximum effect can be obtained in both maintaining QoE and improving resource efficiency.

4. Optimal resource-calculation results and effects

On the basis of the actual usage trends of commercial web-conferencing services, we generated user workloads assuming that up to 100 users would use the service and verified the effectiveness of our technology. First, we used this technology to predict CPU usage for an instance type with four CPU cores and confirmed that the result was almost the same as the actual measurement when the same number of workloads were actually generated (**Fig. 6(a)**). On the basis of these predictions, the system can change the web-conferencing server to an instance with two CPU cores in advance when resources are predicted to be in surplus and change the web-conferencing server to an instance with eight CPU cores in advance when QoE is predicted to degrade. This enables service provision while maintaining CPU usage below the threshold and efficient use of resources (**Fig. 6(b)**).

From these results, we found that by using this technology to control resources in accordance with the expected amount of workload, we could reduce the amount of server resources by approximately 37% while maintaining QoE compared with when constantly operating excess resources with eight CPU cores.

By greatly improving the efficiency of server resources in this manner, it is possible to reduce



Throughput (Voice)

Evaluation index	Result
Coefficient of determination (R2)	0.604
Root Mean Squared Error (RMSE)	511.208

Throughput (Video)

Evaluation index	Result
Coefficient of determination (R2)	−0.062
Root Mean Squared Error (RMSE)	0.197

Jitter (Audio)

Evaluation index	Result
Coefficient of determination (R2)	0.960
Root Mean Squared Error (RMSE)	0.004

Jitter (Video)

Evaluation index	Result
Coefficient of determination (R2)	0.942
Root Mean Squared Error (RMSE)	0.788

CPU usage

Evaluation index	Result
Coefficient of determination (R2)	0.970
Root Mean Squared Error (RMSE)	5.039

Fig. 4. AI-model evaluation results.

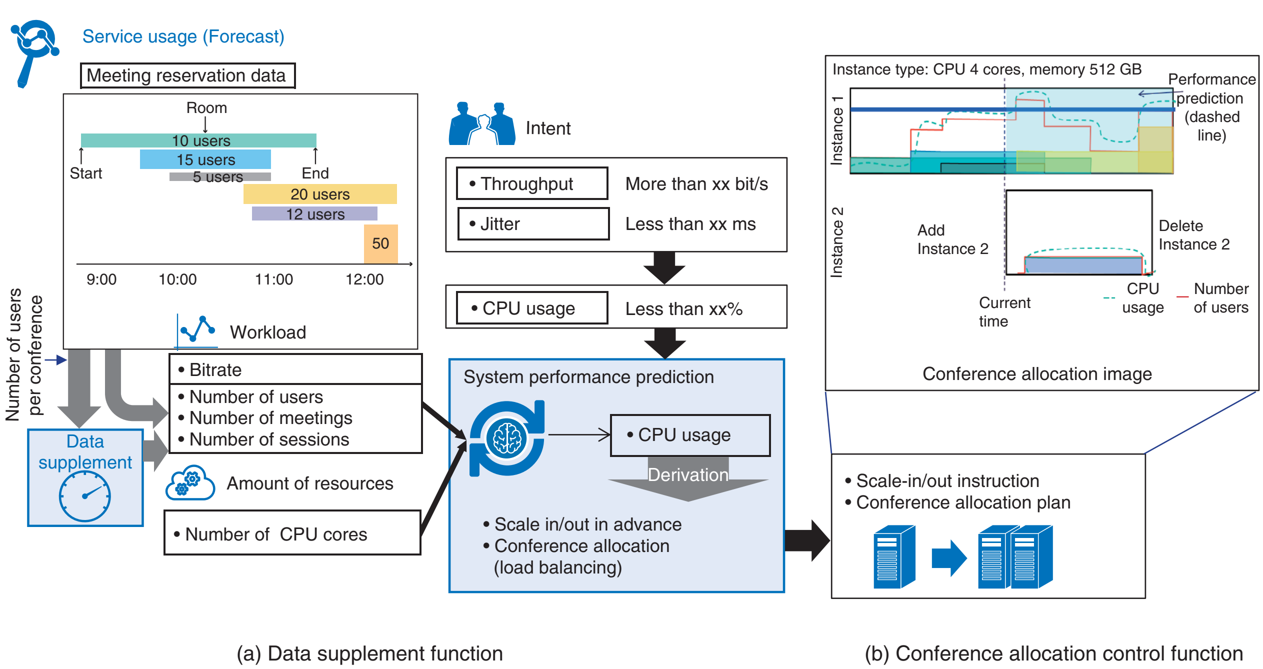
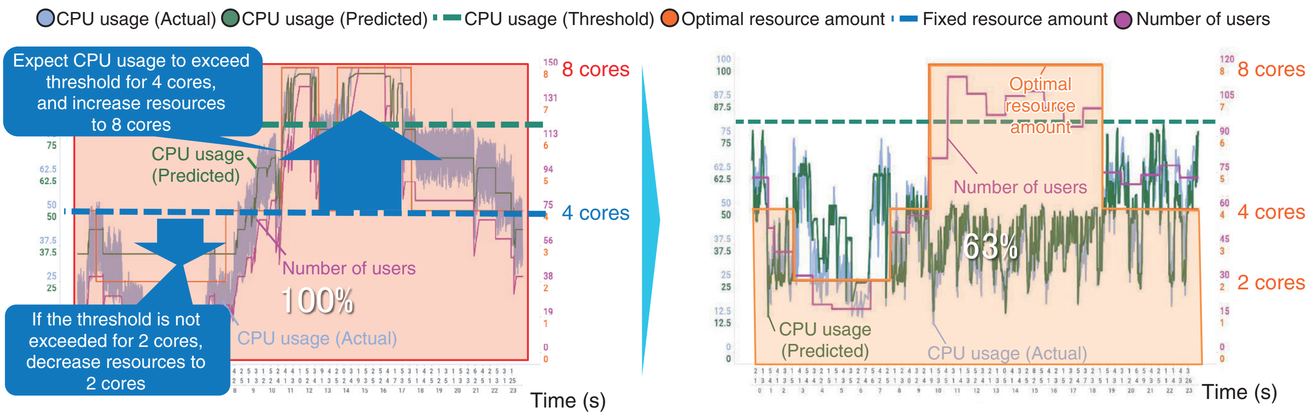


Fig. 5. Application to a web-conferencing service.



(a) CPU usage when fixed 4 cores are allocated to the VM

(b) CPU usage when cloud-server resource-optimization technology applied

Fig. 6. Optimal resource calculation results and effects by cloud-server resource-optimization technology.

energy consumption, and by adapting this technology to various use cases, it will be possible to further contribute to carbon dioxide reduction.

5. Conclusion

This article gave an overview of cloud-server resource-optimization technology and explained its effectiveness when applied to a web-conferencing service.

In the future, we will examine the technology's interface with the current cloud-resource management systems for commercial introduction to a web-conferencing service, improve its functions such as improving the speed of conference allocation, combine it with other control technologies that comprise Mintent, and consider expanding the application area to other use cases in view of the IOWN (Innovative Optical and Wireless Network) era. We will also promote the creation of new technologies to extract quantitative intent from more ambiguous intents of users and service providers and convert business-service-layer intent to resource-layer intent.

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Intent-based Application and Network Cooperative Control Technology for Video-streaming Services

Taichi Kawano and Masahiro Kobayashi

Abstract

We have been conducting research and development to implement the intent AI (artificial intelligence) mediator called Mintent, a technology concept that enables cooperation among application control, network control, and cloud server control on the basis of user requirements (intent) to increase user satisfaction. To implement Mintent, we propose a technology to enable cooperation between application control and network control by using intent as a common index for video-streaming services. This article provides an overview of this technology and discusses its effectiveness determined through simulation.

Keywords: intent, video streaming, cooperative control

1. Introduction

With the development of network virtualization technologies such as software-defined networking and network functions virtualization, networks can be dynamically and flexibly controlled. However, services over networks are becoming more diverse, and the requirements for networks are becoming more complex, such as ultra-high speed, high capacity, ultra-low latency, ultra-low power consumption, and low cost. For users to comfortably use services, it is necessary to understand the user's requirements (intent) for various services, extract resource requirements to satisfy the intent, and control the services on the basis of the established resource requirements. In user applications, the transmission rate of application data is traditionally controlled in consideration of network quality to improve user satisfaction with the service. The information obtained in the network is used to control the routes that satisfy the given network-quality requirements. However, since application and network controls are independent, they may not be fully effective in terms of user satisfaction and network-resource utilization efficiency. Therefore, an approach needs to be taken to increase user satisfaction by making application and network controls cooperate on the basis of intent.

We are engaged in research and development to implement the intent AI (artificial intelligence) mediator called Mintent, a technology concept for multilayer cooperative control of applications, networks, and cloud servers on the basis of intent. As an initial study for implementing Mintent, we focused on video-streaming services, which are widely used and use a large amount of network resources, and propose a technology to enable cooperation between application and network controls on the basis of intent. This article provides an overview of this technology and the results of simulations to evaluate its effectiveness.

2. Issues in application and network controls for video-streaming services

This section provides an overview of application and network control technologies for video-steaming services and the issues that arise when these controls

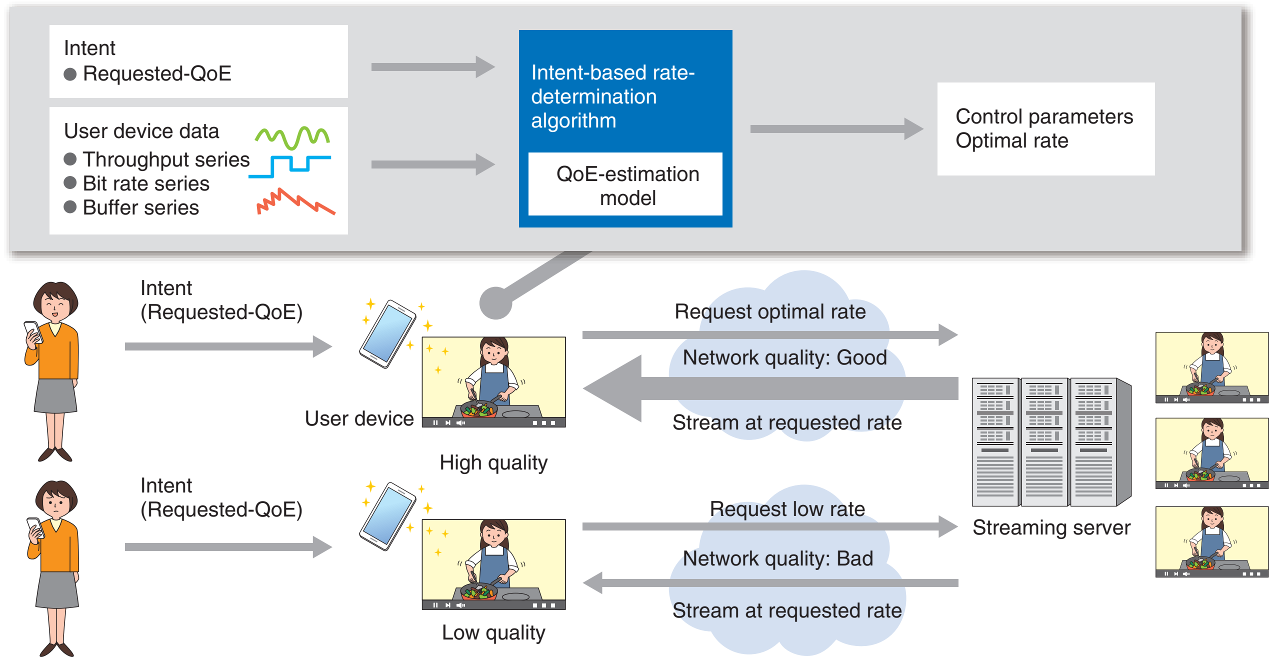

Fig. 1. Intent-based rate control technology.

operate independently.

2.1 Rate control technology for streaming video in applications

Adaptive bitrate (ABR) is one of the application controls at the user device that controls the rate of video streaming. In ABR, multiple-bitrate videos of different quality are pre-populated on the video-streaming server, and the application controls the rate request by switching the bitrate of the video to the streaming server in accordance with network quality such as throughput. This enables the application to increase, for example, user satisfaction by reducing playback stops. As shown in **Fig. 1**, we also developed a technology for predicting future quality of experience (QoE) using our QoE-estimation technology [1] on the basis of throughput measured at the user device and application information (video/audio bitrate time-series information, etc.), and controlling rates to satisfy the QoE set by the user (requested-QoE) in the application [2]. This technology ensures higher user satisfaction than conventional technologies. However, when network quality deteriorates due to congestion, application control alone cannot satisfy the requested-QoE because it can only lower the bitrate and reduce video quality. Thus, application control alone cannot maintain user satisfaction when network quality deteriorates.

2.2 Network control technology

Current network control technology estimates quality of service (QoS) by using traffic forecasts for each traffic flow on the basis of communication logs observed with network devices and controls routes so that the resource-utilization efficiency is high while maintaining actual QoS. Traffic flow is communication traffic with the same source Internet protocol (IP) address, destination IP address, port number, and protocol number. We developed a technology that groups flows with similar characteristics into macro flows by using non-negative tensor factorization then accurately predicts future traffic for each macro flow by using seasonal autoregressive integrated moving average (SARIMA) [3, 4]. Network control using accurate traffic prediction improves the efficiency of network-resource utilization. Therefore, the network control technology controls routes on the basis of the actual QoS estimated from communication logs, but it is difficult to correctly estimate the QoS required to satisfy a user's desired QoE from communication logs alone. The QoS required to satisfy the user's desired QoE is called the requested-QoS. Therefore, if there is a large discrepancy between the requested-QoS and the actual QoS, the QoE may decrease due

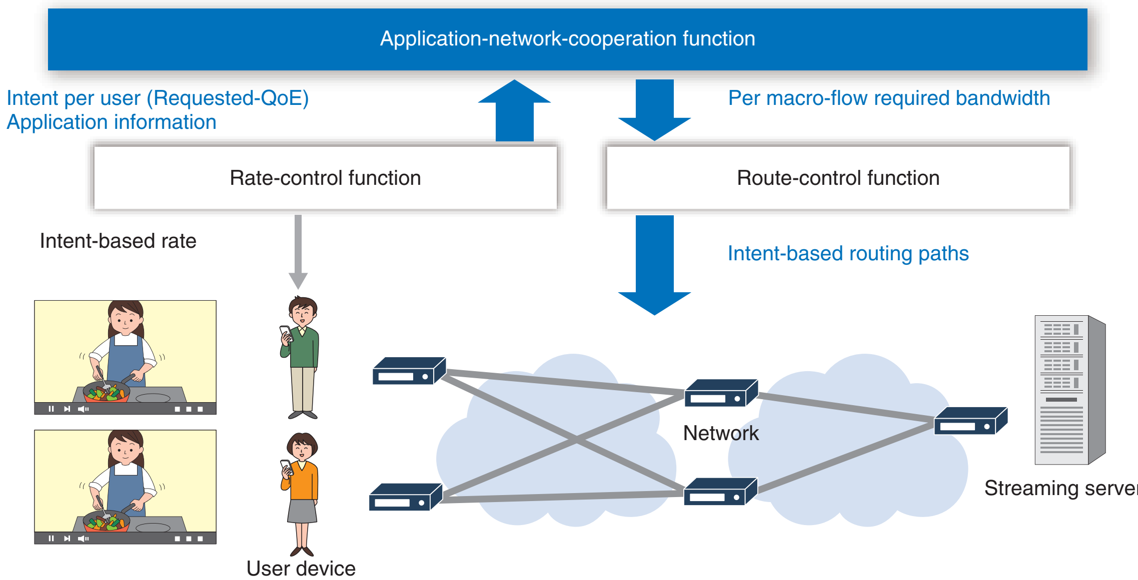

Fig. 2. Intent-based application and network cooperation function.

to insufficient quality, or network-resource-utilization efficiency may decrease due to excessive quality. In addition, if the application-rate control technology described above and network control technology operate independently in video delivery, the QoE may not be satisfied. When network quality degrades due to congestion, the application-rate control technology delivers low-quality video to resolve the congestion. In this case, the network control technology determines that congestion is naturally resolved and does not change the route. As a result, low-quality video continues to be delivered and the QoE decreases. Thus, the network control technology alone cannot satisfy the requested-QoE because requirements of the requested-QoS cannot be accurately estimated and the effect of the application-rate control technology cannot be taken into account.

3. Intent-based application and network cooperative control technology

To solve the problem of application and network controls operating independently in video-streaming services, our proposed technology enables cooperation between these controls by using the requested-QoE, one of the intents, as a common index for application and network controls. This section describes the overall structure and details of the main functions of the proposed technology.

3.1 Overall structure

The overall structure of the proposed technology is shown in **Fig. 2**. The technology consists of a rate-control function and a route-control function using our technology described above, and an application-network-cooperation function that enables cooperation between these functions. In the rate-control function, the user sets the requested-QoE for each user device, and the user device notifies the application-network-cooperation function of the requested-QoE and the representation information (a list of video and audio bitrates, video resolution, and frame rate that can be selected by the rate control). The application-network-cooperation function predicts the required bandwidth as future QoS requirements for each macro flow that bundles flows of users with the same requested-QoE on the basis of the requested-QoE for each user notified by all user devices. Network control satisfies the requested-QoE by executing optimal routing for each macro flow to satisfy the predicted required bandwidth. Therefore, application control and network control enable intent-based cooperative control by using the requested-QoE as a common index.

3.2 Application-network-cooperation function

As shown in **Fig. 3**, the application-network-cooperation function consists of a user-QoS-extraction function, active-user-prediction function, and

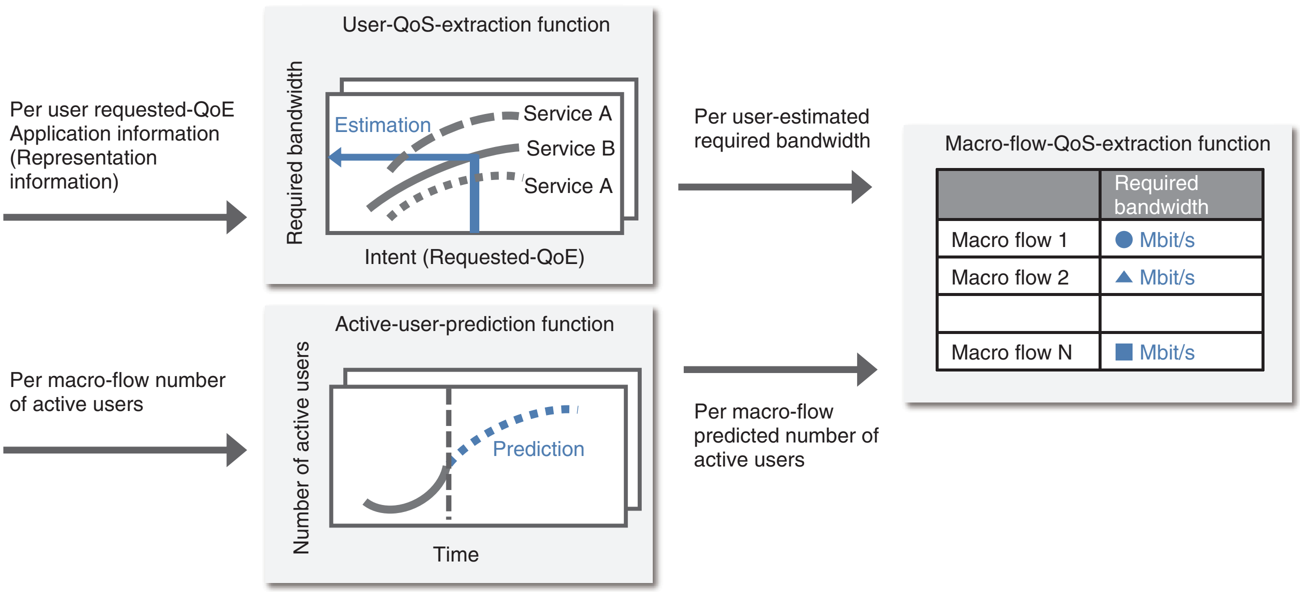

Fig. 3. Application and network cooperation function.

macro-flow-QoS-extraction function. The user-QoS-extraction function calculates the network QoS requirements on the basis of the throughput required from the requested-QoE and application information reported through user devices. The relationship between the requested-QoE and throughput required to achieve it depends on the representation information designed for each video-streaming service. Therefore, the relationship between the requested-QoE and required throughput is modeled in consideration of the representation information, and the model is used to estimate the required throughput from the requested-QoE and representation information. The active-user-prediction function predicts the future number of active users for each macro flow. It derives this number using SARIMA, a time-series prediction method, from the time-series data of the number of active users for each macro flow notified from user devices to the application-network-cooperation function. The macro-flow-QoS-extraction function calculates the required bandwidth for each macro flow on the basis of the estimated required throughput per user and the predicted number of active users per macro flow. These functions enable network routing to be controlled on the basis of network requirements considering the requested-QoE.

4. Effectiveness evaluation through simulation

To evaluate the effectiveness of the proposed technology, we compared it with conventional technologies in which application control and network control operate independently and evaluated its effectiveness in terms of user satisfaction and network-resource-utilization efficiency through simulations. This section provides an overview of the simulations and the results.

4.1 Simulation overview

The simulation scenario assumes routing control when one path is congested in a network structure where network bottlenecks are duplicated, such as a point of interface between a carrier network and the Internet. Simulations were conducted using ns-3, an open source network simulator. **Figure 4** shows the simulation environment. The network structure consists of three routers fully mesh-connected in a triangular structure. There is one video server connected to one router and 90 user terminals connected to each of the remaining two routers. There are also two routes between the video server and user devices. User devices can set their requested-QoE taking values from 1.0 to 5.0 to 4.5, 4.0, or 3.5, and 30 user devices with each requested-QoE were connected to each router. Congestion was generated by flowing background traffic to the video server from a user

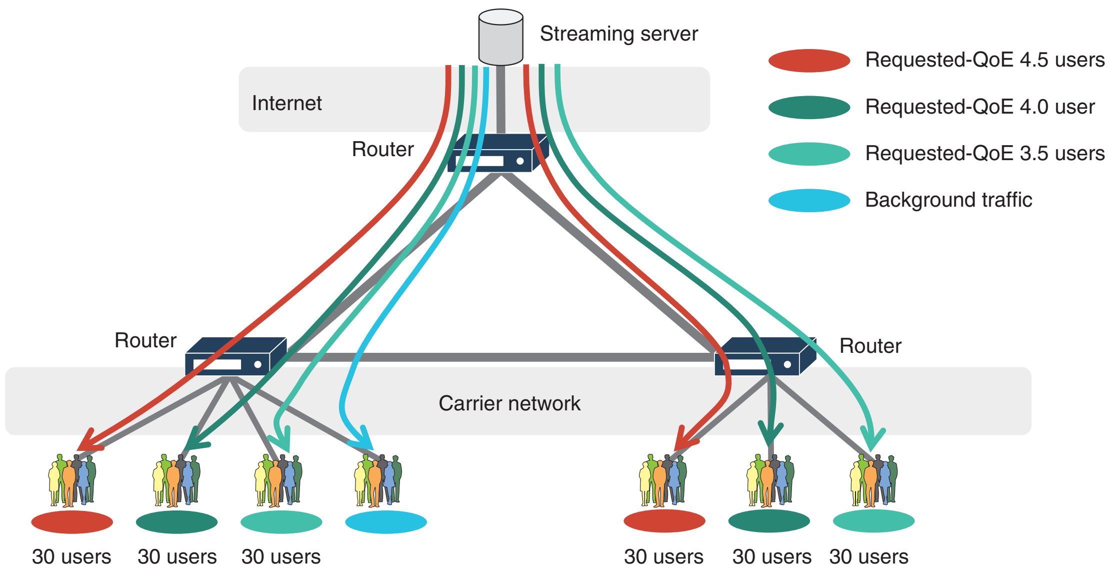

Fig. 4. Simulation environment.

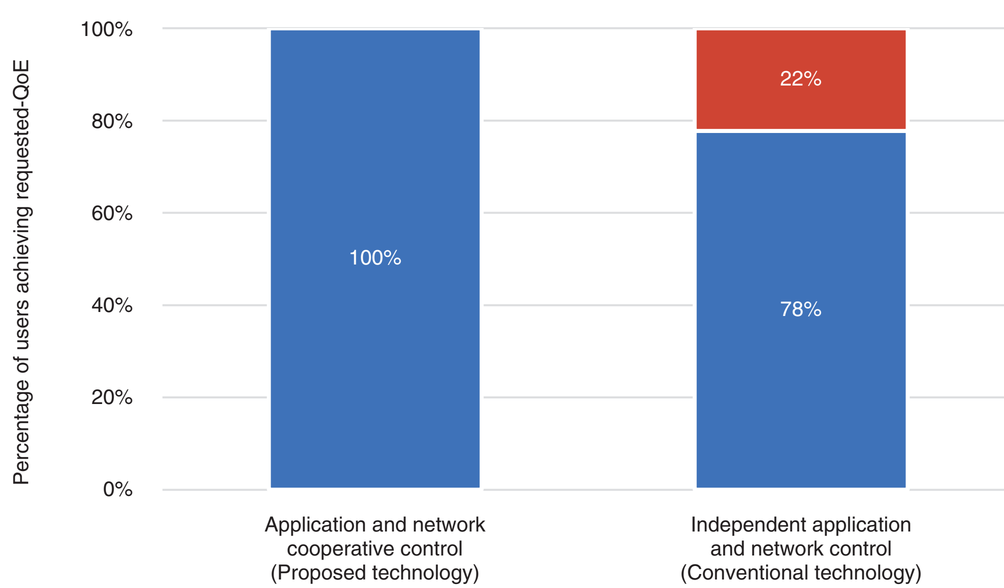

Fig. 5. Results of effectiveness evaluation through simulation.

device. The effectiveness of the proposed and conventional technologies was evaluated by comparing the results of routing control during congestion in terms of achieving the requested-QoE and network-resource-utilization efficiency.

4.2 Effectiveness verification through simulation

Figure 5 shows the percentage of users who achieved the requested-QoE after routing with the proposed and conventional technologies during congestion. About 22% of all users did not achieve the requested-QoE with the conventional technology. When limited to users with a requested-QoE of 4.5, about two-thirds did not meet the requested-QoE. This is because the network control was unable to correctly estimate the required bandwidth because it derived this bandwidth using only the information in the network and could not take into account the requested-QoE or application control. The proposed technology satisfied the requested-QoE for all users. This is because this technology estimates the required bandwidth to satisfy the QoE with higher accuracy than the conventional technology by using the requested-QoE obtained from the user-device application. Thus, the proposed technology can achieve higher user satisfaction than the conventional technology. In addition, if the percentage of users who achieved the requested-QoE with the conventional technology by increasing the link bandwidth is equal to that with the proposed technology, a 16% increase in link bandwidth is required. This indicates that the proposed technology is superior to the conventional technology in terms of network-resource-utilization efficiency.

5. Conclusion

Toward the implementation of Mintent, we proposed an intent-based application and network control cooperation technology for video-streaming services. We have shown that the proposed technology achieves higher user satisfaction and network-resource-utilization efficiency than the conventional technology in which application control and network control operate independently. In the future, we will develop a technology that can be applied universally to various services. In addition to application control and network control, we also aim to develop a multi-layer cooperative technology that includes cloud-server control.

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Wireless-link-quality Prediction and Device-position Estimation Based on Relationship between Wireless-communication-link and Physical-space Information

Riichi Kudo, Hisashi Nagata, Kahoko Takahashi, and Tomoaki Ogawa

Abstract

Various wireless terminals are being connected to a network via wireless communication accesses, and the number of wireless terminals and their traffic are steadily increasing. The information from a huge number of connected devices is expected to be a foundation of new services. The Cabinet Office of Japan proposed Society 5.0, where people, things, and systems are all connected in cyberspace. The optimal results obtained through artificial intelligence will bring new value to industry and society. Society 5.0 is achieved by the convergence between cyberspace and physical space. Innovative Optical and Wireless Network (IOWN) will accelerate the obtaining of physical-space information from a number of various sensors. This article introduces two technologies that use the relationship between physical-space information and wireless-communication-link information for new services in Society 5.0; 1) wireless-link-quality prediction using camera images and 2) device-position estimation using Wi-Fi feedback signals.

Keywords: link quality prediction, position estimation, machine learning, Wi-Fi

1. Background and overview

Advanced wireless-communication systems, such as Wi-Fi, Long-Term Evolution (LTE), and the 5th-generation mobile communication system (5G), enable a wide variety of devices to connect to a network; thus, the number of connected devices and their traffic are exploding. The large number of connected devices will be a foundation of Society 5.0 [1], where a huge amount of physical-space information is accumulated in cyberspace. Physical-space information will be analyzed through artificial intelligence (AI), and the process is expected to bring new value to industry and society in ways not previously possible. Innovative Optical and Wireless Network (IOWN) [2] will accelerate the creation of big data of physical-space information and make them accessible from everywhere.

The advancement of AI technologies will also accelerate the use of physical-space information in the IOWN/6G era [3]. The accuracy of vision-based recognition using deep learning has been improving yearly [4], and the autonomous operation of robots and vehicles have also significantly advanced [5]. By using advanced AI technologies, physical-space information is expected to provide new value for wireless-communication systems.

Wireless communications is also being enhanced

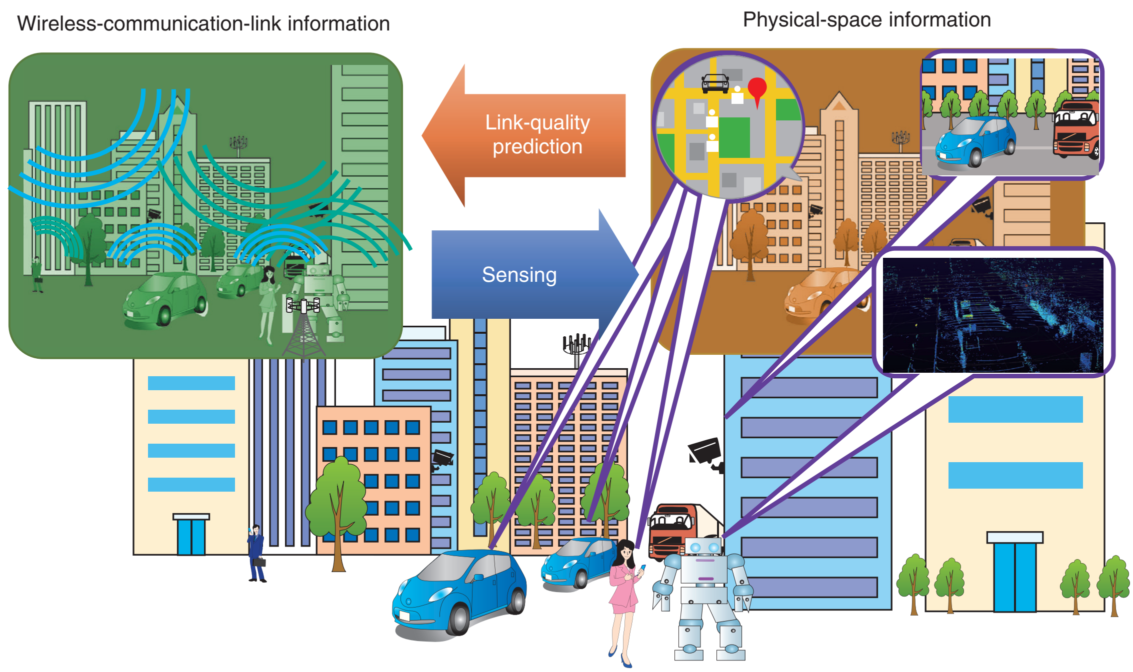

Fig. 1. Image of Society 5.0 and the relationship between wireless-communication-link and physical-space information.

due to the demand of greater wireless link capacities, latencies, and reliabilities [6]. Wireless-communication systems, such as LTE, 5G, and Wi-Fi [7, 8], support a high-speed data rate and an increasing number of user terminals. The radio frequency of such systems is expanding to super high frequency (SHF) (3–30 GHz) and extremely high frequency (EHF) (30 GHz–3 THz) bands to obtain larger capacity. Since the link quality in the higher radio frequency is more subject to microwave propagation such as object shielding [7], the relationship between physical-space and wireless-communication-link information is becoming stronger.

NTT Network Innovation Laboratories is studying the relationship between physical-space and wireless-communication-link information and establishing the core technologies for new services in Society 5.0. In this article, wireless-link-quality prediction and device-position-estimation technologies are introduced to show the effectiveness of using the relationship between physical-space and wireless-communication-link information.

2. Physical-space and wireless-communication-link information

Figure 1 shows the relationship between physical-space and wireless-communication-link information. In Society 5.0, a huge number of devices will connect to a network using wireless-communication links, and cameras/sensors will be located everywhere and be equipped with mobility devices. Cameras/sensors obtain images of the physical space, and the information is updated via wireless or wired connections. The position and status information of wireless devices are also expected to be collected as physical-space information. Wireless signals will propagate through almost all the physical space, and the channel-state information of the wireless links and their link qualities are the result of the propagation through the physical space. Therefore, there are solid relationships between wireless-communication-link and physical-space information.

NTT Network Innovation Laboratories has focused on the relationship between wireless-communication-link and physical-space information and developed wireless-link-quality-prediction and device-position-estimation technologies. Wireless-link-quality-prediction technology uses camera images and provides future throughput variation by using the detected movement of the surrounding objects. Device-position-estimation technology provides wireless-device position by monitoring the pilot signals between the wireless device and a single base

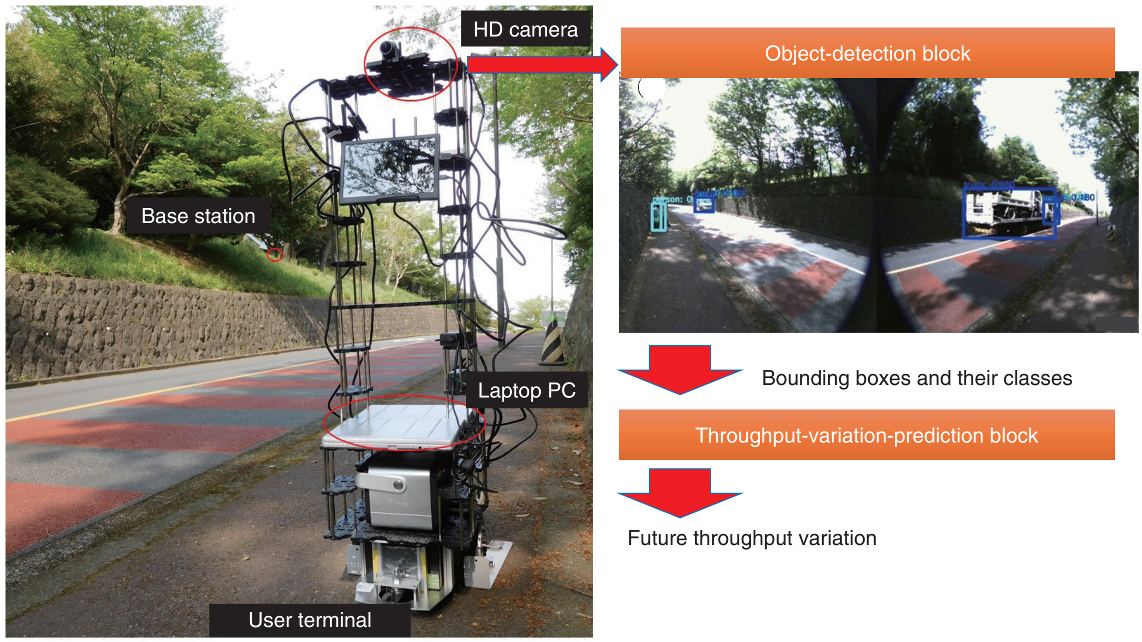

Fig. 2. The wireless-link-quality-prediction testbed in the experimental environment. The camera images are used as the input of the object-detection algorithms, and the throughput-variation-prediction block provides future throughput variation by using the detected bounding boxes and their classes.

station. Both technologies are based on supervised learning. We evaluated the performances of these technologies through experiments in actual outdoor and indoor environments, respectively.

3. Wireless-link-quality prediction using camera images

Wireless-link quality is strongly affected by the objects blocking the line of sight between a base station and user terminals as the radio frequency becomes high such as over the SHF band (> 3 GHz). Wireless-link-quality prediction for the millimeter wave (60 GHz) was proposed [9], and the authors used a depth camera to detect signal blocking. We developed prediction technologies for the SHF band by using high-definition (HD) cameras and confirmed that the long-term prediction corresponding to second-order future was achieved using physical-space information [10]. It is expected that long-term prediction will provide a sufficient lead time to counter the negative change in link quality. Our wireless-link-quality-prediction technology provides future throughput variation between a fixed base station and user terminal by detecting the movements of the objects surrounding the user terminal. We conducted outdoor experiments to confirm the effectiveness of this technology.

Figure 2 shows our developed user terminal testbed and the flow of wireless-link-quality prediction using camera images. The testbed communicates with the base station in the 5.6-GHz Wi-Fi channel. Cars, trucks, buses, and pedestrians passed through this site, and the testbed monitored the surrounding objects using two HD cameras (1920 × 1080 pixel). In wireless-link-quality prediction, the object-detection algorithm of M2Det [11] is used to obtain the bounding boxes of the moving objects from the camera images. It was confirmed that better detection algorithms provide more accurate wireless-link-quality prediction [10]. Object-detection algorithms output the bounding boxes and their classes. By using the bounding boxes, the throughput variation at one second in the future was predicted. The throughput-variation-prediction block uses random forest regression. Throughput variation is defined as the ratio of the future throughput to the median of the throughputs in the past 30 seconds. Therefore, throughput variation becomes 1.0 when there is no such variation.

The measured dataset totaled 3490 seconds of data, containing 288 cars, 20 buses/trucks, and 36

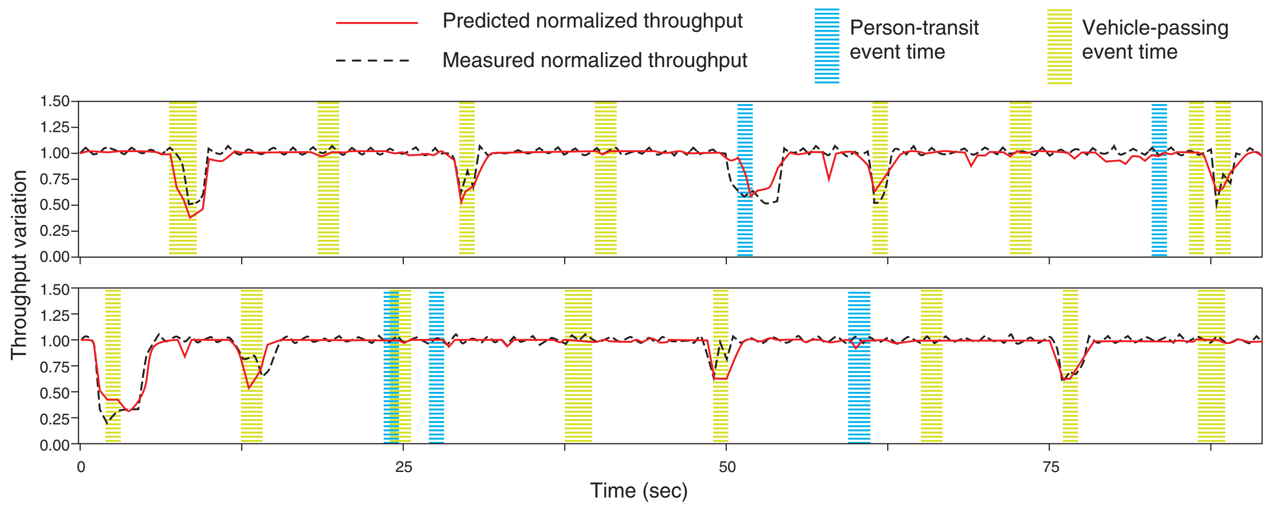

Fig. 3. Predicted and measured throughput variation for person-transit and vehicle-passing events.

people-transit events. The dataset was divided into 10 parts, and 9 were used for training to generate the throughput-prediction model. Wireless-link-quality prediction was conducted using the remaining dataset. The estimated and measured throughput variations are shown in **Fig. 3**. The vehicle-passing events and person-transit events denote the time when the vehicles or persons are passing around the user terminal. We can see that throughput degradation was predicted using camera images. **Figure 4** shows the 90th percentile of the absolute errors of three prediction algorithms against the lead time. We compared the prediction performance of the wireless-link-quality-prediction technology using bounding boxes, past throughputs, and both past throughputs and bounding boxes. We found that the prediction performance using only the bounding boxes was the best when the lead time was greater than 1 second. These results indicate that the contribution of past throughputs becomes negligible for long-term prediction, and physical-space information is valid when the lead time is greater than 1 second.

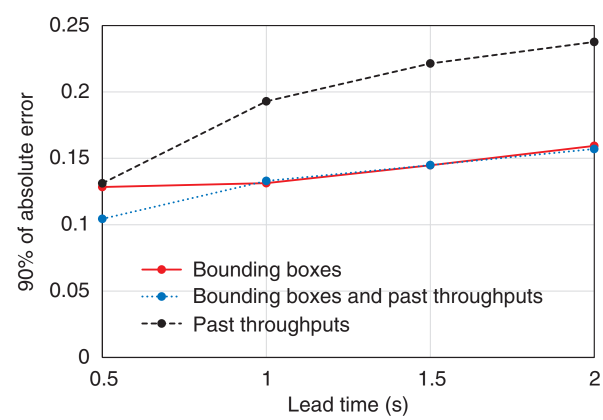

Fig. 4. 90% of the absolute error of throughput variation against lead time.

4. Device-position estimation

The relationship between wireless-communication-link and physical-space information can be used to find the physical-space information using the wireless-communication system information. Wireless sensing technologies have gained much attention [12] for the 6G era. Although the Global Positioning System (GPS) is the most well-known position estimation technology, it works only for outdoor environments and without tall buildings around the device. To obtain accurate position information in an indoor environment, wireless-communication systems are expected to play an important role [13]. We developed our device-position-estimation technology, which uses angle of arrival (AoA) estimation and deep learning using Wi-Fi feedback packets with a single access point [14].

This technology uses a monitoring terminal that detects the feedback signal in the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standards, as shown in **Fig. 5**. The monitoring terminal obtains the information of the channel state information

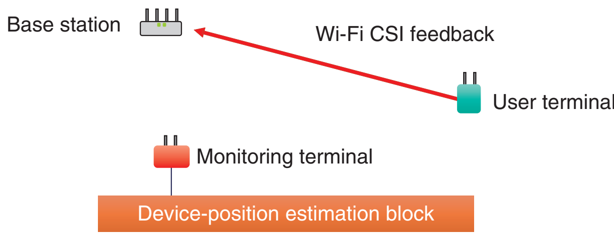

Fig. 5. Device-position estimation using Wi-Fi CSI feedback.

(CSI) between a base station and user terminal and the received signal strength indicator (RSSI) of the feedback signal, which corresponds to the link between the monitoring terminal and user terminal. The monitoring terminal calculates the correlation matrix **R** then outputs **R** as well as the signal-to-noise ratio (SNR) and RSSI into the position-estimation block. Since the elements of **R** contain the information of the phase differences in the arrival waves, the AoA estimation uses **R** [15]. The position of the user terminal is predicted using the input from the monitoring terminal and a deep neural network (DNN), which consists of gated recurrent units and three fully connected layers.

To confirm the device-position-estimation accuracy, we conducted indoor experiments using mobility robots. **Figure 6** shows the developed user terminal and the indoor experimental environment. The user terminal ran in a figure eight, as shown with the black lines. The base station and monitoring terminal were at the locations shown in Fig. 6. The base station and user terminal use the 20-MHz channel in 5.6 GHz of IEEE 802.11ac. The number of transmit and receive antennas were 4 and 2, respectively. The CSI feedback signal of the user terminal was obtained every 100 ms, and 80 samples of the feedback signals were used as input of the DNN-based position estimation. We trained the position-estimation model using a training dataset containing 13.9 hours of the position and CSI feedback signal and evaluated the position-estimation error using a test dataset containing 1.0 hour of the CSI feedback signals.

The cumulative distribution function (CDF) of the position-estimation errors are shown in **Fig. 7**. The position-estimation errors of the DNN with all the input features from the monitoring terminal, i.e., **R**, SNR, and RSSI; DNN with **R**; DNN with SNR and RSSI; and random forest regression with all these input features were compared. The DNN with all the features performed best and the median and 0.9 outage of the prediction errors were only 5.1 and 13.1 cm, respectively. The medians of the DNN with **R** and DNN with SNR and RSSI were 8.2 and 17.1 cm, respectively. The **R**, which is a parameter for AoA estimation, highly contributed to the accurate position estimation. We also found that the median estimation errors of the random forest regression with all features was 44.9 cm, which was 8.8 times that of the DNN with all features.

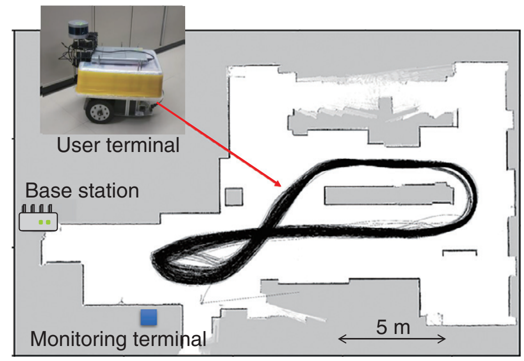

Fig. 6. The user terminal and movement in an indoor experiment.

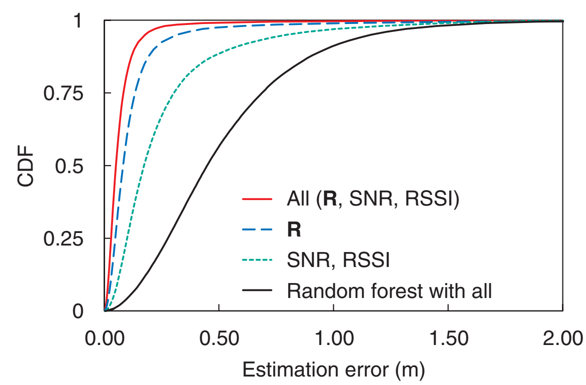

Fig. 7. CDFs of position-estimation errors.

5. Conclusion and future perspective

We presented wireless-link-quality-prediction and device-position-estimation technologies and discussed their effectiveness using a dataset measured in actual outdoor and indoor environments. Wireless-link-quality prediction uses the bounding box information detected using camera images and predicts precise long-term throughput variation. Device-position-estimation technology estimates the user device position on the basis of the correlation matrix, SNR, and RSSI obtained from the received Wi-Fi feedback packets. Both technologies are based on the relationship between wireless-communication-link and physical-space information. We believe that this relationship is one of the keys to creating new value in Society 5.0 and will continue to develop the core technologies of link-quality prediction and position estimation.

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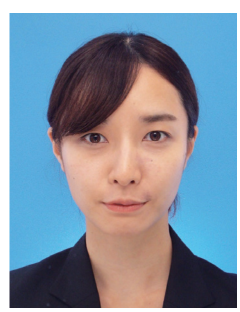

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Development of Compact/Power-saving Optical Open Line System

Sachio Suda, Kenichi Aoyagi, Yasutaka Sugano, Hiroshi Shibata, Takeshi Seki, Kenta Hirose, and Daisaku Shimazaki

Abstract

NTT Network Innovation Center has developed a compact/power-saving optical open line system that can provide optical transmission of 100 Gbit/s per wavelength in an economical, space-saving, and power-saving manner. The goal with this system is to achieve large-capacity transmission up to edge buildings in the metro network to deal with the rapid increase in traffic accompanying the introduction of the 5th-generation mobile back haul. This article presents an overview of this system and its features.

Keywords: optical transport, DWDM, compact/power-saving

1. Capacity enhancement in core and metro networks

To deal with increasing volumes of traffic driven by the expanded use of smartphones, cloud services, video delivery services, etc., the optical transport network of the NTT Group has up to now been using a wavelength division multiplexing (WDM) system at 100 Gbit/s per wavelength for the core network. At the same time, traffic across the entire network up to edge buildings located in rural areas is predicted to increase with the introduction of the 5th-generation (5G) mobile back haul (MBH), so even metro networks will require greater capacities. However, issues with the current 100G-WDM system in terms of installation space and power consumption have hindered its implementation, so we developed a compact/power-saving optical open line system (OOLS) that greatly reduces the amount of space needed for installation and the amount of power consumed. This system will enable system configurations that optimize installation space and power consumption in accordance with traffic volumes driven by diverse service demands.

2. Technical features of the compact/power-saving OOLS

The system configuration of the compact/power-saving OOLS is shown in **Fig. 1**. This is an optical transport system based on digital coherent technology and dense WDM, which transmits multiple wavelength signals in a single fiber. It achieves a maximum transmission capacity of 8 Tbit/s by multiplexing 100-Gbit/s-per-wavelength signals over a maximum of 80 wavelengths. The system includes an optical cross-connect function that enables add, drop, or through settings for any optical path in a maximum of eight directions. It can also connect with an existing 100G-WDM system without converting optical signals to electrical signals, which can make effective use of existing facilities. For this compact/power-saving OOLS, we developed technology for a system configuration conducive to advanced optical devices and compact/power-saving characteristics with the above specifications and succeeded in achieving a compact and power-saving system. The main features of this compact/power-saving OOLS are (1) compact/power-saving transponders, (2) alien-wavelength connection, and (3) compact/power-saving system

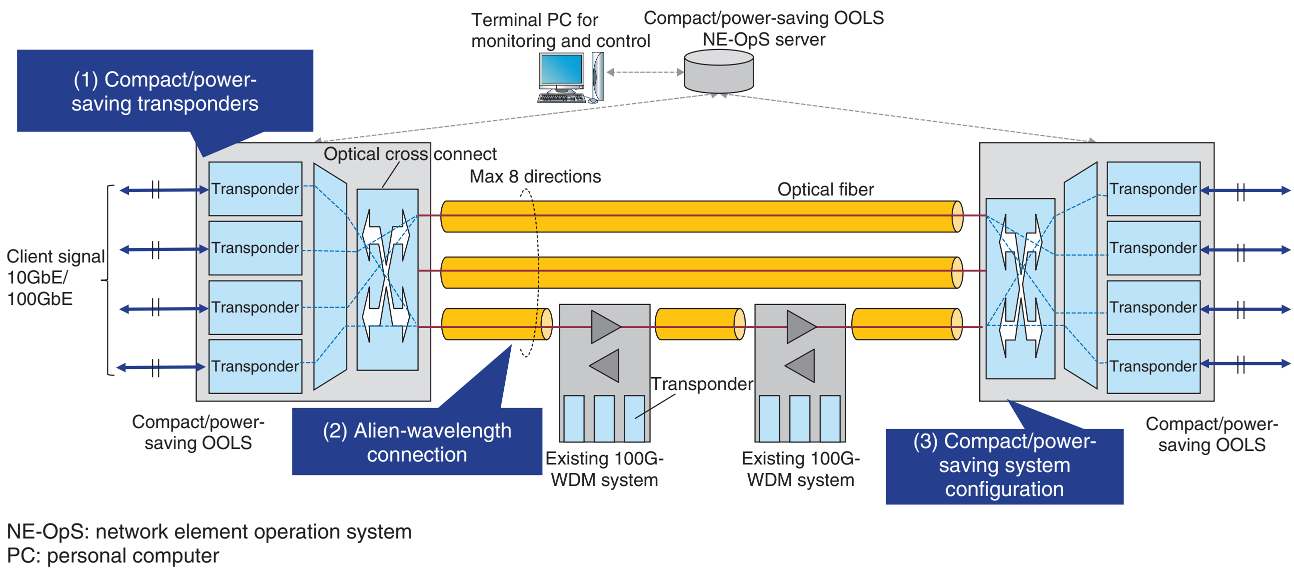

Fig. 1. Overview of compact/power-saving OOLS.

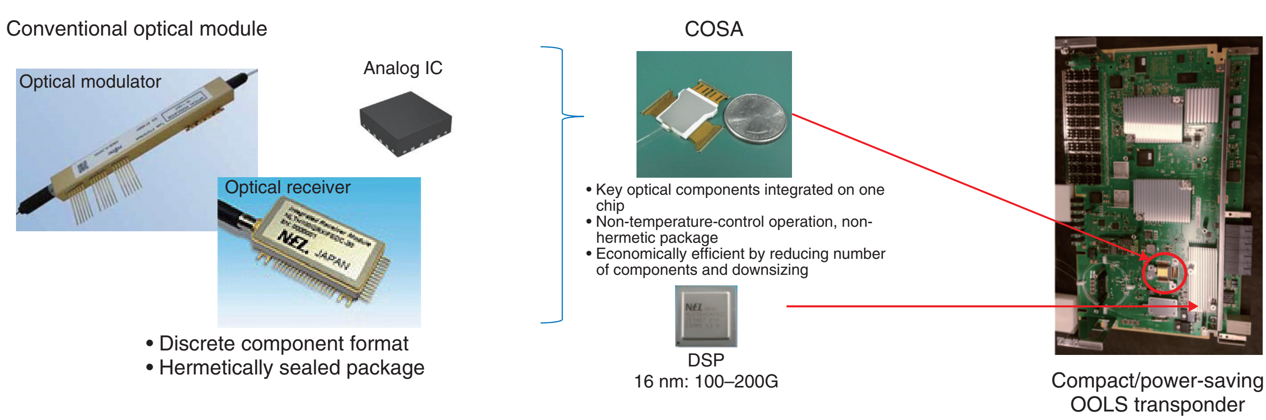

Fig. 2. Compact/power-saving transponder.

configuration.

2.1 Compact/power-saving transponders

This compact/power-saving OOLS consists of multiple transponders, each of which converts a client signal used for connecting this system to a service node to a wavelength signal or vice versa. Each transponder features a compact and power-saving configuration by using advanced devices such as a coherent optical subassembly (COSA) [1], low-power digital signal processor (DSP), and compact optical module. A COSA is a silicon photonics device developed by NTT Device Innovation Center integrating an optical modulator, optical transceiver, and analog integrated circuit (IC) on one chip. Combining the COSA with a DSP developed by NTT Network Innovation Laboratories and maximizing transmission characteristics has enabled L-band transmission and the mounting of these devices on a compact/power-saving OOLS transponder (**Fig. 2**). In addition, the 100GbE optical module used to connect this OOLS to a service node adopts a quad small form-factor pluggable 28 (QSFP28) downsized from the conventional centum gigabit form-factor pluggable, resulting in a compact form factor approximately one-fourth the current size.

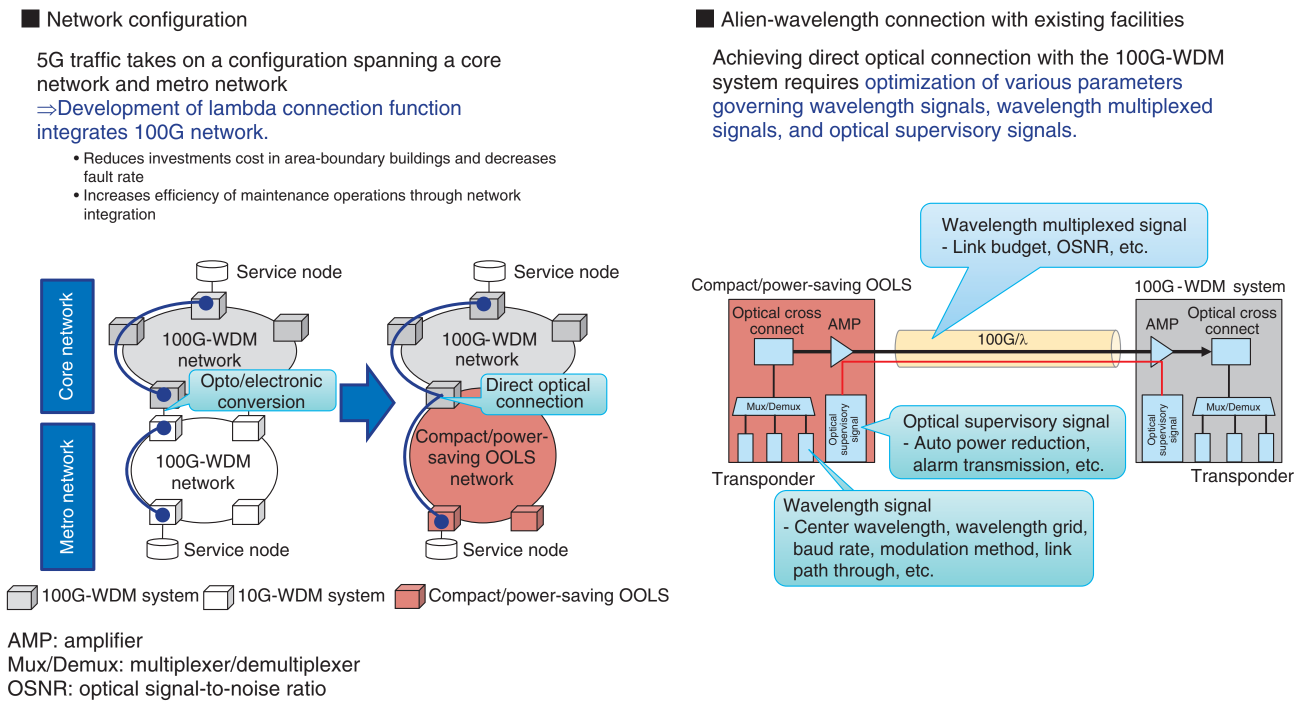

Fig. 3. Network configuration and overview of alien-wavelength connection function.

2.2 Alien-wavelength connection

The 5G MBH takes on a configuration spanning a core network constructed using an existing 100G-WDM system and a metro network scheduled to be constructed using the compact/power-saving OOLS. For constructing optical paths across different networks in the conventional transmission system, it was necessary to execute a one-time electric-optic conversion using a transponder, which was a problem in terms of facility costs. We therefore developed an alien-wavelength connection function in the compact/power-saving OOLS to enable direct connection of optical signals without electric-optic conversion with the existing 100G-WDM system. This scheme achieves a sustainable system through effective use of the existing 100G-WDM system while reducing investment costs and improving maintenance and operations with network integration. A network configuration using the alien-wavelength connection with existing facilities and a function overview are shown in **Fig. 3**.

A WDM system uses wavelength signals (output from transponders), wavelength multiplexed signals (that multiplex wavelength signals for long-distance transmission), and optical supervisory signals (used for setting and controlling equipment, transmitting alarms, etc.). In the compact/power-saving OOLS, various parameters for those wavelength signals, wavelength multiplexed signals, and optical supervisory signals are optimized to achieve the alien-wavelength connection with the existing 100G-WDM system.

2.3 Compact/power-saving system configuration

The compact/power-saving OOLS reduces the size and power consumption of the entire system by improving the system configuration conducive to downsizing and power saving in addition to applying advanced devices such as a COSA and DSP. Conventional WDM systems have taken on a unit configuration or package-mounted configuration under the assumption of using with a maximum number of directions and wavelengths. Applying such a system to a building using a small number of directions or wavelengths results in unnecessary (empty) slots, which is an inefficient implementation. In response to this problem, we developed a compact unit for the compact/power-saving OOLS that reduces the number of packages that can be mounted for buildings having small-scale demands such as a small number of paths or wavelengths and downsized the package configuration by consolidating function sections and

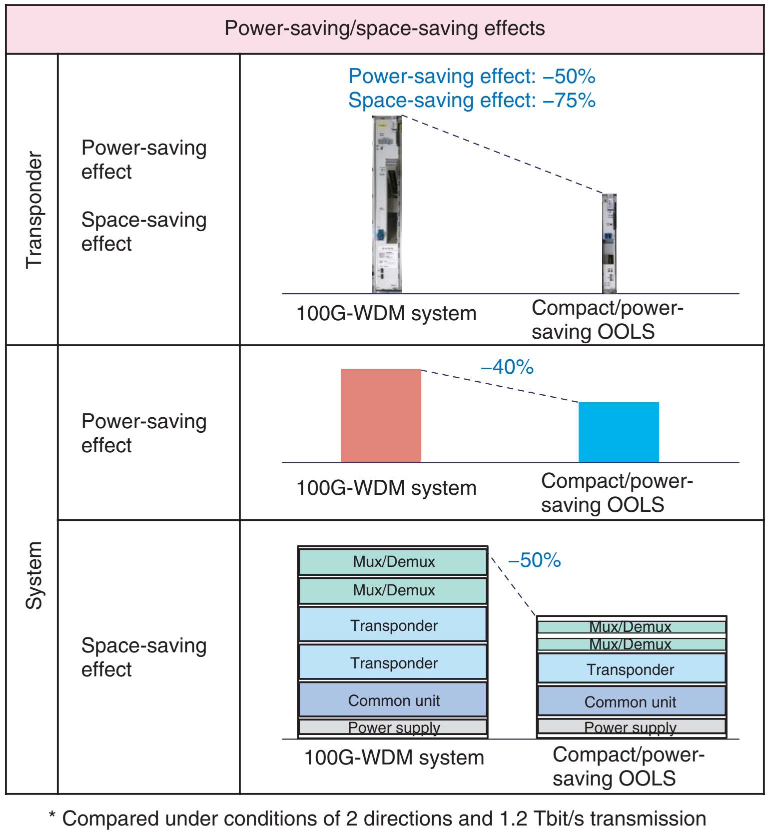

Fig. 4. Power-saving/space-saving effects.

high-density mounting. Regarding reducing package size, we achieved high-density system mounting without decreasing maintenance work efficiency for insertion/removal of optical cable connectors, packages, etc. We also developed a unit for mounting on general-purpose racks to enable a transition from large specialized racks, as used in the past, to general-purpose small racks. By applying these compact/power-saving system configurations to the compact/power-saving OOLS, we achieved downsizing by approximately 50% and power savings by approximately 40% over the entire system compared with conventional 100G-WDM systems (**Fig. 4**).

3. Conclusion and future perspective

The compact/power-saving OOLS has achieved large-capacity transmission and compact/power-saving configuration for a more economical transport network. NTT is now conducting research and development for the All-Photonics Network (APN) [2]. The APN is one of the innovative optical transport platforms for IOWN (the Innovative Optical and Wireless Network). We are aiming to further speed up signal per wavelength such as 400-Gbit/s or 1-Tbit/s. We will also target further high-capacity transmission by using multi-band transmission [3] to expand the transmission wavelength range or using space-division multiplexing technology such as multi-core fiber [4]. We will continue to conduct research and development for further improving optical transport systems and for dramatically expanding the transmission capacity.

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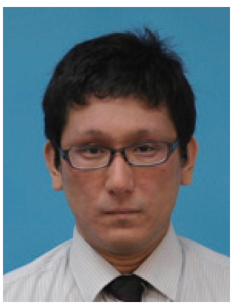

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Report on the 34th Asia-Pacific Telecommunity Standardization Program Meeting

Noriyuki Araki

Abstract

The 34th Asia-Pacific Telecommunity Standardization Program meeting (ASTAP-34) was held from 18 to 22 April 2022. This meeting was held in an online format due to the impact of the spread of novel coronavirus infections and was attended by approximately 230 participants (registered) from 19 Member States. This article reports on ASTAP-34 and the Industry Workshop held in conjunction with ASTAP-34.

Keywords: APT, ASTAP, standardization

1. Introduction

The Asia-Pacific Telecommunity (APT) is an international organization promoting development in the field of information and communication technology (ICT) in the Asia-Pacific region and was established in 1979 with 38 Member States in the Asia-Pacific region [1].

The APT Standardization Program (ASTAP) is a conference promoting standardization activities in the APT region and was established in 1998 [2]. The main objectives of ASTAP are 1) to build a cooperative and collaborative system for standardization in the APT region and contribute to international standardization; 2) train standardization practitioners in the APT region and support skill development in the ICT field among members of the region, especially those from developing countries; and 3) make joint proposals to international standardization organizations such as the International Telecommunication Union (ITU) as a regional standardization organization.

The 34th ASTAP meeting (ASTAP-34) was held from 18 to 22 April 2022 with approximately 230 participants from 19 Member States. On the first day of the meeting, the Industry Workshop on "Blockchain" and Standardization Workshop on "Guidelines on setting up a National ICT Standardization Regime" were held and attended by about 130 participants.

2. Structure of ASTAP

The structure of ASTAP and the positions held are listed in **Table 1**. Japan is now able to lead the discussions in each Working Group (WG) and Expert Group (EG) by serving as the Chair or Vice-Chair of each group.

3. Review of working methods

A proposal was made by the Steering Committee, consisting of the Chair, Vice-Chair, and others of ASTAP, to review the working methods for changing the title of the Chair during meetings and in documents from "Chairman" to "Chair," from the perspective of gender equality. The working methods were thus reviewed and changed from "Chairman" to "Chair." This was implemented from this meeting and reflected in the meeting and document amendments.

There was also a request not to use the designations "He," "She," etc. However, it is not always possible to know all the names of the speakers in a meeting, and

Table 1. Structure of ASTAP.

Group	Chairs	Vice-Chairs
ASTAP	Dr. Hyoung Jun Kim (Korea)	Hideyuki Iwata (TTC, Japan) Mr. Xiaoyu You (China)
Working Group Policy and Strategic Co-ordination (WG PSC)	Mrs. Nguyen Thi Khanh Thuan (Vietnam)	Kaoru Kenyoshi (NICT, Japan) Mr. Wu Tong (China)
Expert Group Bridging the Standardization Gap (EG BSG)	Mrs. Nguyen Thi Khanh Thuan (Vietnam)	Mr. Ki-Hun Kim (Korea) Masatoshi Mano (TTC, Japan)
Expert Group Green ICT and EMF Exposure (EG GICT&EMF)	Dr. Sam Young Chung (Korea)	Mr. Min Prasad Aryal (Nepal) Mr. Nur Akbar Said (Indonesia) Mr. Uttachai Mannontri (Thailand)
Expert Group ITU-T Issues (EG ITU-T)	Kaoru Kenyoshi (NICT, Japan)	Mr. Tran Quoc Binh (Vietnam)
Expert Group Policies, Regulatory and Strategies (EG PRS)	[*No Chair nominated*]	
Working Group Network and System (WG NS)	Dr. Joon-Won Lee (Korea)	Hiroyo Ogawa (NICT, Japan)
Expert Group Future Network and Next Generation Networks (EG FN&NGN)	Dr. Joon-Won Lee (Korea)	Kazunori Tanigawa (NICT, Japan)
Expert Group Seamless Access Communication Systems (EG SACS)	Hiroyo Ogawa (NICT, Japan)	
Expert Group Disaster Risk Management and Relief System (EG DRMRS)	Noriyuki Araki (NTT, Japan)	
Working Group Service and Application (WG SA)	Miho Naganuma (NEC, Japan)	Dr. Jee-In Kim (Korea)
Expert Group Internet of Things Application/Services (EG IOT)	Toru Yamada (NEC, Japan)	Dr. Seung-yun Lee (Korea) Ms. Li Haihua (China)
Expert Group Security (EG IS)	Miho Naganuma (NEC, Japan)	Dr. Heuisu Ryu (Korea)
Expert Group Multimedia Application (EG MA)	Hideki Yamamoto (OKI, Japan)	Dr. Dong il Seo (Korea)
Expert Group Accessibility and Usability (EG AU)	Dr. Jee-In Kim (Korea)	Ms. Wantanee Phantachat (Thailand)

there are sometimes cases in which the designations "He," "She," "him" and "her" are used, so we need to be more aware of this.

4. Main results

At ASTAP-34, 19 output documents were approved, including reports of each WG. The plenary of this meeting approved two revised Terms of Reference (EG Future Network and Next Generation Networks (FN & NGN), EG Internet of Things Application/Services (IOT)), two new report documents, four liaison documents to other standardization bodies (ITU Telecommunication Standardization Sector (ITU-T) Study Group 16, ITU-T Focus Group on Autonomous Networks (FG-AN) [3], ITU-T Focus Group on AI for Natural Disaster Management (FG-AI4NDM) [4], APT Wireless Group (AWG) [5]), and one questionnaire; the two new report documents are as follows:

- Final draft of the 2nd Version of APT Report on Asia-Pacific Regional Activities of Human Exposure to EMF (electromagnetic fields)
- APT Report on Airport Runway Foreign Object Debris Detection System using Radio over Fiber

Table 2. Program of the Industry Workshop in ASTAP-34.

Program of ASTAP Industry and Standardization Workshop **Industry Workshop: Blockchain technology and standardization**
10:30 – 12:30 **Introductory Remarks** by Dr. Hideyuki Iwata, TTC, Japan, Industry Workshop Corresponding Member Chair: Mr. Xiaoyu You, CAICT, China • **Standardization of ISO TC 307** (**Blockchain and DLT**) by Mr. Jae Hoon NAH, Principle Engineer, ETRI, Rep. of Korea. • **Experience and Thinking on International Standardization of DLT Enhanced Future Network for Supporting Web3.0** by Ms. Xiaoou Liu, China Telecom Research Institute, People's Republic of China. • **Technical and Copyright Issue with NFT and Blockchain** by Mr. YongJoon Joe and Mr. DongMyung Shin, Principal Research Engineer, LSware Inc., Rep. of Korea.
12:30 – 14:00 **Industry Workshop: Blockchain industry and application** Chair: Dr. Seungyun Lee, Director, ETRI, Rep. of Korea • **Maximize the Benefits of Blockchain in Many Applications of Many Industries** by Dr. Manodha Gamage, Founder/Managing Director, Intelligent Solutions and Consultancy (Pvt.) Ltd., Sri Lanka. • **Digital Federation on Trade Facilitation by Blockchain** by Ms. Chaemee Kim, VP (CDO Chief Digital Officer), KTNET, Rep. of Korea. • **Chinese Blockchain Industry Overview & Xinghuo Blockchain and Infrastructure Facility** by Mr. Xiantang SUN, Director of International department of IIIIoT, CAICT, People's Republic of China. • **Auditing B2C communication Utilizing Blockchain** by Shigeya Suzuki, Specially Appointed Professor, Keio University, Japan.
14:10 – 15:40 **Standardization Workshop: Guidelines on setting up National ICT Standardization Regime** Chair: Mrs. Nguyen Khanh Thuan, Ministry of Information and Communications, Vietnam • **TTC Activity Report** by Dr. Hideyuki Iwata, CEO&S.V.P., TTC, Japan. • **The Introduction of ICT Standardization Regime in Korea** by Dr. Kyoungcheol Koo, Vice President, Telecommunications Technology Association, Rep. of Korea. • **The Operations of MTSFB as the Malaysian ICT Standardization Organization** by Ms. Zaleha Abu Bakar, General Manager, MTSFB, Malaysia. • **Guidelines on Setting up National ICT Standardization Regime** by Dr. Kamol Uahchinkul, Researcher, National Electronic and Computer Technology Center, Thailand. • **Introduction on Standardization System in China** by Mr. Shizhuo Zhao, Director, International Standardization Department, CCSA, People's Republic of China. • **Guidelines on Setting up National ICT Standardization Regime** by Mr Satish Jamadagni Vice Chair TSDSI (Reliance Jio).
15:40 – 16:00 **Conclusion of Industry Workshop** Dr. Hideyuki Iwata, CEO&S.V.P., TTC, Japan

DLT: distributed ledger technology
NFT: non-fungible token

Technologies

5. Industry Workshop

In the ad hoc discussion on strengthening ASTAP activities held at ASTAP-33, it was agreed that the workshop at this ASTAP-34 would be an Industry Workshop in combination with a Standardization Workshop with standards developing organizations (SDOs) invited to attend. The topic of the Industry Workshop was "Blockchain," which was carried over from the Correspondence Group planning the program of the previous ASTAP-33 workshop. The topic of the Standardization Workshop was "Guidelines on setting up a National ICT Standardization Regime," a Work Item of the EG Bridging the Standardization Gap (BSG).

Table 2 shows the program of the workshop. The

Industry Workshop consisted of two sessions: Session 1: Blockchain technology and standardization and Session 2: Blockchain industry and application. Seven experts from Japan, Korea, China, and Sri Lanka gave presentations. Keio University gave a presentation from Japan. The Standardization Workshop in Session 3 was attended by SDOs from six countries: The Telecommunication Technology Committee (TTC) from Japan, the Telecommunications Technology Association (TTA) from Korea, the China Communications Standards Association (CCSA), the Malaysian Technical Standards Forum Bhd (MTSFB), Telecommunications Standards Development Society, India (TSDSI), and the National Electronics and Computer Technology Center (NECTEC) from Thailand. During the workshop, information was shared in response to the following questions raised by emerging countries that do not have a national SDO.

- National ICT standardization processes
- National legislation relating to ICT standardization
- Role of governments, SDOs, fora, and standardization bodies
- Industry initiatives
- Recommendations to APT Member States on the establishment of national standardization systems
- Proposals to ASTAP and APT

The schedule was tight because the workshop was held online, taking into account time differences and other time constraints, and the aim was to have as many speakers as possible share information.

6. Future plans

The APT Secretary General reported that the next meeting (ASTAP-35) would be held on site from April to June 2023, that Bangkok was currently being considered as a possible venue, and that invitations were being sought from other countries and regions. An Industry Workshop will be held independently in conjunction with the next meeting, while the Standardization Workshop will be organized by the EG BSG, with mini-workshops inviting emerging countries.

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

External Awards

The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, Award for Science and Technology in Research Category
Winner: Hiroki Takesue, NTT Basic Research Laboratories
Date: April 8, 2022
Organization: Ministry of Education, Culture, Sports, Science and Technology

For his achievements in quantum communications such as quantum key distribution and quantum entanglement generation for the telecommunication band and coherent Ising machines based on optical parametric oscillators.

The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, the Young Scientists' Award
Winner: Koji Azuma, NTT Basic Research Laboratories
Date: April 8, 2022
Organization: Ministry of Education, Culture, Sports, Science and Technology

For his achievements in theory of quantum repeaters necessary for the development of a quantum internet.

IEICE Communications Society Excellent Paper Award, Best Paper Award
Winners: Yuya Omori, NTT Computer and Data Science Laboratories/NTT Device Innovation Center; Ken Nakamura, NTT Computer and Data Science Laboratories/NTT Device Innovation Center; Takayuki Onishi, NTT Computer and Data Science Laboratories; Daisuke Kobayshi, NTT Computer and Data Science Laboratories/NTT Device Innovation Center; Tatsuya Osawa, NTT Corporate Strategy Planning Department; Hiroe Iwasaki, Tokyo University of Agriculture and Technology
Date: May 11, 2022
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE)

For "4K 120fps HEVC Encoder with Multi-chip Configuration."
Published as: Y. Omori, K. Nakamura, T. Onishi, D. Kobayshi, T. Osawa, and H. Iwasaki, "4K 120fps HEVC Encoder with Multi-chip Configuration," IEICE Transactions on Communications, Vol. E104-B, No. 7, pp. 749–759, 2021.

Papers Published in Technical Journals and Conference Proceedings

Dither-free Bias Condition Monitoring Technique Utilizing Reference Light for Inservice Optical IQ modulator

H. Kawakami, S. Kuwahara, and Y. Kisaka

27th OptoElectronics and Communications Conference (OECC 2022), TuP-B-7, Toyama, Japan, July 2022.

We developed a dither-free bias condition monitoring technique for IQ modulators utilizing reference light and a low-speed power monitor. Experimental results for confirming the principle are also shown.

Divide-and-conquer Verification Method for Noisy Intermediate-scale Quantum Computation

Y. Takeuchi, Y. Takahashi, T. Morimae, and S. Tani

Quantum, Vol. 6, p. 758, July 2022.

Several noisy intermediate-scale quantum computations can be regarded as logarithmic-depth quantum circuits on a sparse quantum computing chip, where two-qubit gates can be directly applied on only some pairs of qubits. In this paper, we propose a method to efficiently verify such noisy intermediate-scale quantum computation. To this end, we first characterize small-scale quantum operations with respect to the diamond norm. Then by using these characterized quantum operations, we estimate the fidelity $\langle\psi_t|\hat{\rho}_{\mathrm{out}}|\psi_t\rangle$ between an actual n-qubit output state $\hat{\rho}_{\mathrm{out}}$ obtained from the noisy intermediate-scale quantum computation and the ideal output state (i.e., the target state) $|\psi_t\rangle$. Although the direct fidelity estimation method requires $O(2^n)$ copies of $\hat{\rho}_{\mathrm{out}}$ on average, our method requires only $O(D^3 2^{12D})$ copies even in the worst case, where D is the denseness of $|\psi_t\rangle$. For logarithmic-depth quantum circuits on a sparse chip, D is at most $O(\log n)$, and thus $O(D^3 2^{12D})$ is a polynomial in n. By using the IBM Manila 5-qubit chip, we also perform a proof-of-principle experiment to observe the practical performance of our method.

Passive Verification Protocol for Thermal Graph States

K. Akimoto, S. Tsuchiya, R. Yoshii, and Y. Takeuchi

Physical Review A, Vol. 106, 012405, July 2022.

Graph states are entangled resource states for universal measurement-based quantum computation. Although matter qubits such as superconducting circuits and trapped ions are promising candidates to generate graph states, it is technologically hard to entangle a large number of them due to several types of noise. Since they must be sufficiently cooled to maintain their quantum properties, thermal noise is one of the major ones. In this paper, we show that, for any temperature T, the fidelity $\langle G|\rho_T|G\rangle$ between an ideal graph state $|G\rangle$ at zero temperature and a thermal graph state ρ_T, which is a graph state at temperature T, can be efficiently estimated by using only one measurement setting. A remarkable property of our protocol is that it is passive, while existing protocols are active, namely, they switch between at least two measurement settings. Since thermal noise is equivalent to an independent phase-flip error, our estimation protocol also works for that error. By generalizing our protocol to hypergraph states, we apply our protocol to the quantum-computational-supremacy demonstration with instantaneous quantum polynomial time circuits. Our results should make the characterization of entangled matter qubits extremely feasible under thermal noise.

Computational Self-testing for Entangled Magic States

A. Mizutani, Y. Takeuchi, R. Hiromasa, Y. Aikawa, and S. Tani
Physical Review A, Vol. 106, L010601, July 2022.

Can classical systems grasp quantum dynamics executed in an untrusted quantum device? Metger and Vidick answered this question affirmatively by proposing a computational self-testing protocol for Bell states that certifies generation of Bell states and measurements on them. Since their protocol relies on the fact that the target states are stabilizer states, it is highly nontrivial to reveal whether the other class of quantum states, *nonstabilizer states*, can be self-tested. Among nonstabilizer states, magic states are indispensable resources for universal quantum computation. Here, we show that a magic state for the *CCZ* gate can be self-tested while that for the *T* gate cannot. Our result is applicable to a proof of quantumness, where we can classically verify whether a quantum device generates a quantum state having nonzero magic.