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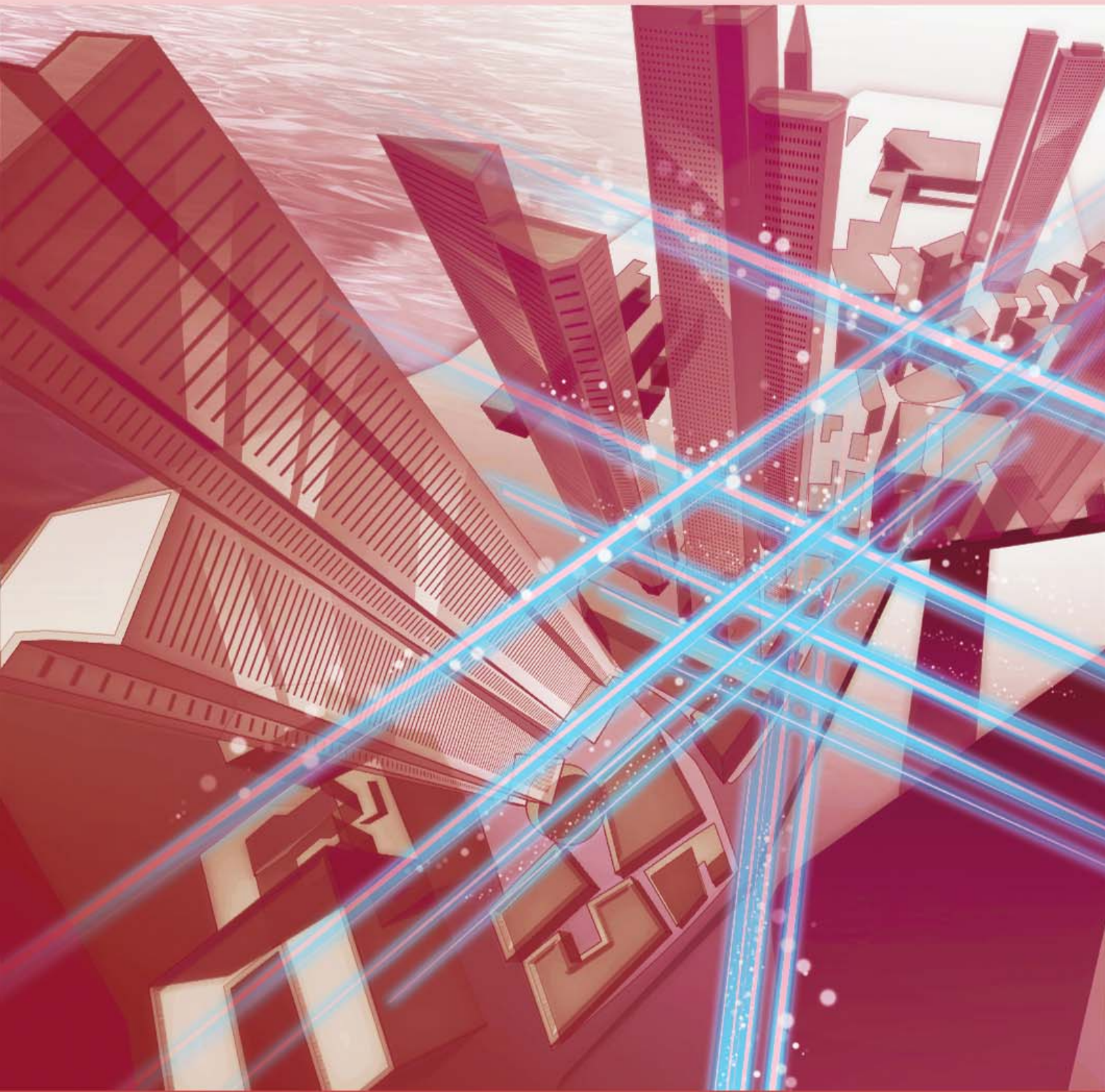

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A Year for Refining Our Abilities to Become a Partner of Choice—Creating New Value for Our Customers through Outstanding Technologies and Collaborative Skills

Hiromichi Shinohara
Senior Executive Vice President and Head of R&D Strategy Department, NTT

Overview

Great expectations are being placed on the NTT Group both inside and outside Japan to provide high-quality and stable network services, ensure a safe and secure network through advanced security measures, and provide a moving user experience and new value. The NTT Group itself is committed to solving social issues and providing new ways of creating value. How will the NTT Group approach these needs in 2018? We asked NTT Senior Executive Vice President Hiromichi Shinohara to tell us about his outlook and aspirations for the NTT Group.

Keywords: B2B2X, collaboration, global

2017: A year of exciting developments

—Mr. Shinohara, please sum up last year for us. What kind of year was it?

In short, it was an exciting year! In November 2017, for example, the NTT laboratories and NTT DOCOMO conducted a worldwide streaming experiment connecting three global locations (Tokyo, London, and New York) to present a live, dispersed performance by Perfume, a popular three-member Japanese pop group. This experiment constituted part one of the FUTURE-EXPERIMENT project that aims to provide people with totally new experiences. The highlight of the experiment was a remote collaboration making use of NTT's immersive telepresence technology called Kirari!, which uses Advanced MMT (MPEG Media Transport) high-presence media synchronization technology, and NTT DOCOMO's 5G (fifth-generation) mobile communications technology. Given the task of achieving a live hookup from three different points in the world and making the separate dance performances at each of these locations appear as if they were taking place on the same stage, I was naturally quite tense. However, the result was an amazing success, with viewers seeing each member of the group dancing lively in step with each other.

In addition, although the business-to-business-to-X (B2B2X) model that NTT is pursuing requires time to create something new through repeated trial and error, it expanded greatly last year through collaboration with NTT operating companies and partner companies. As a result, exciting new business opportunities were created.

For example, in the manufacturing industry, collaboration between FANUC CORPORATION and the NTT laboratories, NTT Communications, and NTT DATA led to the service launch in October 2017 of the FIELD system (FANUC Intelligent Edge Link and Drive system), an open platform for achieving an unprecedented smart manufacturing site. Furthermore, in collaboration with Mitsubishi Heavy Industries, Ltd., NTT accelerated the development of InteRSePT —a cybersecurity technology targeting control systems for critical (social) infrastructures—and entered the finishing stage of the development. InteRSePT enables real-time anomaly detection and response against unknown cyberattacks to achieve safe and secure system operations. Our aim is to apply this technology to commercial fields such as thermal power generation facilities and chemical plants. In the sports industry, a virtual reality baseball coaching system developed with NTT DATA is now in use by the Tohoku Rakuten Golden Eagles professional baseball team.

—It was certainly a year that produced material results in a variety of fields. What direction will this year take?

Last year saw a shift from what had been a construction and production stage to a phase of actual use, or in other words, to the "genuine launch of business." At the same time, we must expand services and products of the same kind to other companies in the same industry. This is not to say a haphazard expansion but the further penetration of necessary technologies in need-to-have industries through collaboration.

In our approach, our objective is not to form associations with only specific companies but rather to horizontally roll out the technology and knowledge cultivated at various companies. Additionally, as problems differ according to industry, our plan is to form partnerships with companies representative of various industries to obtain a firm grasp of those problems and to then horizontally roll out technologies useful for solving common problems in that industry. We also seek to horizontally expand technologies and knowledge within the NTT Group.

At present, we are engaged in joint research with Toyota Motor Corporation, NTT Communications, NTT DATA, and NTT DOCOMO in the field of "connected cars." Our aim here is to create new value such as self-driving technology by connecting automobiles that serve as information and communication technology (ICT) terminals to the network and by accumulating and analyzing various types of data. In the maritime industry, meanwhile, we have begun a joint experiment with the NYK Group, NTT Communications, and NTT DATA on an on-board Internet of Things (IoT) platform applying edge-computing technology.

Moreover, in the field of artificial intelligence (AI), we achieved impressive results with ForeSight Voice Mining, a system provided by NTT Communications using AI technology developed by the NTT laboratories. It has been implemented in the customer support chatbot service of SMBC Nikko Securities Inc. since May 2017 and will be introduced at about 10,000 desks at Sompo Japan Nipponkoa Insurance Inc. in February 2018 as part of an operator support system using voice recognition.

In addition, NTT DATA is providing an intelligent-microphone and anomaly sound detection technique to Hitachi Zosen Corporation, while NTT DOCOMO is providing people-flow prediction technology to Tokyo Musen Cooperative Association (a taxicab association). Although the focus up to a few years ago was on the sharing of technology, it has recently become possible to share information in a way connected to actual market conditions.

In the above ways, uncovering and solving issues in all sorts of industries and fields in a collaborative manner has brought into view a structural theory in the sense of how best to design an architecture

tailored to industry. Though we are not yet at the point of an all-inclusive theory covering all fields, we think we can eventually establish such an overall theory by accumulating experience in a number of fields.

—Obtaining an entire picture from architecture tailored to various industries is very interesting. Can a universal structural theory actually be derived?

To derive a universal structural theory, I think it's important that we first thoroughly work out specific solutions. We all hear the word "platform" quite frequently nowadays, and we tend to think of a platform as an infrastructure that can be provided in common for everything. However, in the world of IoT, requirements differ according to industry, so there is no platform from the start that can do everything. What we first need to do is to clearly stipulate industry-specific requirements to realistically operate the individual platforms. Then, when viewing this conglomeration of platforms from afar, we may be able to recognize it as a "platform" in the full meaning of the word.

However, recognition as a genuine platform will not hold unless each instance of architecture has the same structure to some extent. To discover a universal structural theory and give it life, we would first like to thoroughly construct individual architectures and work out specific solutions.

For example, given that we are not a manufacturer, we are not familiar with the "nuts and bolts" of the manufacturing industry. It therefore stands to reason that collaboration with partners would be essential to enter this industry. The key approach here is to search for a solution while examining the issues of concern together with a partner using the "full-stack" capabilities of the NTT Group.

Enhancing virtuous cycles in B2B2X through NTT genetic thinking

—I have heard that the way of thinking cultivated over many years in the NTT Group has genetic qualities. Can this genetic way of thinking be applied to B2B2X too?

The ideas to "achieve (the service launch) at all cost" and "do whatever it takes to make it right (fix the fault)" have been cultivated at NTT over many years and passed down to us as a kind of NTT "DNA" (deoxyribonucleic acid). This way of thinking also took root in the NTT operating companies following NTT's restructuring in 1999. We take pride in our obsession with "getting things done" that no other company can equal. At the same time, we have cultivated a spirit of teamwork and cooperation through various types of operations. Optical-cable installation work, for example, cannot be accomplished by just one person—it is essential that people of various capacities work together. Moreover, since efficiency drops if someone slacks off in their work, no one can cut corners. This type of operation holds not only for optical-cable installation but also for system development.

In the process of collaborating with business partners in B2B2X, cooperation between NTT and the sales departments of NTT Group companies can be a potent force. The past has shown that the sales teams of these Group companies have first and foremost prioritized sales with their own company in mind instead of unambiguously pursuing Group-wide sales. These days, however, I believe that the sharing and cultivating of business opportunities that come along during such activities have been done within the Group and have resulted in a number of collaborations.

At present, a virtuous cycle has already started turning in fields such as agriculture and medical care, and this year, I expect such virtuous cycles to spread to other fields and take off on their own. However,

undertakings involving B2B2X-like collaboration will not work at all by simply issuing commands or will come to a halt if there is a break in the chain of command. While a top-down command structure may be necessary to some extent, it is important that each member of a project inherit NTT DNA, place importance on "teamwork" and "doing whatever it takes to make it right," and discover value and push the project forward on their own!

The importance of providing new value through collaboration

—There are only two years left till 2020. What are your goals going forward?

With 2020 in sight, we have three goals. The first goal is to provide high-quality network services as a telecommunications carrier. Our preparations in this regard are progressing steadily and include the provision of high-speed wireless local area networks.

Our second goal is to provide extensive security measures. We are making steady progress here as well, in cooperation with the NTT laboratories and NTT Group companies. However, in terms of a national project, we are aware of the need to enhance our technical capabilities with a view to cooperating with various industries and agencies at the national level. Security problems include cyberattacks from abroad, so a system of cooperation at the global level is also crucial. To this end, we aim to strengthen our ties with major ICT players in the world.

Our third goal is to help provide new user experience through the power of ICT. For example, I would like to convey the excitement created by athletes, who have the leading role at sports events, to a wide range of people. To meet this goal, we are conducting highly realistic video streaming experiments and other types of trials. Networks and security are fields that NTT has already been involved in, so we have an intuitive grasp of those areas. However, I think that we don't have enough experience or sense when it comes to conveying emotions and excitement. Accordingly, without limiting ourselves to sports, we will take this as a challenge and work on collaborating with leading artists and creators and refining our sense of such expression.

We have also set up an experimental laboratory for the Sports Brain Science project inside the NTT Atsugi R&D Center. While it has become possible to understand the differences between top-class and regular baseball athletes, research has yet to advance

to the point of knowing how to guide athletes to a top-class level. Our plan is to advance research toward this objective in cooperation with the Japanese National Women's Softball Team with the hope that the results obtained may be useful in enhancing the ability of active athletes. In addition, we would like to work with middle-school athletes to research the extent to which an athlete can improve through effort taking into account psychological factors.

—It appears that business is becoming all the more global in nature.

In November 2017, we received the Nishina Memorial Prize for our quantum neural network using optical fiber (The Nishina Memorial Prize is the most prestigious physics award in Japan). We also began testing the provision of this technology as a service on the cloud. There are fields applicable to the use of quantum neural networks, but to expand this service to even more fields, we would like to refine the technology and improve the power of the software while the service is used by various people.

The annual NTT R&D Forum welcomes many customers of the NTT operating companies, and both their number and business diversity have been increasing in recent years. The number of customers of overseas NTT Group companies is increasing as well, reflecting an acceleration of globalization. In this regard, we take pride in the steady growth of collaboration among the domestic NTT Group companies, but at present, collaboration with an overseas NTT Group company gets underway only after an offer is made.

When making a business trip, for example, progress tends to be slower in the case of an overseas trip compared with a domestic one, so some measures are

needed to facilitate collaboration. I recognize this as a current issue. This year, I would like to create a scheme to facilitate the selection and service of at least five or six projects while listening to the aims of our overseas operating companies. The NTT laboratories and the domestic operating companies collaborate frequently, and I would like to see multiple collaborative projects among domestic and overseas research laboratories and operating companies in the same way at the global level. Specifically, I would like to complete a framework for such global collaboration in the first half of this year and bring new service to the actual market in the second half.

Language, technology, and an understanding of local values are essential to becoming active on a global level. Especially in regard to values, differences clearly exist not only between Japanese people and people from other countries but also among non-Japanese people from different countries. Consequently, in wondering what we want to achieve using ICT, the answer is to provide "new value." To this end, it is vitally important to be able to grasp the values of the target country and of your business partner without delay. Of course, differences can occur according to industry, and viewpoints can differ between domestic and global project teams. In the end, studies are needed to obtain a keen awareness of the situation.

Refining our abilities to become a partner of choice

—How should researchers approach this borderless era at home and abroad?

By facing the challenges of B2B2X in our domestic market, we have already changed our mindset to recognize the need to create things that the customer appreciates. And to do so, we have also developed a process that makes talking with the customer an absolute requirement. In addition, past experiences have shown us that this mindset of "creating something useful for the customer instead of something that we want to create" is a universal approach that can be applied on the global level too.

With this in mind, and considering the difficulty of making direct contact with customers in the global market, I would like researchers to think in terms of collaborating with sales teams that are very familiar with the needs of those customers. In this regard, researchers who can speak English and have outstanding technology to offer deserve our respect. However, if the technology offered is no more than average, such a researcher, regardless of English ability, will not be able to speak as a global partner. An interpreter can always be used in an English-speaking setting, but there is no alternative to mediocre technology. It's more important to have the technology than to worry about English ability. Language, in the end, is simply a tool. I therefore would like researchers to focus their efforts on having and refining core technologies.

I would like to ask all researchers to refine their technologies to generate new value. To advance B2B2X, they must have the abilities to become a partner of choice. This means strength in individual technologies and skills of collaboration. Here, it is important that researchers be able to customize the outstanding technologies that they bring with them to meet the needs of customers. That is, they must somehow change the seeds of their technologies to give value.

—Mr. Shinohara, please leave us with a message for everyone in the NTT Group.

Against the background of a changing market from domestic to global customers, NTT has undergone a change from a straightforward telecommunications service provider to a bona fide ICT player. We are transforming ourselves into an enterprise that creates new customer value even as far as the provision of applications. In light of these changes, we must take up the challenge of strengthening the ties within the NTT Group and raising customer value to even higher levels.

Interviewee profile

■ Career highlights

Hiromichi Shinohara joined Nippon Telegraph and Telephone Public Corporation (now NTT) in April 1978. In 1998, he was promoted to Vice President of the Information Sharing Laboratory Group at Access Network Service Systems Laboratories. He became Senior Vice President of the Information Sharing Laboratory Group in June 2007. In June 2009, he became a member of the Board of NTT and Head of the R&D Strategy Department. In June 2012, he became Executive Vice President and Head of the R&D Strategy Department. He took up his present position in June 2014.

No Need to Hurry! Taking a Roundabout Way Means Time to Gain Experience. The Essence of a Researcher Is "Finding Something Interesting in Everything."

Hiroshi Sawada
Senior Distinguished Researcher, NTT Communication Science Laboratories

Overview

Nonnegative matrix factorization (NMF) enables big data such as Internet of Things sensor data to be represented in the form of matrices having only nonnegative values and to be analyzed by using simple mathematical expressions. NMF has found application in many areas including the analysis of audio, image, and text data. Dr. Hiroshi Sawada is a Senior Distinguished Researcher at NTT Communication Science Laboratories known for his research and development efforts in NMF and signal separation technology. We asked him about his current research projects and the mind frame needed by a researcher.

Keywords: nonnegative matrix factorization, independent component analysis, audio source separation

Analyzing complex data in a simple manner—development of groundbreaking technology for predicting the near future

—Dr. Sawada, please tell us about your current line of research.

I am now working on the integration of nonnegative matrix factorization (NMF) technology, which excels in uncovering the structure and features of an information source such as data or signals, and independent component analysis (ICA) technology, which estimates how data or signals were observed by sensors through an observation system (**Fig. 1**). Of course, I am also focusing on enhancing each of these technologies prior to integration and applying them effectively to social issues.

NMF is an algorithm for extracting frequency patterns. It leverages the fact that much data in the real world can be represented in matrix form and that individual matrix elements can be assumed as 0 or positive values, and it analyzes that data by matrix factorization using simple mathematical expressions (**Fig. 2**). Application to a wide variety of fields can be

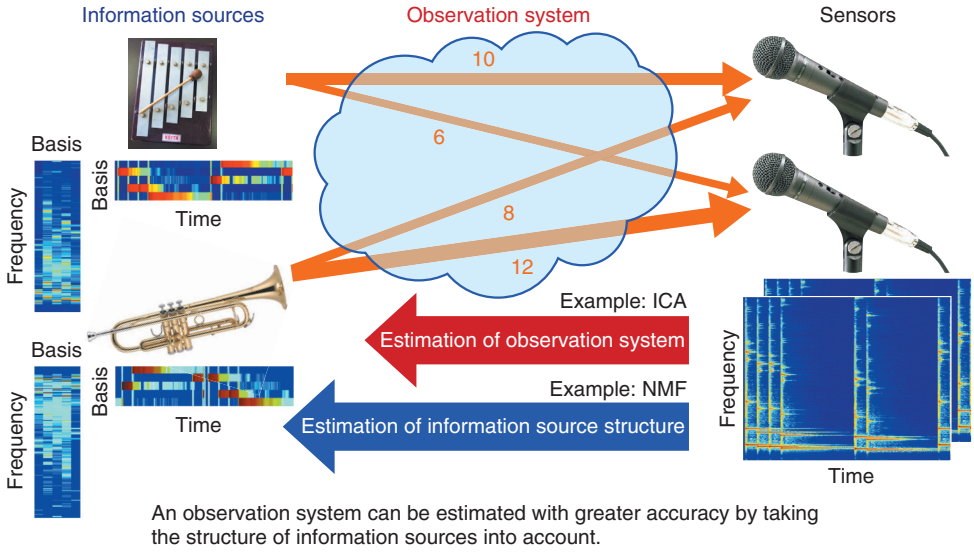


Fig. 1. Simultaneous estimation of information source structure and observation system.

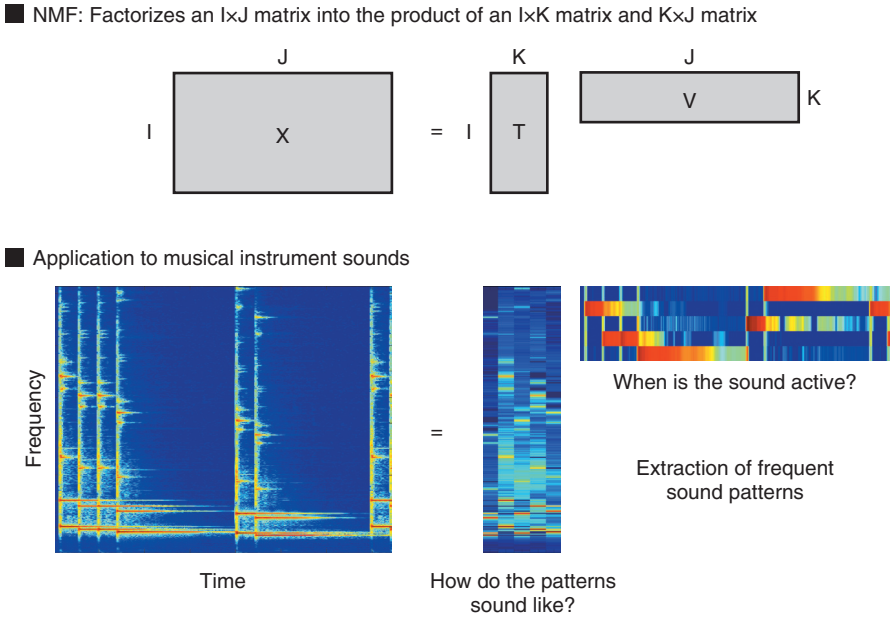


Fig. 2. Overview of NMF.

considered, including document data, purchase histories, sounds, images, biological signals, and genetic data.

In contrast, ICA has progressed as an audio source separation technology (**Fig. 3**). If we take, for example, an audio recording of more than one person talking at one time, ICA is a technology that can cleanly extract the voice of each person from that mixture. It is said that Prince Shotoku (an early regent of Japan) could listen to ten people at once and understand what each was saying. ICA accomplishes this feat by computer. As human beings, we hear sounds with both ears, and it is easier for us to make out a voice and to shut out superfluous information with two ears rather

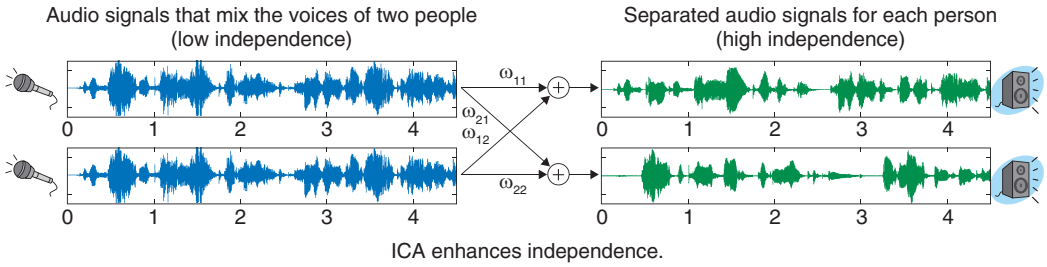


Fig. 3. ICA and audio source separation.

than one. In addition, we tend to catch sound coming from a certain direction with the ear closest to that sound, while catching the same sound arriving at the farthest ear slightly later. Consequently, by compensating for that time difference and subtracting the time-compensated sound from the original sound, it becomes possible to delete that sound. This may be easier to understand if we imagine replacing our two ears with two microphones and performing compensation and subtraction processing of audio signals (waveforms) by computer.

As in the case of a stereo mixer, the simple mixing of sound is called instantaneous mixing. The simple result of multiplying the waveform of one sound by three and that of the other by two and mixing the two sounds with a mixer can be easily analyzed. In real space, however, reverberation from desks, the ceiling, and other objects would make it difficult to cleanly extract those sounds when such echoes were present, or in other words, to delete those echoes. However, processing those sounds on a frequency-by-frequency basis would make such extraction possible. In actuality, though, sounds targeted for such extraction are not always clear, so it would be necessary to skillfully estimate a variety of conditions such as the time difference of the sound targeted for deletion and the environment in which the sounds including echoes are being recorded.

As an alternative, attempts at processing sounds using blind source separation first began in 2000. Here, *blind*, as the word implies, refers to processing using technology that separates audio sources in an environment in which "your eyes are closed" to the conditions under which the audio is being recorded. At that time, researchers throughout the world began to compete fiercely to develop this technology, but progress was slow at first. Starting in 2003–2004, however, various techniques embodying the concept of blind source separation were announced, and our research as well came to contribute to this effort.

Support from senior colleagues and a robust human network reflecting NTT's strength in the research of sound

—Research activities have a mutually beneficial effect on other research work

In our research on audio source separation, it became possible to separate audio sources in the case of human voices, but when we applied the technique to music, good results were not forthcoming. We therefore thought that perhaps the use of NMF would enable music data as well to be separated, but it was not that simple. However, after engaging in beneficial discussions with researchers having specialized knowledge in this field and determining the direction that this research should take, we completed a number of studies culminating in a paper that we presented in 2013. Researchers in various areas have since cited this paper, so I feel that it marked a successful application of NMF to audio source separation.

With NMF, we can break down various kinds of data such as music data, purchase histories, and data on the activities of inbound tourists using a matrix format, and we can analyze such data using simple mathematical formulae. In this simplification process, a "researcher sense" based on an understanding of past research plays a major role in classifying such data. Incidentally, I would say that in our research up to now, as to what techniques to apply to what types of data, the sense of not only our research team but also that of the entire NTT research planning team as reflected by their viewpoints and activities have been beneficial.

Partly due to being a longtime provider of telephone services, NTT is recognized the world over as

being strong in the area of research involving sound. It has a diverse history in this area, such as giving birth to technology for digitizing and compressing audio/speech signals for efficient transmission and for making mobile phones a reality. In addition, my senior colleagues have a long history in the research of speech and acoustics that I just mentioned, and their support has been immense. I joined the speech research team in 2000, and I intuitively felt from the start that this team was a little different from other teams and was highly competent. Consequently, when I started to give presentations at international conferences, I was often approached in the manner of "Ah, Dr. Sawada of NTT" by people who had an interest in my work, so I was able to find fellow researchers from around the world early on. Of course, these researchers were good rivals in a sense, but I was able to make a connection with the world thanks to my seniors at NTT. In this way, I was able to feel NTT's strength in research. This NTT research team had certainly built up a diverse and robust network of prominent researchers from around the world.

—You seem to have formed reassuring relationships with your colleagues through research activities.

Apart from research, there is not much that I have done for any length of time. I have tried a variety of things, but I tend to lose interest in the end. My research activities, however, have endured for a long time. I believe that producing something new is one reason for being a researcher. To present something new to the world, I put down my ideas or findings in a journal paper. I am pleased if other researchers read my paper and expand upon it, and I am happy to see my paper explained in easy-to-understand terms to people on the business side and to then have my findings used.

By the way, there are all kinds of people involved in research, and I myself am one that likes to try experimenting, prototyping, and programming on my own. After all, there are many things that you will not understand unless you conduct tests on your own. You can find that something examined in a journal paper or using a mathematical formula differs from reality when you do tests on your own.

In recent years, the work I do in areas outside of my own research, for example, in organization management, has been increasing, so opportunities for doing my own work have been decreasing, but I try to make as much time as possible for myself. On returning home, I spend time with my family and help out with the housework, but there is always a corner of my mind that is thinking about research. Something may pop into my head before I go to bed or while I'm soaking in a hot bath, and I may think about giving it a try when I get back to work the next day. I have not thought much as to why I became a researcher. The truth is, I have come this far without any misgivings about the path I have chosen.

I was originally involved in research on LSIs (large-scale integrated circuits), but in 2000, that research group was dissolved. I think my group leader at the time took my aspirations into account, as I then spent half a year studying overseas. On returning to Japan, I shifted to my present line of research. Then, for about two years starting in 2007, I worked in a joint department for organizational purposes, and my research work was suspended. However, this applied only to my work as a professional researcher, as I continued to keep in touch with research activities. For example, I would provide consultation to young researchers as part of human resource development, and I would look over the research plans unfolding at various research laboratories.

At first, I was irritated at being separated from my research, but by advising college students worried about their future path solely from the standpoint of a researcher, I was able to look back at my own history. Additionally, by touching on research outside of the fields that I had worked in, I was able to broaden my horizon and my personal values. Furthermore, though I was able to present my research on audio source separation at an international conference in 2007, I had to step away from my research just when I was planning to expand on that paper and present it again two years later. As a result, that presentation was delayed by another two years. However, I was eventually able to make that presentation despite that blank period in my research, so in hindsight, it was just a two-year gap, and in a sense, no more than a part of my ten-year period of research.

Working to make social activities more efficient through experience, intuition, and courage

—The period in which you were not directly involved in research became an experience that brought more depth to your later research activities. What is your current research objective?

I would like to contribute to society by making good use of large volumes of data. For example, I

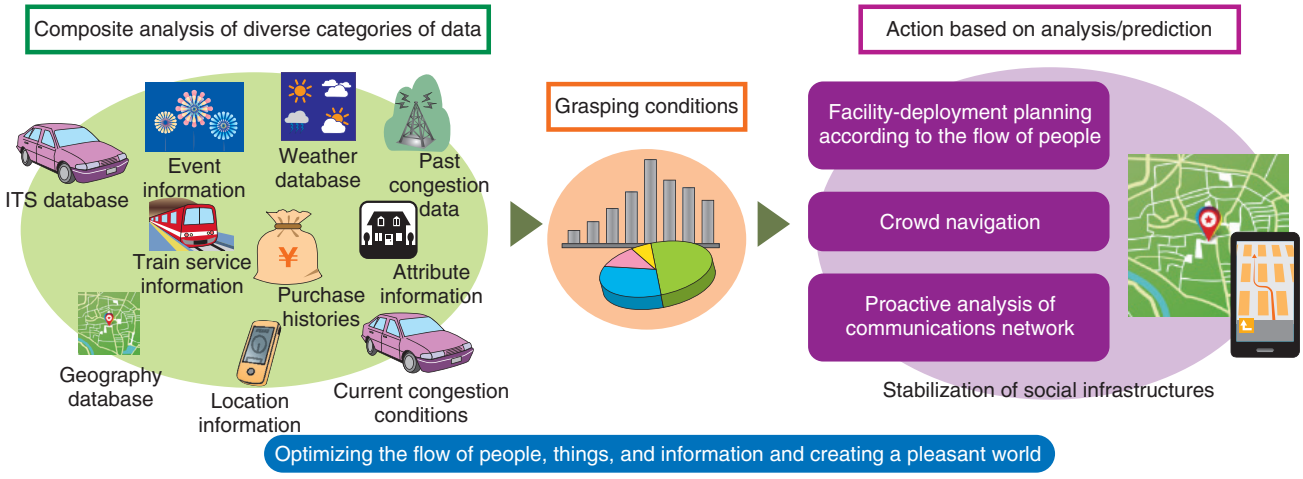


Fig. 4. Multidimensional mixture data analysis technology.

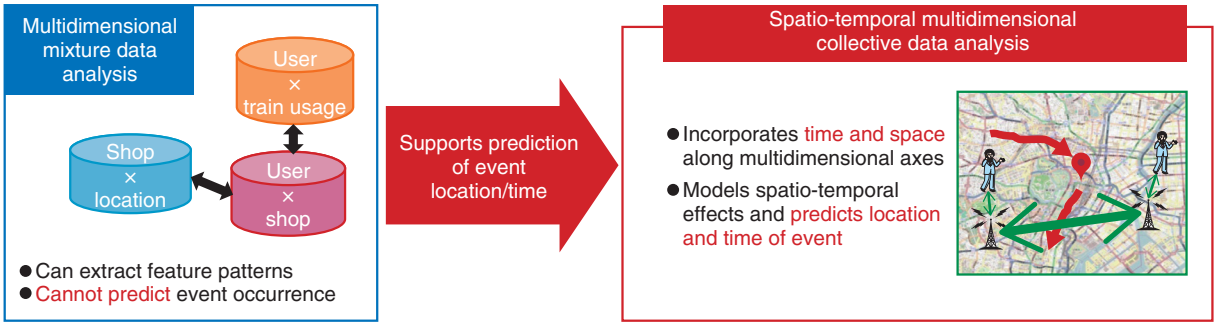


Fig. 5. Spatio-temporal multidimensional collective data analysis technology.

would like to analyze data that can provide people with good hints as grounds for making important decisions. With this need in mind, we have come to establish and apply multidimensional mixture data analysis technology (**Fig. 4**). Moreover, with innovative analysis technology capable of predicting the future, our aim now is to foresee and obtain insight from things that will happen in the somewhat near future taking into account the four data aspects of time, space, multidimensionality, and collectivity (**Fig. 5**).

With a view to 2020, we envision using this technology to predict the occurrence of congestion at large event venues so that countermeasures can be taken and a stable communications infrastructure can be ensured. Furthermore, using such activities as a foundation, I would like to make social activities more efficient. For example, it would be good if a governmental or administrative body could use this technology to make objective decisions such as on constructing a new road. I would also be pleased if the technology could be applied to the shared assets of society. I would like to join up with the NTT laboratories and partner companies to propose such applications to the real world and to create a variety of case studies.

In the past, when I was involved in analyzing the data of a company performing user surveys, I was very happy to hear comments from the company side such as “These results are the same as what we had thought to be true, so they corroborate our beliefs.” This was gratifying because I was able to corroborate using mathematical data what is usually judged on the basis of “experience, intuition, and courage” in an

ordinary society. There is an aspect of my own research that is based on experience, intuition, and courage. This is why I have to try things on my own. It is also useful to corroborate what one has done on the basis of intuition using none other than data analysis. By the way, I don't think my intuition is that good, and as for courage, I wouldn't say I have more than anyone else! However, I have been able to gain much experience by being involved in research over many years, and this is very gratifying to me.

Actually, I have been able to secure a little more time for research than before, so I have been writing up patent applications based on ideas and creating programs and beginning experiments. I am excited about my work and look forward to the results. This is because as a researcher, I want to produce results that are good enough to have my basic research or papers cited by other researchers. In addition, as I look to the future, I feel it would be great if I could team up with other researchers or even students in these research endeavors.

—Dr. Sawada, could you leave us with a word of advice for young researchers?

Finding a research theme that is always on your mind, even while you're soaking in a hot bath as I mentioned before, is happiness for a researcher. Furthermore, on hearing about other research, it's important that you find it interesting as well. I believe that a researcher, in essence, is a person that finds something interesting in everything. Whatever you approach may be general in nature or stem from research in another specialized field, but it should not be something that exists solely in your world. Being motivated by external stimuli is good.

Nowadays, however, papers on the level of international conferences can be retrieved off the Internet, and new information is always being uploaded, so you may discover that your research is already over the instant you begin your search! However, even if your search results reveal that someone else has beat you to it, I think a good response would be: "It can't be helped, but what matters is that I have chosen my direction." It is not rare for two or more groups in the world to be thinking about the same type of research at the same time. In such a case, I think it would be good that all groups concerned are acknowledged. Of course, if patents are involved, being the first to apply is important, but research also involves an element of having one's work understood, so while speed is important, please proceed without worrying too much. I am behind you in your work.

■ **Interviewee profile**
Hiroshi Sawada

Senior Research Engineer (Senior Distinguished Researcher), Head of Innovative Communication Laboratory, NTT Communication Science Laboratories.

He received a B.E., M.E., and Ph.D. in information science from Kyoto University in 1991, 1993, and 2001. He joined NTT in 1993. His research interests include statistical signal processing, audio source separation, array signal processing, machine learning, latent variable models, graph-based data structures, and computer architecture. From 2006 to 2009, he served as an associate editor of the Institute of Electrical and Electronics Engineers (IEEE) Transactions on Audio, Speech & Language Processing. He received the Best Paper Award of the IEEE Circuit and System Society in 2000, the SPIE ICA Unsupervised Learning Pioneer Award in 2013, and the Best Paper Award of the IEEE Signal Processing Society in 2014. He is an associate member of the Audio and Acoustic Signal Processing Technical Committee of the IEEE Signal Processing Society and a member of IEEE, the Institute of Electronics, Information and Communication Engineers, and the Acoustical Society of Japan.

Direction of Research and Development of Life-cycle Maintenance

Akira Okada, Akimasa Kaneko, and Masaki Kobayashi

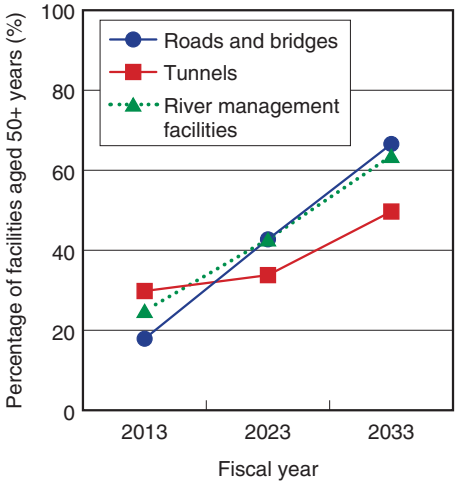
Abstract

Various social-infrastructure facilities have been constructed in Japan since the period of the country's rapid economic growth. These facilities are currently aging, and the cost related to their maintenance, management, and renovation has become a serious issue. It is therefore necessary to improve the efficiency of the maintenance and management cycle to reduce this enormous cost and extend the service life of facilities. In this article, we use the term *life-cycle maintenance* to refer to the entire life cycle of the maintenance and management of telecommunication infrastructure, from maintenance planning to inspection, diagnosis, and repair, reinforcement, and renovation. We introduce the direction of research and development of life-cycle maintenance and present case studies.

Keywords: life-cycle maintenance, safety and security, cost reduction

1. Introduction

Social-infrastructure facilities in Japan such as roads, bridges, and tunnels were built extensively during the period of rapid economic growth and just after, meaning that at present, these facilities are aging. The results of a survey on the aging of social-infrastructure facilities under the jurisdiction of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) (**Fig. 1**) indicated that about 20% of facilities in fiscal year 2013 (FY2013; from April 1, 2013 to March 31, 2014) were 50 years older or more. That percentage is expected to reach approximately 40% in FY2023, and approximately 60% in FY2033. These estimates show a trend of rapid aging of facilities. The cost of maintenance, management, and renovation of these facilities was estimated to be about 3.6 trillion yen in FY2013. In 20 years, the figure is expected to be somewhere between 4.6 trillion yen (1.5 times the FY2013 cost) and 5.5 trillion yen (**Table 1**). It is therefore necessary to reduce the total cost associated with maintenance, management, and renovation and to maintain the budget at a certain level.



Source of data: "FY2016 White Paper on Land, Infrastructure, Transport and Tourism in Japan" published by MLIT

Fig. 1. Percentage of social-infrastructure facilities aged 50 years or older.

Table 1. Cost of future maintenance, management, and renovation of social-infrastructure facilities.

	Estimated cost of maintenance, management, and renovation (trillion yen)
FY2013	3.6
FY2023	4.3–5.1
FY2033	4.6–5.5

Source of data: "FY2016 White Paper on Land, Infrastructure, Transport and Tourism in Japan" published by MLIT

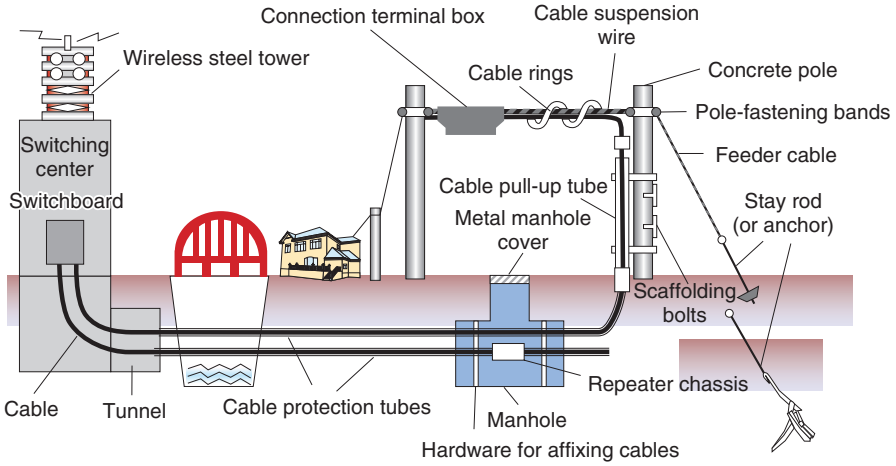


Fig. 2. Examples of typical telecommunication facilities.

Japan must also prepare against disasters and deal with rapidly aging social-infrastructure facilities under various constraints. These constraints include a decline in the working age population accompanying an overall shrinking population due to aging and a low childbirth rate and a strict fiscal environment. In recent years, socioeconomic conditions have been undergoing great changes due to the development of technologies such as the Internet of Things (IoT), big data, artificial intelligence (AI), robotics, and sensors. Efforts to overcome a variety of challenges and achieve sustained economic growth are underway by creating innovations and dramatically increasing productivity. The application of these advanced technologies to social-infrastructure facilities is expected to improve safety, reliability, and economic efficiency.

2. Current state of NTT Group's telecommunication infrastructure

Without exception, the conditions of the NTT Group's telecommunication facilities (**Fig. 2**) are similar in most ways to the rest of Japan's social-infrastructure facilities. In the areas of telephones and the Internet, equipment and devices such as servers and switches installed in telecommunication buildings are renovated when systems and technologies advance or diversify. In contrast, telecommunication infrastructure such as tunnels, conduits, manholes, concrete poles, branch wires, bridges, and wireless steel towers are maintained and managed for long-term use after their installation. The NTT Group currently operates a large number of telecommunication facilities (**Table 2**). It has been estimated that of these facilities, the proportion of manholes aged 50 years or older will reach about 60% in 2020 and 90% in 2030. For tunnels, the rate is estimated to be about

Table 2. Telecommunication facilities operated by NTT Group.

	Quantity possessed
Concrete poles	About 12 million
Cables	About 2.24 million km
Conduits	620,000 km
Tunnels	650 km
Manholes	680,000
Bridge-supported conduits	36,000 sites

Source of data: "Information NTT EAST 2016"

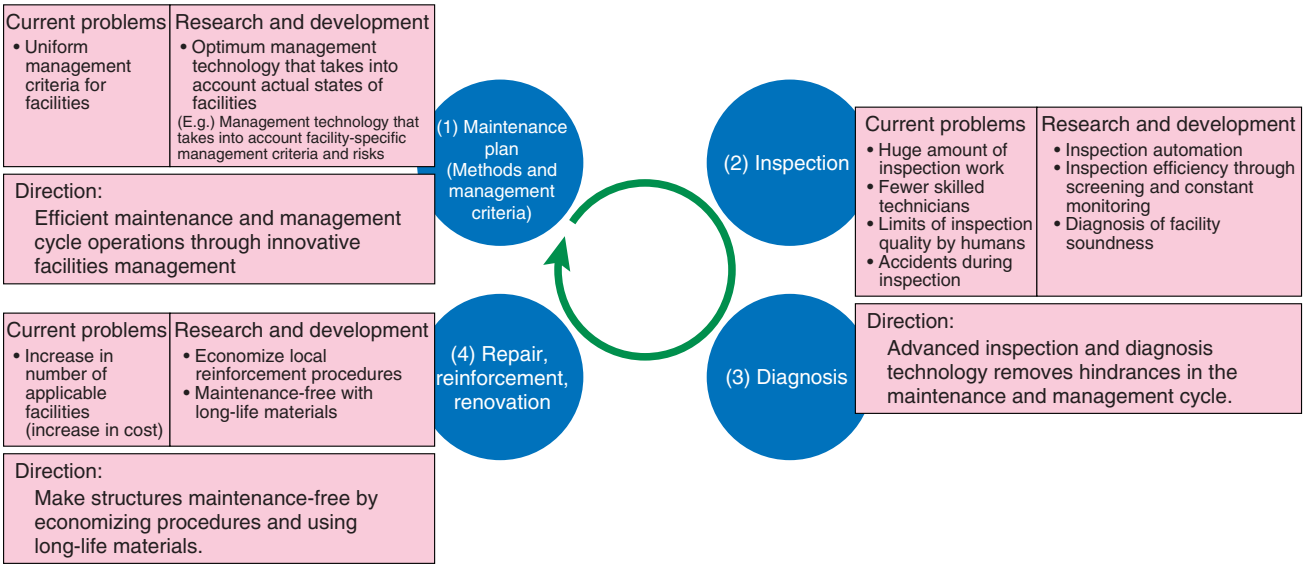


Fig. 3. Direction of R&D on life-cycle maintenance.

40% in 2030 and about 80% in 2040 [1]. Consequently, ensuring the safety and security of deteriorating telecommunication infrastructure while continuing to carry out maintenance and management has become a challenge.

Because of such conditions of the telecommunication infrastructure, the NTT research laboratories are developing technologies to maintain and improve the safety and security of telecommunication infrastructure, as well as to economically maintain and manage it. The maintenance and management cycle is shown in **Fig. 3**. Maintenance and management consists primarily of the steps of (1) maintenance planning, (2) inspection, (3) diagnosis, and (4) repair, reinforcement, and renovation. In the first four Feature Articles in this issue, this life cycle of maintenance and management in its entirety is called life-cycle maintenance. The direction of research and development (R&D) on life-cycle maintenance is introduced in these articles.

3. Direction of R&D of life-cycle maintenance

Maintenance and management of telecommunication infrastructure is carried out in accordance with management criteria determined in advance for each type of facility. Management criteria are standards for determining the inspection interval, inspection items, degree of degradation, and methods of repair, reinforcement, and renovation based on the extent of degradation. The stage of planning overall maintenance and management is called the maintenance

planning stage. A maintenance plan is formulated based on the facility's management criteria such as the inspection interval, inspection items, determination of pass/fail, and timing of repair, reinforcement, and renovation.

In many cases, management criteria are currently dealt with uniformly for facilities using as references standards already established for general buildings worldwide. Because the inspection interval is uniformly determined, facilities with almost no degradation and facilities with progressing deterioration can take up about the same amount of labor. As a result, efficiency is reduced. However, if we adopt management criteria based on the degradation conditions of individual facilities, the maintenance and management cycle can proceed more efficiently. Inspection of facilities with almost no degradation can be omitted, and detailed inspection and repair and reinforcement can be applied to deteriorating facilities. In this way, the objective of the maintenance planning stage is to achieve efficient maintenance and management cycle operations through innovative facilities management.

Next, inspection and diagnosis are carried out according to the maintenance plan. Currently, visual inspections are still conducted for many facilities. Despite the growing number of deteriorating facilities, the number of skilled workers is declining. As a result, implementing more efficient inspection and diagnosis has become a challenge.

In recent years, the Fourth Industrial Revolution, as represented by IoT, big data, AI, robotics, and sensors, has been advancing globally, and technological developments have been progressing [2]. Specifically, technologies for predicting the timing of inspection and renovation are being developed by leveraging facility degradation data accumulated over long-term use, establishing models to predict degradation, and using big data such as facility data, inspection data, and weather and soil data. In this way, the removal of hindrances in the maintenance and management cycle is being sought with advanced inspection and diagnosis technologies.

Repair, reinforcement, or renovation is carried out when the results of inspection and diagnosis indicate a facility exceeds predetermined criteria. Repair, reinforcement, or renovation is implemented taking into account the state of a facility's degradation and damage. An appropriate level of repair and reinforcement is carried out for facilities with slight degradation to keep down the cost in the total life cycle. In contrast, for facilities with advanced degradation and damage, the sharp rise in the number of facilities to be repaired, reinforced, or renovated—and the associated cost—is a problem. Therefore, ways to improve the economic efficiency of methods of local reinforcement, repair, and renovation are being sought. Making facilities maintenance-free is also desired in the case of facilities requiring renovation by using materials with a long service life.

Next, we describe the effects of R&D on life-cycle maintenance. Here we define the amount of maintenance needed due to facility degradation as the *necessary amount of maintenance*. We define the amount of maintenance that can be carried out by maintenance and management workers and the maintenance budget as the *feasible amount of maintenance*. To carry out sustained maintenance, the feasible amount of maintenance must exceed the necessary amount of maintenance. The necessary amount of maintenance increases greatly for telecommunication infrastructure facilities with advanced degradation. Furthermore, the feasible amount of maintenance is decreasing due to the shrinking number of skilled workers. If this situation is left unchecked, the necessary amount of maintenance will exceed the feasible amount of maintenance, and there is the danger that sustained maintenance and management will no longer be possible.

Advances in inspection and diagnosis technologies such as those reported above and improvements in the economic efficiency of repair, reinforcement, and renovation methods can effectively boost the feasible amount of maintenance. Also, making facilities maintenance-free by prolonging and extending service life through repairs and reinforcements is effective in controlling the increase in the necessary amount of maintenance. As a result, it is possible to maintain the state in which the feasible amount of maintenance exceeds the necessary amount of maintenance, making it possible to carry out sustained maintenance and management of telecommunication infrastructure (**Fig. 4**).

4. Life-cycle maintenance-related efforts

Three examples of NTT's efforts in life-cycle maintenance are introduced in Feature Articles in this issue.

4.1 Improved efficiency of manhole inspection using technology to automatically determine degree of degradation [3]

Degradation of telecommunication infrastructure

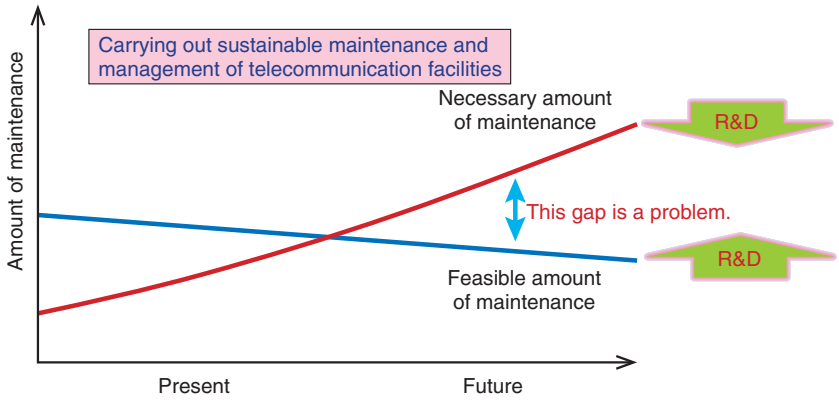


Fig. 4. Effects of R&D on life-cycle maintenance.

facilities not only interrupts telecommunication services but is also a cause of road collapses. Such degradation can be highly problematic in society, so it is necessary to understand degradation conditions in a timely manner (inspection) and to carry out appropriate repair, reinforcement, or renovation based on the degree of degradation (maintenance planning and repair and reinforcement). Because many of these facilities in Japan were constructed more than 30 years ago, maintenance in the form of inspection and planning and repair and reinforcement is necessary for a great number of facilities. To efficiently execute the maintenance cycle, it is critical to model and predict degradation. Data accumulation is also considered to be important for modeling degradation and improving the accuracy of deterioration prediction.

To improve inspection efficiency and accumulate high-quality images, NTT has developed technology to inspect manholes without having to enter the manholes by using a deterioration determination function (with an original image processing algorithm). A robotic arm equipped with a camera is inserted into the manhole; it captures images of the upper floor plate where degradation such as cracks exposing reinforced bars in concrete are noticeable and automatically determines the degree of degradation from the obtained images. The accuracy of degradation detection is improved by combining color detection and shape detection. In this way, workers can carry out tasks safely without the need to enter manholes, and in most cases, without having to drain water from manholes, which had been necessary in the past. As a result, inspection tasks can be greatly simplified. Because high-quality images can be accumulated, they can also contribute to improving the sophistication of future maintenance cycles.

4.2 Accelerated corrosion testing of anti-corrosion coatings simulating water absorption behavior [4]

Outdoor steel structures such as wireless steel towers installed on NTT stations are applied with new paint or repainted if the results of inspection fall below maintenance criteria. The NTT Group possesses a large number of outdoor steel structures, and the cost associated with painting is enormous. This cost must therefore be lowered by selecting paints with strong anti-corrosion and longevity properties through accelerated corrosion testing and by lengthening the interval between repainting. The corrosion resistance and longevity properties of paints have improved. However, as a consequence, there is an increase in the number of cases where determining the quality of paints has taken more time than in the past.

There is therefore a growing need to shorten the testing time. However, simply introducing stricter testing conditions can lead to the occurrence of different kinds of degradation in the actual environment. A type of paint with outstanding test results may not necessarily perform well in the actual environment.

We therefore developed the NTT Cyclic Corrosion Test (CCT-N). This test can promote corrosion faster than conventional accelerated corrosion tests. It also uses new testing conditions that quickly mimic actual conditions in which the relative merits and deficiencies of test paints can be well observed. This new approach focuses on the water absorption/desorption behavior of test paints. The results of studying test conditions with this new method showed that water absorption was almost the same in the test environment

as in the actual environment. We are achieving quick and similar testing conditions by adopting test conditions that hold water desorption to a minimum.

4.3 Deterioration mechanism-based risk assessment of telecommunication facilities [5]

The aging of social-infrastructure facilities is becoming a social issue. To resolve this problem and to establish an efficient long-term maintenance plan, priority must be assigned to the great number of aging facilities that should receive attention, and when and what measures should be carried out. We adopt the concept of *risk* as an indicator of prioritization and are researching techniques for estimating this risk. The Feature Article "Risk Assessment of Outdoor Telecommunication Facilities Based on Deterioration Mechanisms" introduces our research on buried anchors.

Risk assessment of buried steel structures considers that risk equals (1) the degree of degradation × (2) the consequences of failure. To devise a long-term and efficient plan, it is necessary to predict the degree of degradation of facilities in the future. However, because underground structures are particular environments that cannot be inspected visually, it is difficult to directly understand a facility's degree of degradation. The extent of degradation also cannot be predicted statistically from past accumulated data. We are therefore seeking to predict deterioration by clarifying from the standpoint of materials science the deterioration mechanisms of buried steel structures and creating theoretical models.

Degradation of buried steel structures proceeds primarily as a result of soil corrosion. To elucidate the mechanisms of soil corrosion, we are conducting buried soil tests outdoors and electrochemical experiments in simulated soil environments created in the lab. We set the goal of estimating environmental factors of soil from information on weather and soil conditions. We are also continuing to clarify relationships between the rate of corrosion and environmental factors under various soil conditions. Going forward, we seek to develop concrete theoretical models that predict deterioration from information on weather and soil conditions and calculate the consequences of failure as a risk factor (2).

5. Future development

To advance R&D on life-cycle maintenance, it is necessary to not just focus on technologies related to telecommunication infrastructure and the materials of facilities, as has been done until now. It is also necessary to apply diverse technologies such as IoT, big data, AI, robotics, and sensors. Toward this end, the NTT laboratories are actively collaborating with one another and with external organizations. Because there are also social infrastructures similar to telecommunication infrastructure, we are also seeking to expand our achievements externally.

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Automatic Deterioration Evaluation Technique to Improve the Efficiency of Manhole Inspection

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Abstract

We have developed a non-entry manhole inspection technique with a function for automatic deterioration judgment. This enables workers to operate safely without having to enter manholes and can eliminate the need to drain manholes, substantially reducing the inspection workload. This technique not only improves the safety and efficiency of manhole inspections but also yields high-resolution inspection images that can be used to accurately predict the deterioration of facilities. It can therefore play an important role in improving the maintenance cycle.

Keywords: manholes, non-entry inspection, automatic deterioration evaluation

1. Introduction

Telecommunication and civil engineering facilities such as ducts and manholes are mostly buried under roads, where they are subjected to external forces such as soil pressure, groundwater pressure, and the loads exerted by passing vehicles. Over time, this can lead to degradation of the facilities such as corrosion, deformation, and cracks in concrete structures. This degradation can lead to various problems, including not only interruption of telecommunication services but also the collapse of roads. It is therefore important to inspect these facilities in a timely manner so that appropriate repair/reinforcement or renewal measures (maintenance planning/repair and reinforcement) can be implemented.

Much of the telecommunication infrastructure in Japan was constructed over thirty years ago, and trends such as long-term deterioration of facilities and reductions in the number of skilled workers make it important to ensure that the abovementioned maintenance cycle (inspection, maintenance planning, and repairs/reinforcement) of the enormous number of equipment facilities is made more efficient. For this sort of maintenance cycle, we are promoting at NTT Access Network Service Systems Laboratories research and development aimed at achieving fundamental reforms (operational innovation) in operation and maintenance work.

2. Importance of inspection technology

Implementing a maintenance cycle efficiently requires technologies for preferentially inspecting and preserving equipment that has already deteriorated, as well as techniques for preventing deterioration. The degree of deterioration in facilities is greatly influenced by the installation environment, so it is important to ascertain, examine, and model the effects of this environment. It is also necessary to prioritize conservation efforts by predicting deterioration based on time-series analysis of the state of degradation.

The inspection results are traditionally recorded in

a form such as text input or sketches that are difficult to analyze as a temporal series, making it impossible to model or predict deterioration with sufficient accuracy. However, obtaining and storing the inspection results in the form of high resolution images may make it possible to solve these issues. With high resolution images, image processing techniques can be used to determine the amount of deterioration automatically, and the resulting data can also be used for time-series analysis because it is possible to gather information about how the degradation is progressing. This problem has a strong affinity to deep learning,[*1] which is evolving rapidly, and is expected to lead to innovative deterioration analysis tools through the use of advanced next-generation image processing technology.

Thus, in developing techniques aimed at revolutionizing the maintenance cycle of such facilities, it is vital to develop techniques that not only ascertain the current state of deterioration but also provide data that can be used to model and make future predictions about this deterioration.

3. Difficulties in manhole inspection

NTT is responsible for approximately 680 thousand manholes nationwide. Currently, these manholes are mostly inspected by having workers enter the manholes to perform a visual inspection and record the state of deterioration. However, these inspections involve dangers including the risk of falls and a lack of oxygen. Also, since most of the manholes have accumulated water, it is necessary to drain the accumulated water from the manhole with a pump before entering it, and this greatly increases the time and cost of inspections. At NTT Access Network Service Systems Laboratories, we have developed a non-entry manhole inspection technique aimed at resolving these problems and using image processing to enhance the quality of inspections.

4. Non-entry manhole inspection technique

Long-term deterioration of manholes is caused by corrosion of reinforcing bars inside the concrete. As the corrosion proceeds, the reinforcing bars eventually become exposed. This corrosion reduces the cross-sectional area of the reinforcing bars and reduces the manhole's strength.

We confirmed from the results of previous research done by NTT Access Network Service Systems Laboratories that the sign of reduced strength in NTT's standard manholes tends to be manifested more clearly in the upper plates of these structures [1, 2]. We therefore focused on the upper plates where deterioration such as exposed reinforcing bars is likely to occur and developed an inspection technique in which a camera mounted on a movable arm is used to capture images of the upper plate, and the state of deterioration is automatically judged from these images.

The apparatus consists of a movable arm equipped with a camera that is inserted through the manhole opening on the ground. The camera then takes pictures of the upper plate of the manhole interior. We used a structure whereby an L-shaped guide is provided so that the camera can move parallel with the upper plate. By using a camera with a wide-angle lens, we can take pictures over the entire length of the upper plate as long as a distance of 50 cm can be maintained between the upper plate and the camera (**Fig. 1**). The upper plate is photographed at fixed intervals while moving the camera, and then image processing is carried out to stitch these photographs together and automatically evaluate the state of deterioration. With this technique, since the movable arm moves to a position 50 cm away from the upper plate, in most cases there is no need to drain the interior of the manhole. This speeds up the inspection work and reduces the cost.

5. Automatic upper plate imaging device

A manhole must be repaired when there is pronounced deterioration involving exposed reinforcing bars and peeling concrete, which can be detected from the results of stitching together images of the upper plate. To ensure that the images are of sufficient quality for detecting deterioration, two types of lighting are provided: fixed lighting and movable lighting. Direct light from the fixed lighting and indirect light from the movable lighting can be used together to provide uniform illumination of the manhole upper plate (**Fig. 2**). Furthermore, when the photographs are processed, a laser pointer mounted next to the camera makes it possible to correct variations in the camera range and orientation by detecting the spot of light produced by this pointer (Fig. 2).

In the image stitching process and automatic deterioration judgment, it is preferable that the series of images are of uniform quality. If the camera is kept at

*1 Deep learning: A machine learning method whereby a system recognizes or classifies data by learning its characteristics.

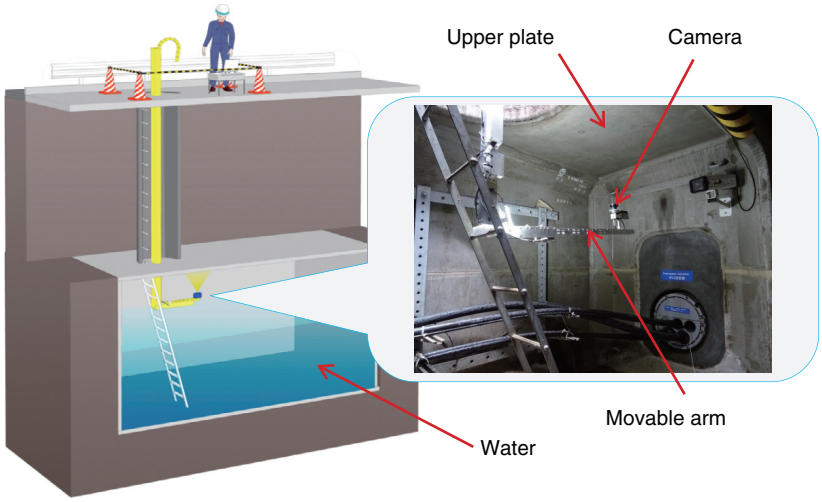


Fig. 1. Non-entry manhole inspection.

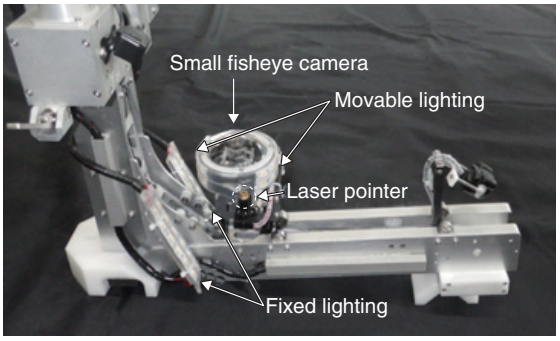


Fig. 2. Mechanism of illuminance homogenization.

a fixed distance and orientation with respect to the upper plate, then each pixel will have the same length and information content. However, in a large manhole, the arm must be extended up to 2.5 m. With such a large extension, the arm can sag due to the weight of the arm material and the clearance between adjacent parts of the arm. This would necessitate some sort of mechanism to suppress sagging when the movable arm is extended. However, by making improvements including reducing the weight of the camera arm, optimizing its shape, and inserting spacers at its connection points, we were able to suppress the amount of sagging at the tip of the L-shaped guide to within 5 cm vertically.

6. Upper plate image stitching

Image stitching is necessary in order to obtain a single image of the upper plate, but first the variations in the distance between the upper plate and the camera and the viewing angle between each individual photo due to deflection of the camera arm must be corrected. This was done by using light spot detection as discussed above. Light spot detection is an image analysis technique that detects and acquires coordinates of red laser light emitted from the device [3].

After the photographs captured at fixed intervals were corrected by light spot detection, we used AKAZE feature quantities (OpenCV 3.0.0 library) to detect the locations in each neighboring image with matching features, and we stitched the images together by superimposing these points (**Fig. 3**). By repeating this operation, we ended up with a single upper plate image.

7. Deterioration evaluation technique

The color of each deteriorated location (such as exposed reinforcing bars) differs significantly from that of the concrete surface (**Fig. 4**), but the large number of false positives caused by surface dirt or surface patterns leads to practical difficulties when attempting to detect deteriorated locations based on color information alone. We therefore improved the detection accuracy by concentrating on the fact that the reinforcing bars are linear, and combining color-based detection with the detection of shapes with

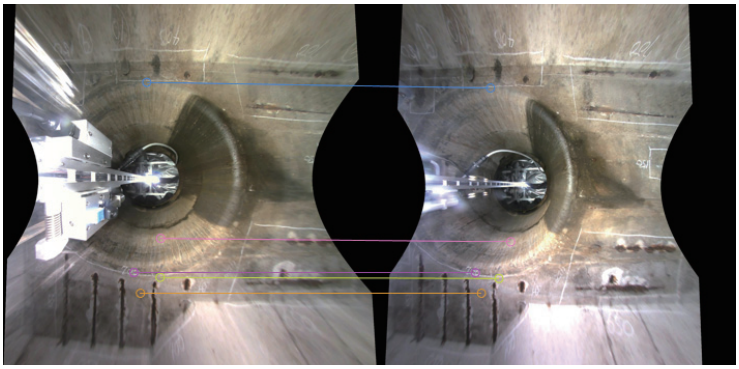


Fig. 3. Image stitching using feature matching.

Fig. 4. Degradation of upper floor plate (exposed reinforcing bars).

linear characteristics corresponding to the reinforcing bar width.

7.1 Color detection

Since the brightness and hue of the photos vary depending on the imaging environment inside the manhole, a threshold value for the detection of deteriorated parts was set based on the color of an area of sound concrete when performing color detection. The color of sound concrete is defined as the color that occupies the largest area in an image with reduced colors. To distinguish between rust water stains and reinforcing bars, we converted the image into the L*a*b* color space[*2] for processing. In the L*a*b* color space, it is possible to distinguish between rust water stains and reinforcing bars in the b* (blue-yellow) channel, as shown in **Fig. 5**. With the ability to distinguish between rust water stains and reinforcing bars in this way, it is possible to classify darker patches as rust water stains when they are adjacent to a reinforcing bar and as surface contamination when they are not adjacent to a reinforcing bar, as shown in **Fig. 6**. To extract these corresponding regions at each site of deterioration (exposed reinforcing bars, rust water stains, or peeling), we set a threshold value t as shown in Eq. 1 to distinguish these regions from the color of a sound concrete surface (L^*_N, a^*_N, b^*_N).

$$t_{N,M} = \alpha_{N,M} \mathrm{N} + \beta_{N,M} \quad (1)$$

Here, $\mathrm{N} = L^*_N, a^*_N, b^*_N$, $\mathrm{M} = \{\text{rebar/stain/peel}\}$. The L*a*b* color space image is binarized[*3] using the derived threshold value, and candidate regions for each type of deterioration are obtained by evaluating the following logical products.

$$\text{Reinforcing bar } \mathrm{F} = B_{L^*,\,\text{rebar}} \,\&\, B_{a^*,\,\text{rebar}} \,\&\, B_{b^*,\,\text{rebar}}$$
$$\text{Rust water stain } \mathrm{R} = B_{L^*,\,\text{stain}} \,\&\, B_{a^*,\,\text{stain}}$$
$$\text{Peeling } \mathrm{S} = B_{L^*,\,\text{peel}} \,\&\, \mathrm{not}(B_{a^*,\,\text{stain}})$$

B is a binarized image obtained by applying each set threshold value.

7.2 Shape detection

For shape detection, we used information about the width of the reinforcing bars. The reinforcing bars inside manholes are generally 8–12 mm in diameter. The number of pixels occupied by the width of a reinforcing bar can be calculated from the light point coordinates of the laser pointer as described above. This enabled us to detect reinforcing bars by scanning

*2 L*a*b* color space: A color space that is derived from the XYZ color space but has greater perceptual uniformity. L* represents a color's lightness, while a* and b* are chromaticity values representing its hue and saturation.

*3 Binarization: The process of converting an image into two tones (white and black).

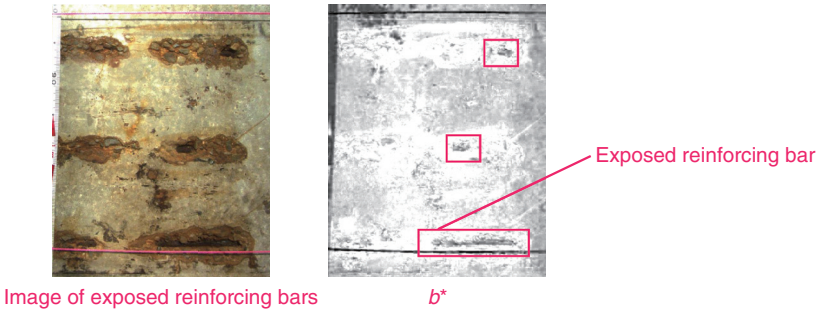


Fig. 5. Conversion by L*a*b* color system.

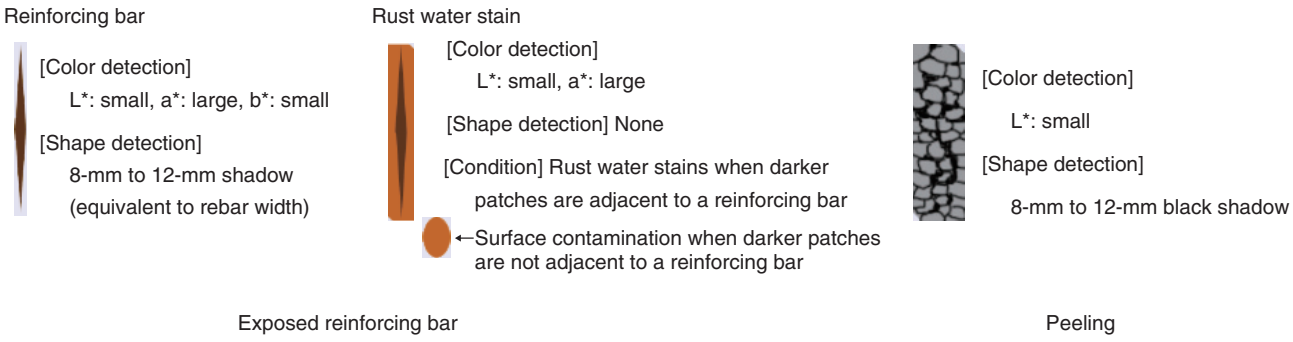


Fig. 6. Color information of each deteriorated part.

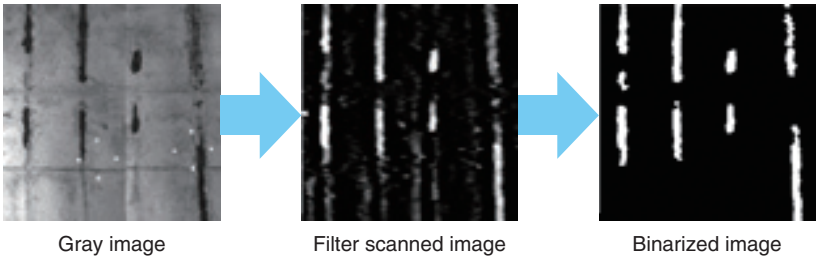
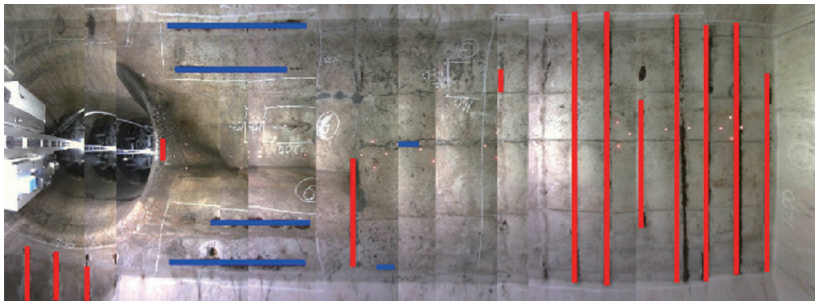


Fig. 7. Shape detection by image filter operation.

the image with a filter having a column width equal to the calculated number of pixels. The results are shown in **Fig. 7**, where one can see that it is possible to extract linear shapes having the width of reinforcing bars.

8. Application of technique to inspect manholes

In manhole inspections using this technique, a fixed pedestal is set in place after opening the manhole, and the movable camera arm is fixed to this pedestal. Then a personal computer is used to control the arm extension, photograph the upper plate, stitch the photographs together, and perform automatic deterioration judgment. In the inspection results, as shown in **Fig. 8**, the exposed reinforcing bar locations are shown as masked out regions, enabling the user to visually judge the state of deterioration. The series of inspection tasks from installing to removing the equipment can be performed by one worker in about



Red lines: vertical rebar
Blue lines: horizontal rebar

Fig. 8. Shape detection by image filter operation of automatic deterioration detection.

15 minutes (equivalent to the actual inspection time taken for a conventional manhole check). In this technique, however, since the movable arm moves at a position 50 cm away from the upper plate, there is no need to drain the manhole in most cases, which substantially reduces the inspection time compared to the conventional method. Thus, it reduces the amount of labor and the cost compared with conventional inspection. Also, since deterioration is detected automatically from photographic images, this technique is less dependent on worker skill and less likely to overlook degraded parts. Furthermore, it can be used to prioritize maintenance efforts by accumulating data that can be quantitatively evaluated.

9. Future prospects

To thoroughly reform our facilities maintenance cycle, we have developed a non-entry manhole inspection technique with a function for automatic deterioration judgment. This technique makes it possible to carry out manhole inspection work more safely since there is no need for workers to enter the manhole. Also, since it is possible to eliminate almost all of the drainage work that has hitherto been necessary, this technique can greatly reduce the time taken for manhole inspections and can increase the efficiency of inspection work. Furthermore, since the state of deterioration is automatically judged from high resolution images, it is possible to prevent problems from being overlooked. This means that a high inspection quality can be guaranteed without having to rely on the skills of the worker performing the inspection.

The use of high resolution images in the operation and maintenance of infrastructure facilities yields valuable information for increasing the precision of deterioration models and deterioration predictions. Although this current study was focused on improving the efficiency of the maintenance cycle from the viewpoint of inspection technology, NTT Access Network Service Systems Laboratories aims to further increase the efficiency of the maintenance cycle and will continue to promote research and development of all factors relating to inspection, conservation planning, and repair reinforcement.

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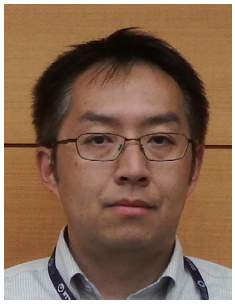

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Accelerated Corrosion Test for Evaluating the Corrosion Resistance of Coatings

Takashi Miwa, Yukitoshi Takeshita, Azusa Ishii, and Takashi Sawada

Abstract

We developed a new accelerated corrosion test for evaluating the corrosion resistance of coatings. The new test was designed to approximate the water absorption and desorption behavior of anti-corrosion coatings in actual outdoor environments. This test makes it possible to well approximate atmospheric corrosion in seafront areas and to accelerate the corrosion of steel and zinc by around 1.4 times compared with the conventional method. This test will make it possible to efficiently and accurately select coatings in a shorter test time. Consequently, the maintenance cost of steel structures can be reduced by selecting the appropriate coatings.

Keywords: coating, accelerated corrosion test, cyclic corrosion test

1. Introduction

The NTT Group has a huge number of outdoor telecommunication facilities, with many composed of metallic materials or painted metallic materials. Whether outdoor steel structures such as wireless towers on NTT buildings should be painted and repainted is determined on the basis of inspection results. The NTT Group has many outdoor steel structures, so the cost of painting is huge. Furthermore, in the near future, the number of facilities that need new paint is expected to increase, which will drastically increase maintenance costs. Therefore, highly reliable and long-lasting coating materials with high resistance to corrosion must be selected in order to reduce the maintenance costs of outdoor steel structures. The selection process involves conducting various accelerated tests to evaluate the performance of coatings. Coatings that surpass the criteria are subsequently adopted.

2. Accelerated corrosion tests for evaluating coatings

The various accelerated tests for coatings include accelerated corrosion tests for evaluating resistance to atmospheric corrosion in seafront areas. The representative accelerated corrosion tests are the salt spray test (SST), which uses a continuous salt water spray (salt fog), and the cyclic corrosion test (CCT), which repeats salt fog, drying, and humidity steps (**Fig. 1**).

In the past, the SST was widely used as a basic accelerated corrosion test. However, since corrosion behaviors differ considerably between the SST and outdoor environments, the performance of coatings evaluated using SST does not necessarily match the performance of coatings in those environments.

Therefore, the CCT has become popular over the past 20–30 years. The CCT is certainly an excellent accelerated corrosion test that has few problems, but it requires a very long test time. With CCT, the corrosion resistance and lifetime of the coatings have improved year to year, but at the cost of longer test times to judge the comparative merits and demerits of

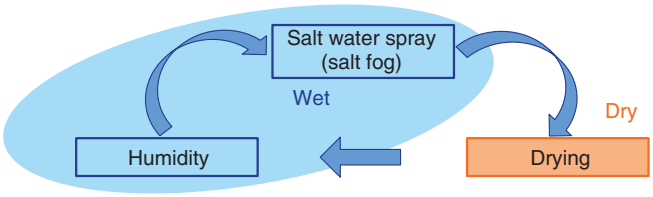


Fig. 1. Flow of accelerated corrosion test.

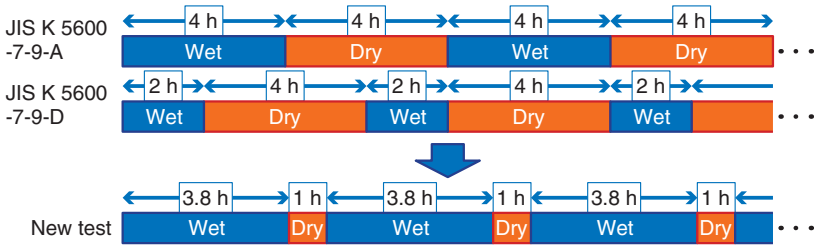


Fig. 2. Wet-dry intervals of existing CCTs and new CCT.

the improved coatings. Therefore, there is an increasing need to shorten the test time.

In this article, we introduce a new CCT called the NTT Cyclic Corrosion Test (CCT-N) that can accelerate corrosion compared to the conventional SST and CCT and reproduce the corrosion behavior of outdoor exposure.

3. Conventional CCT and new hypothesis

Despite the increasing demand for shortening the test time, a method to further accelerate corrosion in the CCT has not been studied in recent years. In the prevailing test conditions in the existing CCT (JIS* K 5600-7-9 methods A and D) in Japan, drying times account for over half of the total test time (**Fig. 2**). Since corrosion does not proceed after a sample has completely dried, the average corrosion rate (the speed at which a metal deteriorates in a specific environment) could be improved and the test time shortened by reducing the drying time. However, when the CCT was developed, it was considered that a low wet-time ratio was absolutely essential for approximating the actual environmental corrosion. The wet time ratio is defined as the sum of the times for the salt fog and humidity steps divided by the total testing time. Wet time ratios of 50% or less have been recommended up to the present [1]. In addition, coating standards in Japan stipulate that many kinds of coatings should be evaluated using JIS K 5600-7-9 method A or D; therefore, there was not much motivation to modify the test conditions. For these reasons, much research in recent years has been aimed at approximating atmospheric corrosion in seafront areas rather than improving the corrosion rate and shortening the test time.

In contrast, we consider that a continuous wetting time, not the wet time ratio, is of major importance for achieving corrosion behavior similar to that in outdoor exposure. Normally, absorbed water in the coatings takes some time to reach the coating/steel substrate interface. Consequently, the behavioral variation in water quantities at the interface will be very different between short dry-wet intervals and long dry-wet ones even if the wet time ratios of the CCTs have the same value.

Thus, we focused on the behavior of water absorption and desorption in the coating film. Water and oxygen are necessary for corrosion to progress. When the coating film is dry, only oxygen is present in it. After wetting, water is absorbed into the coating film and reaches the interface between the coating/steel substrate, and the steel is corroded by water and oxygen. In contrast, if the coating has been wet for a long time, oxygen will run short at the coating/steel interface. In actual outdoor environments, this wetting and

* JIS: Japanese Industrial Standard

drying is repeated.

In an accelerated corrosion test, in order to accurately simulate coating corrosion in actual outdoor environments, it is desirable to set the test conditions of the CCT so that the water absorption of the coating film is not excessive or insufficient, as in the actual outdoor environments. In addition, a wet time ratio of more than 50% of the test time is not considered to be a problem.

A survey of the CCT literature revealed that authors consider a continuous wetting time of four hours or less to be appropriate in CCT. From this consideration, we decided to increase the wet time ratio and set the continuous wetting time at four hours or less in our new CCT.

4. Test conditions of CCT-N

In this section, we explain the key elements of the CCT-N test conditions.

4.1 Temperature dependence

In accelerated corrosion tests, corrosion is generally accelerated at temperatures higher than those in the actual outdoor environments. The temperature in the salt fog, drying, and humidity steps differs depending on the CCT. The water absorption and desorption rates of the coating films proceed faster as the temperature increases. For this reason, we considered that it is insufficient to simply set the continuous wetting time at four hours or less and that the wetting (salt fog and humidity) time and drying time should be considered with this temperature dependence taken into account.

Therefore, we investigated the temperature dependence of water absorption and desorption in the coating film and tried to prepare test conditions that would make the water absorption/desorption behavior of the coating film in CCT consistent with that in the outdoor environments.

First, we conducted absorption/desorption tests at various temperatures. In these tests, the coating films absorbed water and were then placed in a temperature and humidity controlled chamber and left to dry. The speeds of water absorption/desorption were obtained, and then the diffusion coefficients of water in the coating films at each temperature were obtained. Next, their temperature dependence (activation energy) was calculated using the diffusion coefficient at each temperature. With these values, it is possible to determine the water absorption/desorption behavior of the coating at any temperature and elapsed time.

4.2 Salt fog and humidity steps

Next, we used actual weather data to determine the temperature and time of the salt fog and humidity steps in the CCT. The coating film absorbs the maximum amount of water in the actual outdoor environment when it has been wet for a long time during a high-temperature period. The weather data indicated that the continuous wetting time (humidity of 80% RH (relative humidity) or more or precipitation) in the actual outdoor environment accounted for 20 to 50 hours, and it rarely exceeded 50 hours. It was also found that the temperature in a longer continuous wetting period was around 25°C in the summer.

Therefore, we prepared a new test condition that simulates water absorption at 25°C for 50 hours. Using the temperature dependence of water absorption obtained from the above experiment, we found that the coatings absorbed the same degree of water through the salt fog step at 35°C for 0.8 hours and the humidity step at 50°C for 3 hours [2].

In contrast, the calculation of the water absorption behavior in existing CCTs (JIS K 5600-7-9 methods A and D) suggested that method A (CCT-A) was able to reproduce water absorption similar to that in the outdoor environment (25°C for 50 hours) and that method D (CCT-D) was not able to do so (**Fig. 3**). Although CCT-D is generally used in the evaluation of coatings for steel structures, it is not possible to reproduce water absorption that occurs in wetting for a long time during a high-temperature period. Therefore, a remaining concern was that even if coatings presented good results in CCT-D, not all of them would show good performance in actual outdoor environments.

4.3 Drying step

Next, we examined the time taken for drying in the CCT. As described earlier, since corrosion does not proceed after a sample is completely dry, a shorter drying time is advantageous for shortening the test time. However, if the coating films are not sufficiently dry and tests are conducted in which the moisture content of the coating films is always high, the performance of coatings evaluated by CCT will not match the performance of coatings in actual outdoor environments.

Therefore, it is necessary to ensure that the coating is sufficiently dry. Our simulations of the water desorption behavior of the coating film revealed that the coating film can dry sufficiently even if the drying time is shorter than that in existing CCTs. We therefore determined that the drying step time should be

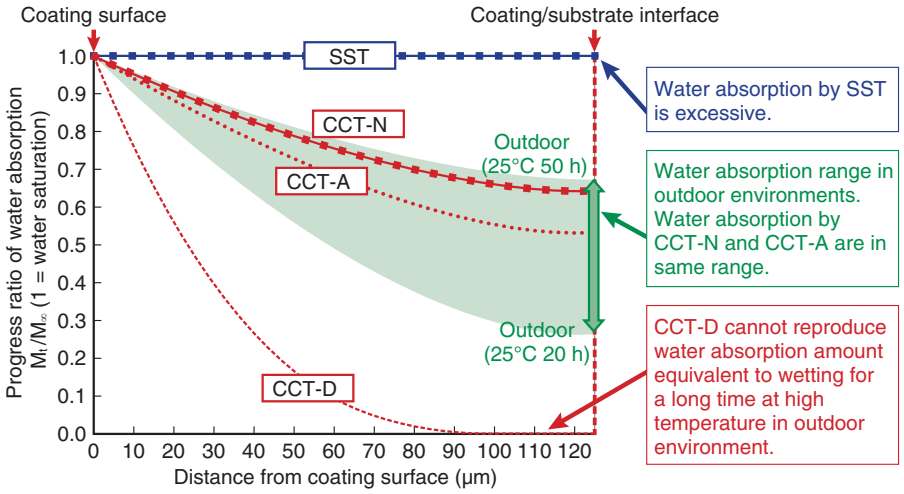


Fig. 3. Simulation result of water absorption behavior.

Table 1. Programs and corrosion rates of each accelerated corrosion test [4].

	Salt fog (salt water spray)		Drying		Humidity		Wet time ratio	Corrosion rate of steel
	Temp. (°C)	Time (h)	Temp. (°C)	Time (h)	Temp. (°C)	Time (h)	(Salt fog + Humidity) /All steps (h)	g/m²/day
SST	35	continuous	–	–	–	–	100%	37.8–40.7
CCT-D	30	0.5	50→30	2→2	30	1.5	33%	27.4–30.9
CCT-A	35	2	60	4	50	2	50%	76.2–80.1
CCT-N	35	0.8	60	1	50	3	79%	108–120

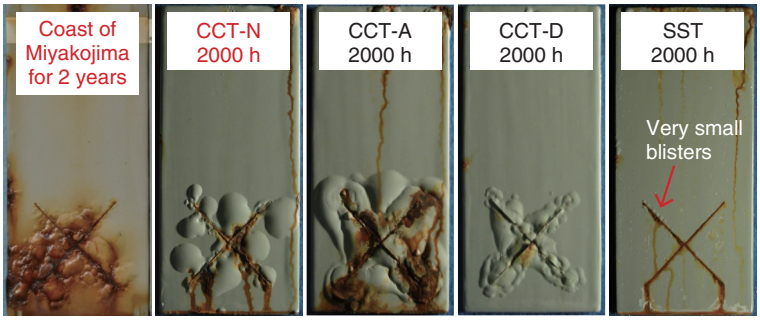
one hour. In general, the diffusion coefficient of water in polymer materials is the same for both water absorption and desorption, and in many cases, only one of them is measured. As easily imagined, it is quite difficult to reduce the time for the drying step using the same diffusion coefficient. We have already reported experimental data suggesting that the coating film had difficulty absorbing water and dried easily [3]. Therefore, we were able to carry out simulations using accurate diffusion coefficients for water absorption and desorption, which differ depending on each process, and to significantly shorten the drying step time as a result.

Under the new CCT conditions in CCT-N determined through our investigations, the corrosion rate of steel was around 1.4 times higher than in CCT-A and 4 times higher than in CCT-D (**Table 1**).

In addition, we prepared coated steel samples and exposed the samples to the outdoors in order to compare their corrosion behavior in different tests. The samples were placed on the coast of Miyakojima island, Okinawa, Japan, for two years, where CCT-N and other accelerated corrosion tests were performed. We found that the corrosion behavior in the SST without the drying step greatly differed from the behavior in the outdoor exposure, that the corrosion behavior did not differ much among various CCTs, and that CCT-N was able to reproduce the corrosion behavior of outdoor exposure well (**Fig. 4**) [4]. Thus, we concluded that CCT-N is an excellent accelerated corrosion test that can speed up the corrosion of steel 1.4 to 4 times compared to existing CCTs and can concurrently reproduce corrosion similar to that in the actual outdoor environment.

5. Future prospects

CCT-N can be carried out by installing test programs in common CCT instruments. Therefore, users of CCT instruments can introduce CCT-N without



pH or water in blisters	Alkaline (from literature)	Alkaline	Alkaline	Alkaline	Acidity
Mechanism of blistering	Cathodic blistering (from literature)	Cathodic blistering	Cathodic blistering	Cathodic blistering	Anodic blistering
Size of blisters	Large	Large	Large	Large	Small

Fig. 4. Corrosion behavior of coated steel samples [4].

any additional cost. CCT-N will enable users to accurately select coatings that are more resistant to corrosion and have a longer life, in a shorter test time. Use of the appropriate selected coatings is expected to reduce the maintenance costs of steel structures.

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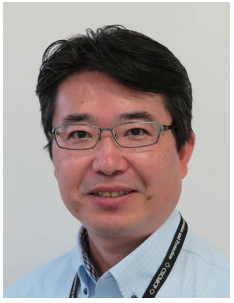

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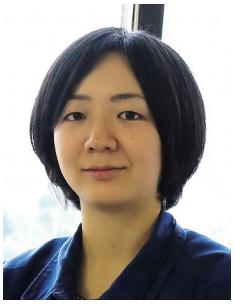

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Risk Assessment of Outdoor Telecommunication Facilities Based on Deterioration Mechanisms

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Abstract

Dealing with the daunting challenges of aging infrastructure will require an efficient long-term maintenance plan for prioritizing the vast backlog of equipment and facilities that need to be upgraded or replaced in the future. To this end, NTT Device Technology Laboratories has introduced the concept of risk as a key indicator for prioritizing maintenance work on telecom infrastructure facilities. We describe here recent work in applying this approach to a basic piece of telecom-related hardware—buried anchors used to stabilize utility poles.

Keywords: deterioration mechanism, risk assessment, soil corrosion

1. Introduction

Much of Japan's public infrastructure, including roads and highways, water and sewer systems, the electrical power grid, and communications networks, was built up during the period of high economic growth through the 1970s, and there is now an enormous backlog of aging infrastructure projects to deal with. Strained budgets for operations and maintenance, and a reduced maintenance workforce make this even more of a challenge. The prospects for maintaining and managing infrastructure are dire, and there is growing concern that our ability to guarantee the safety and security of the nation's infrastructure is beyond our capabilities.

The NTT Group faces the same challenge with its own enormous telecom-related infrastructure. NTT owns and operates a vast array of telecommunication equipment and facilities of all kinds, and these facilities are not only deployed in built-up urban areas. Quite to the contrary, NTT's facilities are scattered from one end of the country to the other in every kind of terrain and environment from rugged mountainous landscapes to coastal districts, from geothermal hot spring areas to frigid cold regions, and from underground settings to underwater environments, and the modes and rates of deterioration all vary for the different environments.

Proper maintenance of this enormous and diverse telecom infrastructure requires a long-term and methodical maintenance plan based on regular inspections and a clear grasp of the current and predicted states of deterioration of facilities. Essentially, this maintenance plan must prioritize what measures should be taken to upgrade which facilities, and when these measures should be implemented. The basic key here is a *prioritization index*. For the purposes of deterioration assessment, NTT Device Technology Laboratories has adopted the concept of risk for the basic prioritization index, and we continue to investigate technologies for assessing risk. This article will discuss the concept of risk in relation to buried anchors, a type of buried steel structure used extensively in the telecom industry to support utility poles.

Fig. 1. Risk matrix.

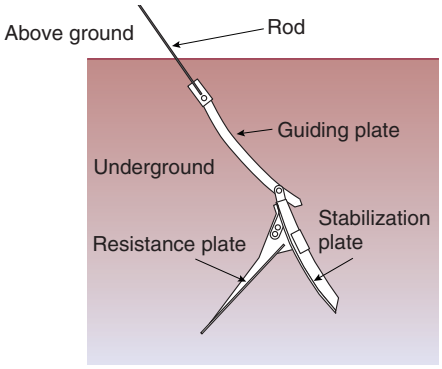

Fig. 2. Buried anchor.

2. Risk assessment trends

The petroleum refinery industry has been at the forefront of efforts to improve plant management based on the concept of risk. In contrast to the older time-based maintenance approach, the new emphasis on risk is known as risk-based inspection / risk-based maintenance (RBI/RBM).

In this context, risk is defined as:

$$\text{Risk} = \text{likelihood of failure} \times \text{consequences of failure}$$

As illustrated in **Fig. 1**, risk calculation results can be presented as a risk matrix taking the *likelihood of failure* and the *consequences of failure* as the vertical and horizontal axes of the matrix. Such a matrix is extremely useful because it enables one to immediately see where a piece of equipment falls on the risk spectrum based on the cell position (with increased risk as the equipment migrates toward the red cell at the upper right). It can then be decided whether the risk level is tolerable (or not) and what remedial measures should be taken.

The American Petroleum Institute [1], the American Society of Mechanical Engineers [2], and other organizations have published guidelines for using RBI/RBM planning methods. In 2010, the High Pressure Institute of Japan also published RBI/RBM-related guidelines for dealing with pressure equipment and other machinery specific to that industry [3]. These guidelines are fine for centralized plant equipment in which the usage environments and deterioration mechanisms are relatively well known and considerable data has already been amassed, but they are less useful for the extremely diverse telecom infrastructure facilities that are widely deployed in many different environments.

3. Risk assessment of buried anchors

A schematic diagram of the buried anchor that is the focus of this work is shown in **Fig. 2**. Buried anchors are embedded in the ground and used to support utility poles. As one can see in the figure, the part consists of two steel plates—a resistance plate and a stabilization plate—that provide support for the pole. There are over ten million of these anchors deployed across Japan, and having an efficient maintenance plan for them is critically important, just as it is with the rest of the company's infrastructure.

A risk assessment of a buried anchor essentially involves estimating whether the *degree of deterioration of the anchor* indicates a likelihood of failure, and whether *uplifting or pulling out of the anchor* could be a consequence of failure, or to express it more parsimoniously:

$$\text{Risk} = \text{degree of degradation} \times \text{consequences of failure}$$

The degree of degradation will vary depending on the deployment site. To assess the risk of a particular piece of equipment or an anchor, one must predict the degree of degradation of that part for a particular installation environment.

The obvious drawback here is that we cannot make a direct visual inspection since anchors are buried underground, and this makes it exceedingly difficult to gage the degree of degradation. Nor do we have a database of past assessment information, so we are unable to make a statistical estimate of the degree of

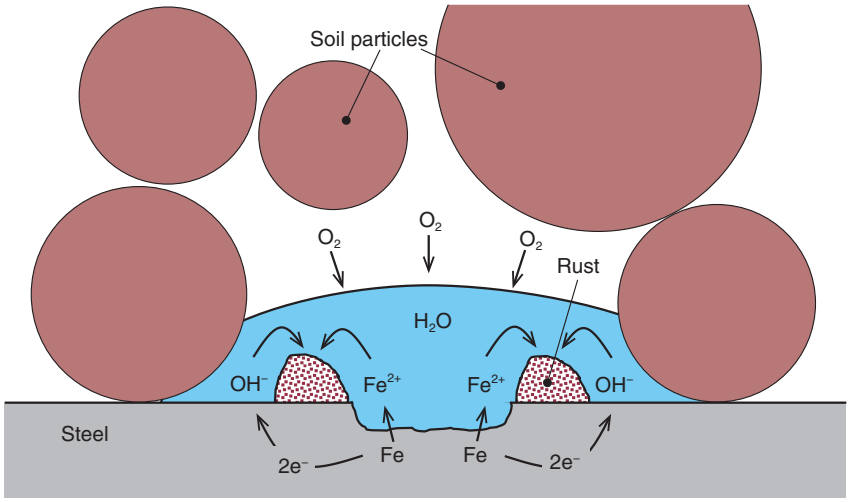

Fig. 3. Schematic image of soil corrosion.

degradation. Indeed, this is the crux of the problem: the difficulty in assessing the risk of a steel structure (such as an anchor) buried underground, compounded by a lack of data that might help in estimating the degree of degradation. As a way around this predicament, we have attempted to analyze the mechanisms of buried anchor degradation from the standpoint of materials science and then build a theoretical model to estimate the degree of degradation.

4. Mechanisms of soil corrosion

The primary mechanism of anchor deterioration is soil corrosion (corrosion of buried metal caused by soil) as illustrated schematically in **Fig. 3**. One will observe in the figure that soil corrosion occurs at the interface where metal (steel in this case) comes in contact with soil, and the corrosion causes the thickness of the metal to gradually diminish; in other words, the metal becomes thinner. A photograph of an anchor recently unearthed after being buried in the ground for over 40 years is shown in **Fig. 4**. One can see that the surface of the part is completely covered with ruddy-colored rust. We used an acidic solution to remove the rust and then measured the thickness of the metal. We found that it was significantly thinner than the original anchor that was put into the ground. If the thickness of the steel is reduced by soil corrosion, then the supporting force provided by the anchor for the utility pole is reduced by a corresponding degree. Predicting the degree of deterioration of a buried anchor can thus be equated to predicting the degree of steel thinning caused by soil corrosion.

Fig. 4. Photo of buried anchor showing considerable deterioration.

Aside from buried anchors, the corrosion of buried water pipes and gas lines is highly problematic and has been extensively studied throughout the world. The American National Standards Institute (ANSI) in particular has drafted soil corrosivity standards [4]. The ANSI standards are widely used in Japan for their effectiveness in evaluating the corrosivity of soils. However, a drawback of these standards is that

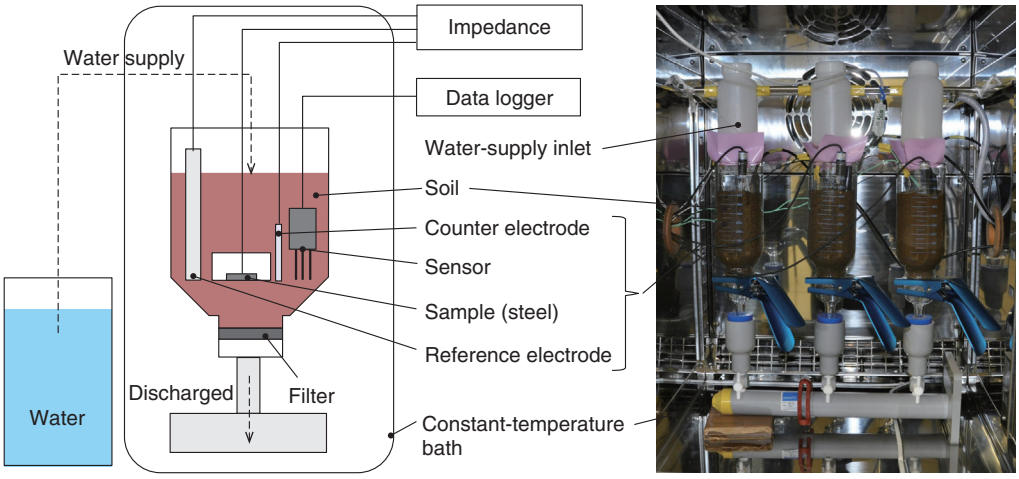

Fig. 5. Simulated soil corrosion testing apparatus: (a) schematic; (b) photo.

the relationship between the criteria for evaluation and corrosivity is left as a *qualitative* expression [5]. In the field of soil corrosion, there are many outstanding issues, and it is difficult to say whether *quantitative* knowledge has been systematized. This is because so many external factors (environmental factors) affect corrosion and interact in ways that make soil corrosion very complex.

Given these circumstances, to predict the degree of steel plate thinning caused by soil corrosion, we have to:

(1) define environmental factors that predominantly contribute to soil corrosion,
(2) quantitatively determine how environmental factors affect the corrosion rate, and
(3) figure out how to gather data about environmental factors at actual soil sites.

By addressing these three issues, we should be able to figure out the corrosion rate from information about the environmental factors, and this would enable us to theoretically calculate the amount of thinning of a steel plate buried for any elapsed period of time. We are now conducting trials to measure electrochemical corrosion in simulated soils in the laboratory and to monitor outdoor soils. These experiments are explained in the following sections.

5. Electrochemical corrosion in simulated soil trial

To develop a theoretical model to derive the corrosion rate from information on environmental factors, we constructed a simulated soil testing apparatus in the lab to measure the electrochemical corrosion rate of a steel plate. A schematic diagram and a photograph of the testing apparatus are shown in **Fig. 5**. As can be seen in the figure, the apparatus regulates water supply and drainage to simulate rainfall, while controlling the temperature of the soil in a temperature-controlled chamber. Soil corrosion occurs on the surface of the steel plate through the following chemical reactions:

$$\text{Anode reaction: } Fe \rightarrow Fe^{2+} + 2e^{-}$$
$$\text{Cathode reaction: } O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-}$$

The corrosion rate can be evaluated by measuring the reaction resistance—an index of how readily the corrosion reaction occurs—and then taking the reciprocal. Various resistance components (electrical resistance of soil, water, etc.) are mixed together in the soil, so in conducting the measurement we employed the alternating current impedance method, which enables us to isolate only the reaction resistance using the frequency band.

The soil environment involves three phases. In the first phase, soil particles are in a solid stage. In the second and third phases, water and air exist respectively in the gaps between soil particles. As is evident from the chemical reactions cited above, water and air (i.e., oxygen) are essential for soil corrosion to occur. We can thus assume that wetting on the surface

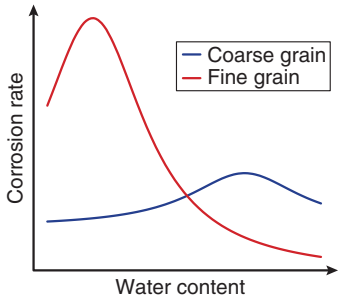

Fig. 6. Corrosion rate as function of water content in soil.

of the buried steel plate and the ratio of water and air (water content) of the soil strongly affect the corrosion rate.

We have thus hypothesized that the primary environmental factors involved in soil corrosion are the soil particle size distribution and water content, which determine the steel plate surface wetting, and the ratios of water and air in soil, and we are now pursuing experiments to corroborate this hypothesis. We measured the corrosion rate for different levels of water content in two kinds of soil—one composed of small-size particles and the other of coarser particles—and obtained the interesting findings presented in **Fig. 6**. One can see that the corrosion rate does not change monotonically with the water content, but rather peaks at a certain water content level. We also found that the water content for the corrosion peak varied widely depending on the particle size distribution of the soil.

These findings suggest that the conventional qualitative wisdom that corrosion increases as the water content in the soil increases (i.e., a high corrosion rate), such as manifested in the ANSI evaluation criteria, may be incorrect. Indeed, we believe that one factor that has never been considered as a predictor of soil corrosion in conventional assessment standards is the nonlinear nature of soil corrosion with respect to the water content. In other words, by identifying the relationship between water content for different distributions of soil particle size and the corrosion rate, we should be able to derive the corrosion rate from the water content and soil particle size distribution, and this would enable us to calculate the amount of corrosion. We are already planning more detailed studies to explore the quantitative interrelations among soil particle size, water content, and the corrosion rate.

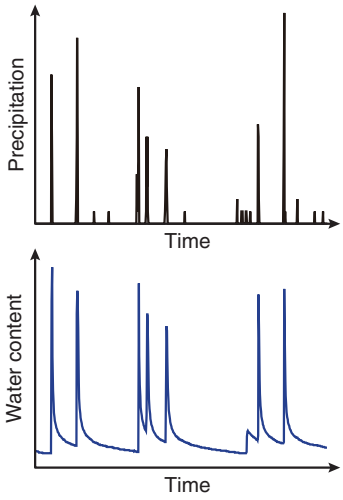

Fig. 7. Water content in soil as function of precipitation.

6. Outdoor soil monitoring trial

In line with our third objective—how to gather environmental factor data in actual soil settings—we are conducting environmental factor monitoring trials to gain a better understanding of actual soil environments. The soil at the test site is a typical Kanto loam, a soil with roughly equal proportions of sand, silt, and clay distributed throughout Tokyo and its surrounding areas. Anchors are typically buried at a depth of 1.5 m, so for these trials we dug holes slightly less than 2 m deep, placed sensor equipment in them, backfilled the holes, and then measured the changing environmental factors over time.

The change in water content over time at a depth of 1.6 m as a function of the amount of precipitation (amount of rainfall per hour) is shown in **Fig. 7**. For the amount of precipitation, we employed data from the local meteorological observation station closest to the test site. The water content of the soil closely mirrored the amount of rainfall, and we observed a regular cycle: the water content sharply increased when it rained, then drained and dissipated in much the same way each time as soon as the rain stopped.

This suggests that the water content of the soil can be calculated with some degree of accuracy based on weather information if the drainage rate for the particular soil is known. Certain information is needed to predict the amount of metal thinning over time—namely, the water content of the soil and the type and distribution of its particle size—but we think this scheme could be implemented using soil classification

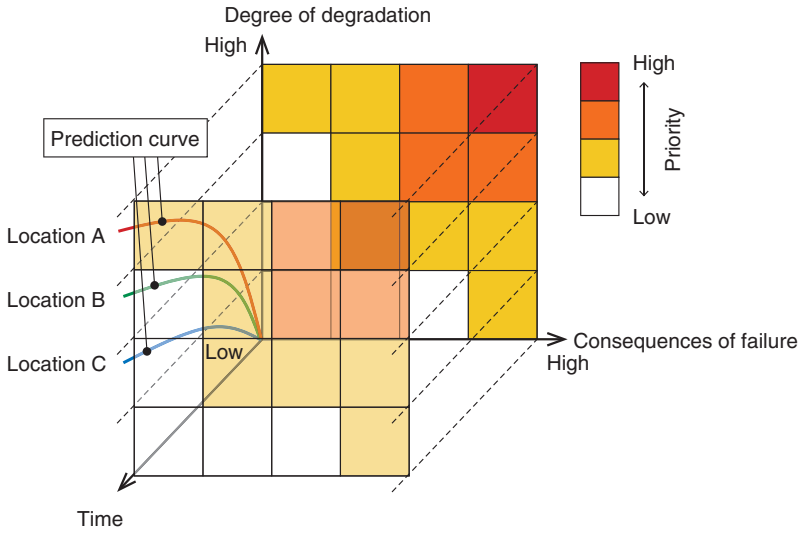

Fig. 8. Risk matrix concept.

maps commissioned by national or local governments.

7. Future development

This article described some of our recent efforts to estimate and assess risk in a case study involving buried anchors, which are steel structures embedded in the ground to support utility poles. The risk matrix concept that we are trying to achieve is depicted in **Fig. 8**. As one can see, this figure includes a time axis along with axes for the degree of degradation and consequences of failure, and priority is represented by colors ranging from white (low priority) to red (urgent priority) as we saw earlier in Fig. 1. The progress of deterioration varies depending on the installation environment as we noted earlier, so naturally, the urgency or priority of the work will also vary along the time axis. Due to our better understanding of soil corrosion mechanisms plus publicly available data (weather reports and soil classification maps), we are getting closer to developing a theoretical model that can predict the degree of degradation of underground anchors after a certain amount of time has elapsed.

Regarding the consequences of failure, in the case of buried anchors, this might mean that the anchor pulls out, which would cause the utility pole to topple over and adversely affect the surrounding area. To assess the consequences of failure in the event that a utility pole collapses or falls over, our research group has already investigated this set of circumstances, so we were able to reference this earlier work in the present study.

With the risk matrix that we developed through this study, we plan to build a prioritization index that will contribute to the development of more efficient maintenance plans.

The challenge of replacing aging infrastructure is certainly not confined to telecom-related equipment and facilities but is a critical issue affecting the entire country. We remain committed to the development and deployment of useful technology that will achieve a safer, more secure, and a better society in the years ahead.

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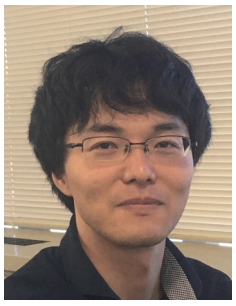

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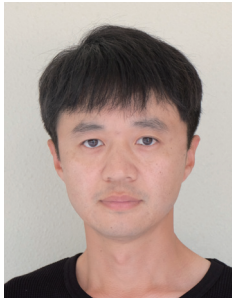

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Deployment of Terrestrial Wireless Systems for Disaster Recovery to Provide Customer Relief

Nobuhiko Tachikawa, Tomohiro Tokuyasu, and Hiroyuki Nakamura

Abstract

NTT Access Network Service Systems Laboratories has been researching and developing new wireless systems for disaster recovery. These Feature Articles introduce the terrestrial wireless systems for disaster recovery that we have developed. They also introduce a cell and radio frequency planning tool supporting wireless system operation. This article provides an overview as an introduction to them.

Keywords: disaster recovery, wireless system, relay, subscriber, business use

1. Introduction

The NTT Group prepares for large-scale disasters according to basic disaster-recovery policies centered around improving the reliability of the network, securing critical communications, and restoring services early. Since the Great East Japan Earthquake of 2011, NTT Access Network Service Systems Laboratories has been researching and developing new wireless systems for disaster recovery. At NTT EAST and NTT WEST, use of the wireless systems developed to date has enhanced measures for achieving early restoration of communication services and early reconnection of areas cut off from communications. These Feature Articles introduce the terrestrial wireless systems for disaster recovery that we have developed with the aim of restoring a wide range of communication facilities affected by a wide-area disaster such as a Nankai megathrust earthquake or an earthquake occurring directly under the Tokyo metropolitan area. They also introduce a cell and radio frequency planning tool supporting wireless system operation (**Fig. 1**).

2. Terrestrial wireless systems for disaster recovery

We briefly describe here the systems developed by NTT Access Network Service Systems Laboratories that are described in detail in the Feature Articles in this issue.

(1) Portable digital wireless system for disaster recovery with long-range operation and compact/lightweight configuration

The 11/15P-150M-N wireless system was designed to restore relay transmission paths with a maximum transmission capacity of 600 Mbit/s. The system features a maximum transmission range of 20 km and a compact and lightweight configuration on a level enabling equipment dismantling and manual transport [1].

(2) Business radio system providing stable means of contact without dependence on other carriers' networks

The TZ-161A wireless system was developed as a means of in-house contact by configuring a network only within an NTT regional company. In addition to a voice-calling function achieved through the use of transceivers, the system includes a location-information

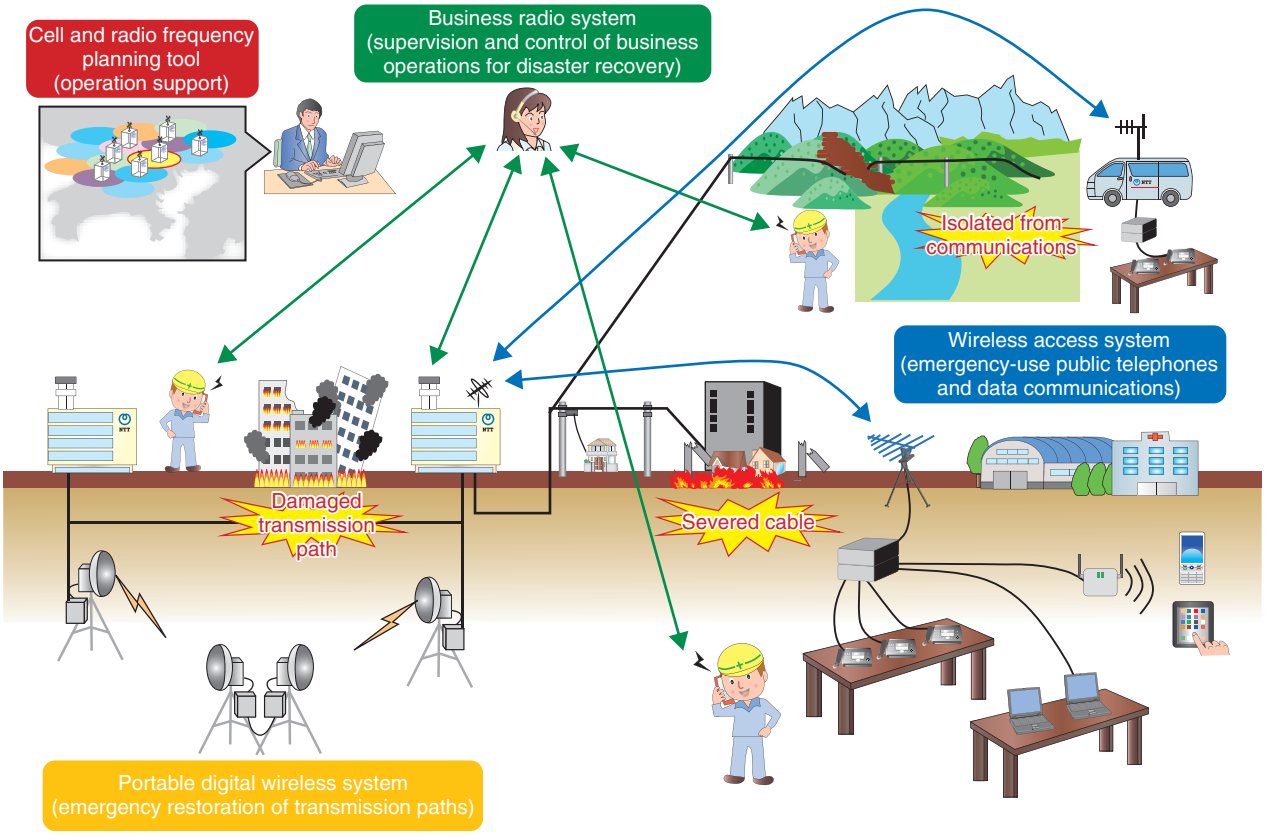

Fig. 1. Operation of terrestrial wireless systems for disaster recovery.

management function enabling efficient contact with personnel in the field [2].

(3) Wireless access system for disaster recovery providing safety and security to customers

The TZ-403D wireless system uses the 400-MHz frequency band to provide emergency-use public telephones and Internet connection services at evacuation centers and other locations that lie beyond line-of-sight with an NTT communication building [3].

(4) Cell and radio frequency planning tool supporting wireless systems for disaster recovery

This tool (software) is used to select which NTT communication buildings to use as optimal locations for installing radio equipment without having to have specialized knowledge or experience in station placement design [4].

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Portable Digital Wireless System for Disaster Recovery with Long-range Operation and Compact/Lightweight Configuration

Nobuhiko Tachikawa, Tomohiro Tokuyasu, and Hiroyuki Nakamura

Abstract

NTT Access Network Service Systems Laboratories has developed a portable digital wireless system for disaster recovery (11/15P-150M-N). This system optimizes gain allocation in the antenna and radio transceiver to achieve a maximum improvement of 30% in radio-interval range while reducing weight and volume by approximately 50% each compared to the existing system. If damage occurs to transmission paths in regions where reliability-maintenance schemes such as looping are difficult, this system enables prompt disaster relief using a 156-Mbit/s or 52-Mbit/s synchronous digital hierarchy interface or Ethernet interface.

Keywords: disaster recovery, wireless system, relay transmission paths

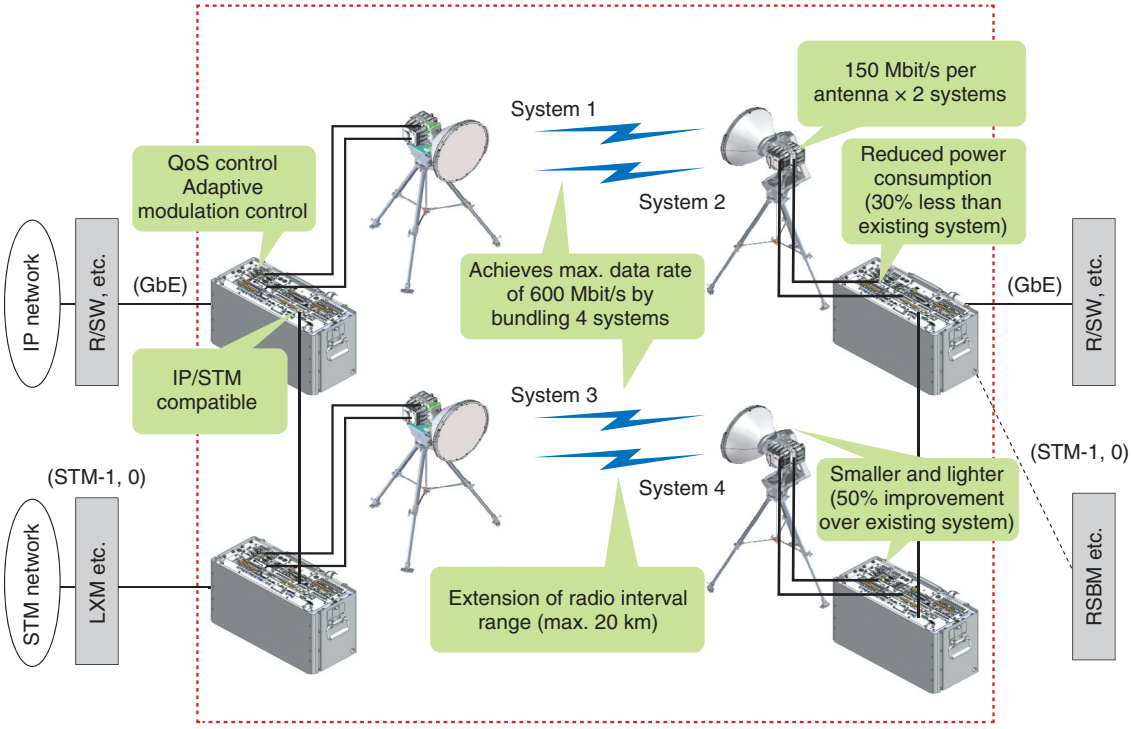
1. Portable digital wireless system unequaled in the world

As a provider of diverse telecommunication services, NTT has developed and deployed various types of wireless systems for disaster recovery. The aim here has been to achieve prompt relief or restoration of damaged landlines and transmission paths (severed optical cables, damaged conduits, fallen bridges, etc.) that occur as a result of an earthquake, flood, volcanic eruption, fire, or other disaster [1, 2].

Recent years, however, have seen a high incidence of disasters such as the Great East Japan Earthquake inflicting massive damage to communication facilities, and in the wake of these disasters, radio-based systems for disaster recovery have become all the more important [3].

The existing wireless system for disaster recovery targeting relay transmission paths can restore a digital transmission path with a 156-Mbit/s or 52-Mbit/s synchronous digital hierarchy (SDH) interface. However, the rapid growth in Internet protocol (IP) networks has made the restoration of transmission paths between communication equipment having an Ethernet interface essential. In addition, there are cases in which the transmission path between NTT communication buildings cannot be restored using the existing wireless system for disaster recovery because of the long distance between buildings.

Against this background, the 11/15P-150M-N system was developed to enable the restoration of IP networks and to extend the range of the radio interval for disaster relief. To achieve restoration of IP networks, the system features a maximum radio transmission capacity of 600 Mbit/s—four times that of the existing system—and incorporates a quality of service (QoS) function and an adaptive modulation function. It also features a maximum radio transmission distance between termination equipment of 20 km. Furthermore, the total weight of a complete set of



GbE: gigabit Ethernet
LXM: line cross connect module
RSBM: remote subscriber module
R/SW: router and switch

Fig. 1. Configuration and features of wireless system.

equipment is approximately 80 kg. The manually transportable system consists of an antenna, radio transceiver, polarization multiplexer, coaxial cable, radio termination equipment, and tripod.

The portability of this digital wireless system used for relay transmission paths is a feature unequaled in the world. It enables prompt recovery of relay transmission paths on a synchronous transfer mode (STM) or IP network anytime and anywhere even if telecommunication facilities are damaged. The configuration and features of this wireless system are shown in **Fig. 1**.

2. System overview

This is a digital wireless system transmitting digital signals at a bit rate of 156 Mbit/s per system on the 11-GHz or 15-GHz radio frequency band using 64 quadrature amplitude modulation (QAM), or 16QAM.

In addition, connecting system equipment in parallel enables system bundling in a 156 Mbit/s × 4 manner for a maximum digital-signal data rate of 600 Mbit/s. The main specifications are listed in **Table 1**, and a photograph of the equipment is shown in **Fig. 2**.

3. Key features of system

The effectiveness of the system is due to its four key features described here.

3.1 Extended range and compact/lightweight configuration by optimizing gain allocation

If range could be extended while maintaining the quality of the radio circuit, it would be possible to restore a long transmission path that could not be restored using the existing system. To achieve this, it would be necessary to increase the gain of the system, but this would also substantially increase the weight of the equipment and antenna, thereby undermining system portability. To secure the desired radio-circuit quality, it was decided to optimize the gain allocated to the antenna and radio transceiver, making it possible to extend the transmission range to a maximum of 20 km (compared to 15 km maximum with the existing

Table 1. Main specifications.

Transmission capacity	155.52 Mbit/s 155.52 Mbit/s × 2 (co-channel arrangement) 155.52 Mbit/s × 4 (2-parallel configuration)
Modulation method	64QAM or 16QAM
Network interface	STM: 52 Mbit/s, 156 Mbit/s IP-NW: GbE 1000 BASE-SX 1000 BASE-LX FE 100 Mbit/s
Operating temperature	Transceiver: –30°C - 50°C Termination equipment: –30°C - 50°C
Power supply	AC: 90 V - 110 V DC: –40.5 V - –57 V

AC: alternating current
DC: direct current
FE: Fast Ethernet

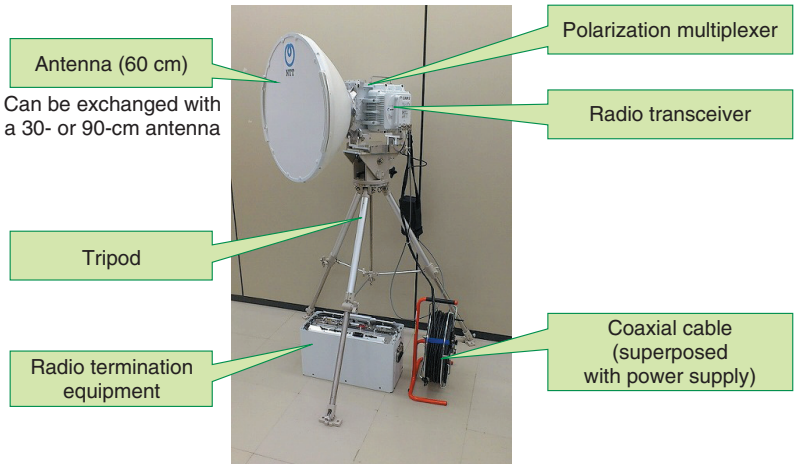


Fig. 2. Appearance of equipment.

system) without sacrificing portability. In addition, the total volume and weight were both reduced by approximately 50% compared to the existing system.

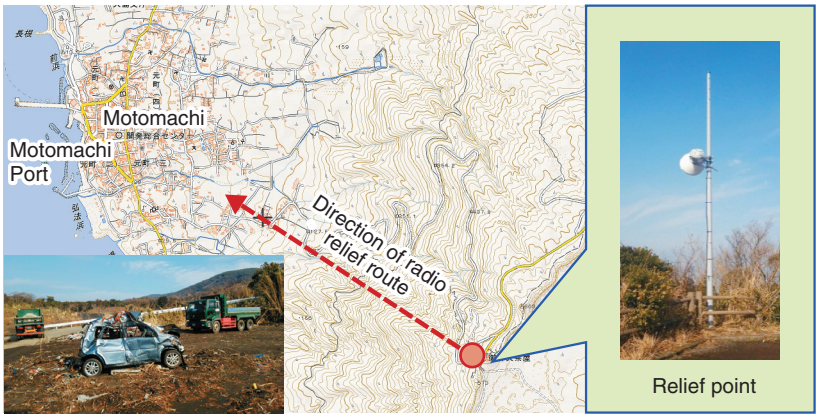
3.2 Implementation of Ethernet interface and provision of QoS function

The new system has an SDH interface (156 Mbit/s and 52 Mbit/s) as used in the existing system, but it also mounts an Ethernet interface (gigabit Ethernet and Fast Ethernet) to enable connection to IP networks; whichever interface is used is selected at the time of operation.

When the Ethernet interface is used, the system performs priority control by identifying passing IP packets and distribution control according to the state of radio circuits. It incorporates a four-class QoS function to prevent the loss of high-priority packets and uses adaptive modulation technology to change the transmission capacity according to the propagation conditions. With these features, the system can provide optimized radio transmission quality and enable interoperability with Ethernet networks.

3.3 Improved spectrum efficiency and greater capacity through multi-value QAM

The new system adopts 64QAM, which is currently the mainstream modulation method for fixed microwave radio systems. This feature achieves a two-fold improvement in spectrum efficiency compared with the existing system. It can also increase transmission capacity by two times the existing value when using a pair of parabolic antennas in a co-channel



Source of data: Ministry of Land, Infrastructure, Transport and Tourism, Geospatial Information Authority of Japan (GSI), GSI Maps (Digital Japan Accessibility)

Fig. 3. System used during a disaster (Izu-Oshima island).

arrangement* and by four times (600 Mbit/s) when using two pairs of parabolic antennas in a parallel setup.

3.4 Improved workability and safety

System workability has been greatly improved by superposing two transmit/receive interface signals and the power supply on a single coaxial cable, whereas the existing system requires three cables. Moreover, because the assembly of the radio transceiver, antenna, polarization multiplexer, and tripod entails high-elevation work on the platform of a steel tower on top of an NTT communication building, all screws used in the assembly have been given an anti-dropping mechanism. In short, the screws have a structure that takes safety into consideration by preventing them from falling to the ground. Moreover, the assembly can be done using only one hexagonal wrench. As a result of these measures, assembly and installation work that required four to five workers and took about 1 hour with the existing system can now be performed with just two to three workers in about 20 minutes.

4. Deployment status and usage scenarios

The system was first introduced in 2013 by NTT EAST and NTT WEST and is gradually being deployed throughout Japan. This system can be used in various scenarios: (1) for prompt response to a damaged relay transmission path between NTT communication buildings (including those caused by damaged conduits, fallen bridges, severed submarine cable due to contact with a ship, and severed cable due to an automobile accident); (2) for construction of redundant transmission paths in the event of a disaster in mountainous areas and on islands where construction work is difficult; (3) for provision of a transmission path as a temporary backup when refurbishing submarine cables or upgrading fixed digital microwave facilities; and (4) for construction of temporary transmission paths for public events in mountainous areas and on islands or for seasonal purposes.

The system has already been used for emergency restoration of facilities following a landslide on Izu-Oshima island caused by typhoon No. 26 in 2013 (**Fig. 3**) and after a severed submarine cable caused by a typhoon that made landfall in Hokkaido in 2016. Additionally, to provide for the possible occurrence of a disruption or accident at the G7 Ise-Shima Summit in 2016, the system was installed on the roofs of several key NTT communication buildings, thereby improving the reliability of telecommunications.

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* Co-channel arrangement: A method of arranging channels of the same frequency along mutually orthogonal polarized waves (vertical polarization (V) and horizontal polarization (H)).

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Business Radio System Providing Stable Means of Contact without Dependence on Other Carriers' Networks

Nobuhiko Tachikawa, Fumiaki Nagase, Junichi Iwatani, and Hiroyuki Nakamura

Abstract

NTT Access Network Service Systems Laboratories has developed a business radio system (TZ-161A). This system uses a nationwide licensed frequency band that prevents interference with other operators, suffers no deterioration in voice quality, and receives and transmits global positioning system data. In addition, the communication channels used by the system are independent of other carriers' networks, enabling stable communications for business operations even in the event of a wide-area disaster.

Keywords: disaster recovery, business radio system, push-to-talk communication

1. Introduction

During the Nippon Telegraph and Telephone Public Corporation era, an analog wireless system based on push-to-talk (PTT)[*1] communications in the 150-MHz band was used for the company's internal communications. This system was further enhanced in 1991 as the TZ-151B system featuring a privacy function and data communications. With the explosive growth in the use of mobile phones thereafter, though, the use of TZ-151B for in-house communications gradually declined.

However, NTT telecommunication facilities sustained an enormous amount of damage over a wide area in the Great East Japan Earthquake in 2011, and the loss of commercial power supplies and depletion of backup batteries on mobile phone base stations made it difficult to use mobile phones to convey conditions in disaster-stricken areas and provide information for restoration [1]. Against this background, NTT again recognized the importance of having a wireless means of in-house communication that was robust against natural disasters and independent of other carriers' networks.

2. Configuration of business radio system

The configuration of the business radio system is shown in **Fig. 1**. This system features radio base station equipment, mobile transceivers, vehicle-mounted transceivers, and portable repeaters as well as network-related equipment consisting of remote control equipment, a command console, a location-information management server[*2], and connection equipment for extension phones.

*1 PTT: A voice-calling system that enters a voice-transmission state by pushing a transmit button.

*2 Corresponds to a risk-management data server for facilities of NTT operating companies.

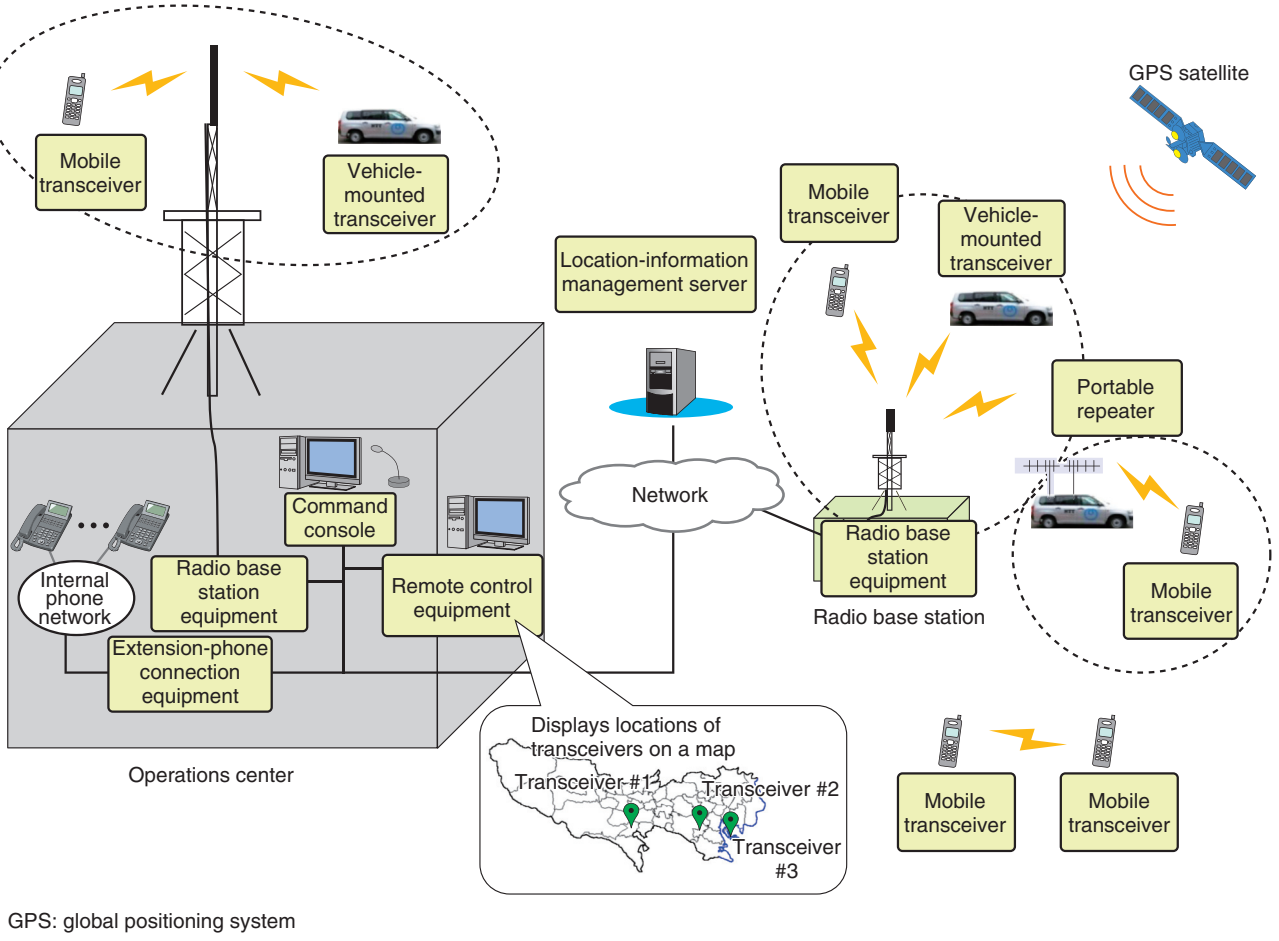

Fig. 1. Configuration of business radio system.

3. Main functions and technical features

The main functions and technical features of the TZ-161A system are described in this section.

3.1 Voice-calling function

This function provides communications with mobile transceivers and vehicle-mounted transceivers within the coverage area of the radio base station equipment and enables voice calling via PTT communications with the command console on the network. It also enables calling on extension phones installed inside the company via the extension-phone connection equipment.

3.2 Location-information management function

This function enables an operator within the operations center to check where mobile transceivers and vehicle-mounted transceivers are located within the area of the radio base station. Specifically, equipping the mobile transceivers and vehicle-mounted transceivers with global positioning system (GPS) capabilities enables them to receive signals from GPS satellites, determine their own locations, and periodically transmit their location information via radio. This information is received by the radio base station equipment and then passed to the location-information management server for periodic updating of location information. Finally, this server transfers the updated information to the remote control equipment, where it is displayed as transceiver location information on a map.

Here, the transmission of location information makes use of the same radio resource as voice calling, so an increase in the number of transceivers in the field can result in the transmission of a large volume of location information, putting pressure on the capacity of that radio resource. The system has a

(1) Command console
(2) Radio base station equipment
(3) Vehicle-mounted transceiver
(4) Mobile transceiver
(5) Portable repeater

Fig. 2. Appearance of TZ-161A system.

technical feature to address this issue; specifically, it incorporates a mechanism for controlling the transmission timing of location information to prevent quality degradation in voice calls and enable efficient transmission of location information [2].

4. Appearance of TZ-161A system

The appearance of the TZ-161A system components is shown in **Fig. 2**.

(1) The command console is installed where the operator is located. Selecting a radio base station displayed on the screen enables PTT communications with mobile transceivers and vehicle-mounted transceivers within the coverage area of that base station.
(2) Radio base station equipment is installed inside an NTT communication building. It uses an omnidirectional or Yagi-Uda antenna*3.
(3) A vehicle-mounted transceiver is installed in a construction vehicle or business vehicle. The whip antenna is equipped with a magnetic mount, making it easy to affix it to the vehicle's body.
(4) A mobile transceiver is carried around and used by personnel in the field. (A vehicle-mounted transceiver connects to a GPS unit, whereas a mobile transceiver connects to a GPS microphone to enable an effective location-information management function in addition to voice calling.)
(5) A portable repeater enables the coverage area of the radio base station equipment to be extended.

5. Radio specifications and coverage area

Radio equipment specifications are listed in **Table 1**. This wireless system conforms to the Association of Radio Industries and Business (ARIB) Standard STD-T102 [3]. It is a narrowband digital telecommunication system using SCPC (single channel per carrier) and 4FSK (4-level frequency shift keying) as the modulation method. The radio frequency band is 160 MHz, and the channel interval is 6.25 kHz. Compared to the analog business radio system used by NTT during its public corporation era, this new system improves spectrum efficiency and accommodates three times the number of communication channels for the same bandwidth. Transmission output is 10 W for radio base station equipment and vehicle-mounted transceivers and 5 W for

*3 Yagi-Uda antenna: A directional antenna consisting of multiple parallel elements in a line. Also called a Yagi antenna.

Table 1. Radio specifications.

Item	Specification
Frequency band	160 MHz
Channel interval	6.25 kHz
Transmission output	10 W (base station, vehicle-mounted station) 5 W (mobile station)
Modulation method	4FSK (ARIB STD-T102)
Calling system	Half-duplex (PTT)

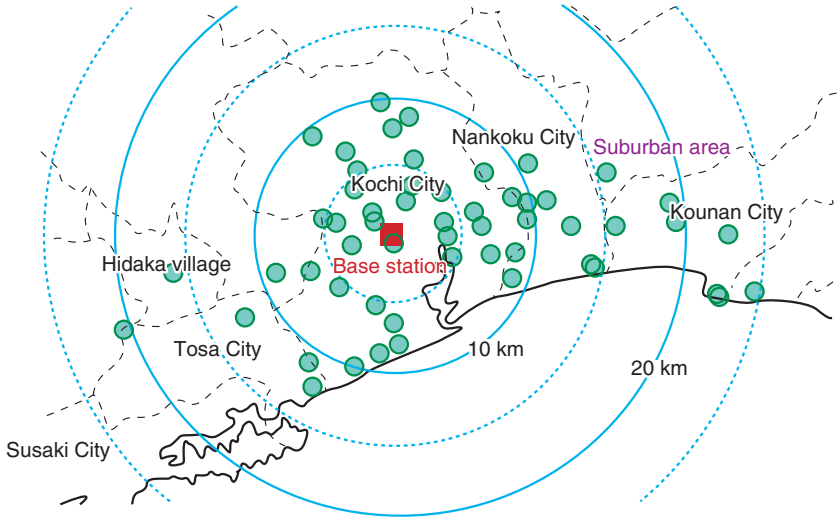

Fig. 3. Coverage area in Kochi Prefecture.

mobile transceivers.

In a field experiment conducted by NTT, a radio base station was installed within Kochi City in Kochi Prefecture to verify and evaluate the area of the voice-calling function. The resulting coverage area is shown in **Fig. 3**. Points corresponding to a clear call based on a subjective evaluation are indicated by the green circles in the figure. This system was found to cover an area extending approximately 20 km from the radio base station and encompassing urban areas as well as suburban areas with few tall buildings.

6. Deployment status

Deployment of the TZ-161A system began in 2014 by both NTT EAST and NTT WEST. As of October 2017, the system has been operating in the Tokyo Metropolis, Chiba Prefecture, Saitama Prefecture, and Shizuoka Prefecture. The plan is to expand the deployment area going forward.

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Wireless Access System for Disaster Recovery Providing Safety and Security to Customers

Tomohiro Tokuyasu, Nobuhiko Tachikawa, Shuta Uwano, Tsutomu Tatsuta, and Hiroyuki Nakamura

Abstract

In Japan, the frequent occurrence of various types of disasters since the Great East Japan Earthquake of 2011 has underscored the importance of having wireless systems available for use in disaster recovery. The existing wireless system, however, has several disadvantages, including the inability to effectively deal with data communications and to function in wide-area disasters. To remedy this situation, NTT has developed and implemented a wireless access system for disaster recovery (TZ-403D) that features digital operations and an increase in the number of simultaneously accommodated terminals. The system also achieves improved portability through a compact and lightweight configuration, and it provides greater safety and operability due to an anti-dropping mechanism for small parts, the use of fewer cables, and assembly requiring only one type of tool.

Keywords: disaster recovery, wireless access system, wide-area disaster response

1. Introduction

The NTT Group places great importance on constructing a communication network that is robust against disasters and establishing a means of early restoration of communication functions if they are disrupted. Here, radio communication technology plays a vital role in prompt restoration of communication functions from the viewpoint of equipment portability and high-reliability communications using frequency bands oriented to disaster recovery. However, aging facilities and the continued decrease in the number of personnel having specialized skills are driving the need for upgrading equipment and making operation and maintenance easier and more efficient.

Various wireless access systems can be used for disaster recovery. A wireless system using the 400-MHz band has been deployed throughout Japan as a means of providing a telecommunications infrastructure as early as possible in the face of disasters. This is achieved by using a frequency band oriented to disaster recovery, leveraging the capability of radio communications having a range of several dozen kilometers, and providing a wireless connection between a radio base station and a radio terminal station installed at an evacuation center or elsewhere.

Nevertheless, in the aftermath of the Great East Japan Earthquake, although email and social networking services using smartphones, tablets, or other compact information terminals proved to be effective communication tools, various problems occurred with existing analog equipment such as a difficulty in providing Internet connection functions.

In this regard, it has been predicted that a wide-area disaster will occur in the event of a Nankai megathrust earthquake, or an earthquake striking directly under the Tokyo metropolitan area, so the establishment of many evacuation centers over a wide area can be envisioned. Existing equipment, however, can only handle a few channels at one time, and one radio base station can only accommodate one radio terminal

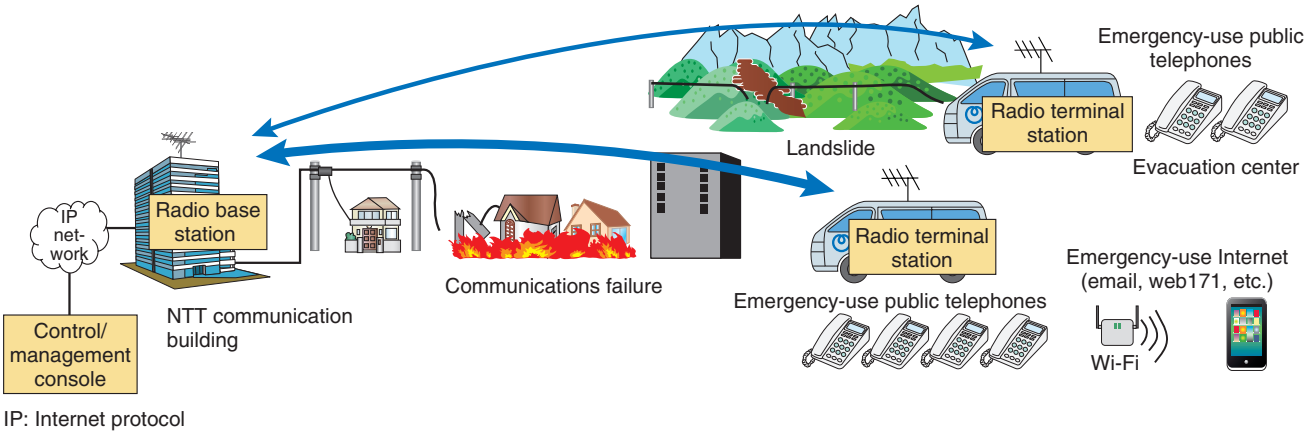


Fig. 1. TZ-403D system configuration.

station, which makes it difficult to deal effectively with a wide-area disaster.

Against this background, NTT has developed and implemented a 400-MHz-band wireless access system for disaster recovery (TZ-403D) that provides an Internet connection function in addition to emergency-use public telephones and improves portability and ease of operation and maintenance through a compact and lightweight configuration. The system is designed to operate in the event of wide-area disasters such as major earthquakes or tsunamis (tidal waves).

2. TZ-403D system configuration

The configuration of the TZ-403D system is shown in **Fig. 1**. In this system, one radio base station can accommodate multiple radio terminal stations, thereby achieving point-to-multipoint (P-MP) communications. In other words, the system can simultaneously accommodate multiple terminal stations installed in many evacuation centers at the time of a wide-area disaster. Various scenarios can be envisioned here; for example, radio base stations may be installed beforehand at NTT communication buildings in preparation for a disaster or readied for transport to NTT communication buildings near evacuation centers, and radio terminal stations may be mounted on disaster-recovery vehicles for quick transport to evacuation centers at the time of a disaster.

The TZ-403D system consists of Layer 2 transmission equipment. It can support a variety of services by changing the adapters connected to the network side and terminal side. The standard configuration of this equipment is shown in **Fig. 2**. For example, the network side and terminal side can be respectively connected to an optical network unit and home gateway to enable connection to an optical communications network and provision of Internet protocol (IP) phone (equivalent to NTT's Hikari Denwa service) and Internet connection services. Alternatively, both the network side and terminal side can be connected to an IP/analog converter to enable connection to a conventional subscriber line switch, or both can be connected to an IP/leased-line converter to provide analog leased-line services. The TZ-403D system also incorporates multiple ports that can be kept independent by port-based virtual local area networks so that multiple connections can be simultaneously accommodated (restored).

3. Equipment appearance and main specifications

Photographs of the equipment are shown in **Fig. 3**, and the main specifications are listed in **Table 1**. The radio base station equipment and radio terminal station equipment consist of an antenna, outdoor equipment, and indoor equipment. The antenna (1) connects to the outdoor equipment and transmits/receives radio signals; the outdoor equipment (2) performs high-frequency signal processing of transmit/receive radio signals, and the indoor equipment (3) performs modulation/demodulation baseband signal processing and IP data processing. For the sake of portability, the weight of each of these components has been kept low enough to allow for transport by two people. The total weight and volume has been reduced by about half in each case compared with existing equipment.

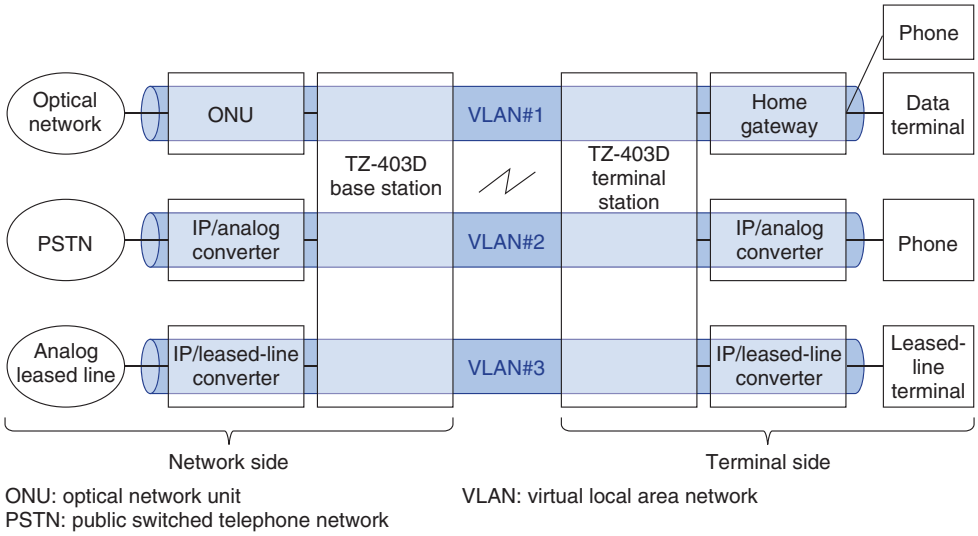


Fig. 2. TZ-403D standard configuration.

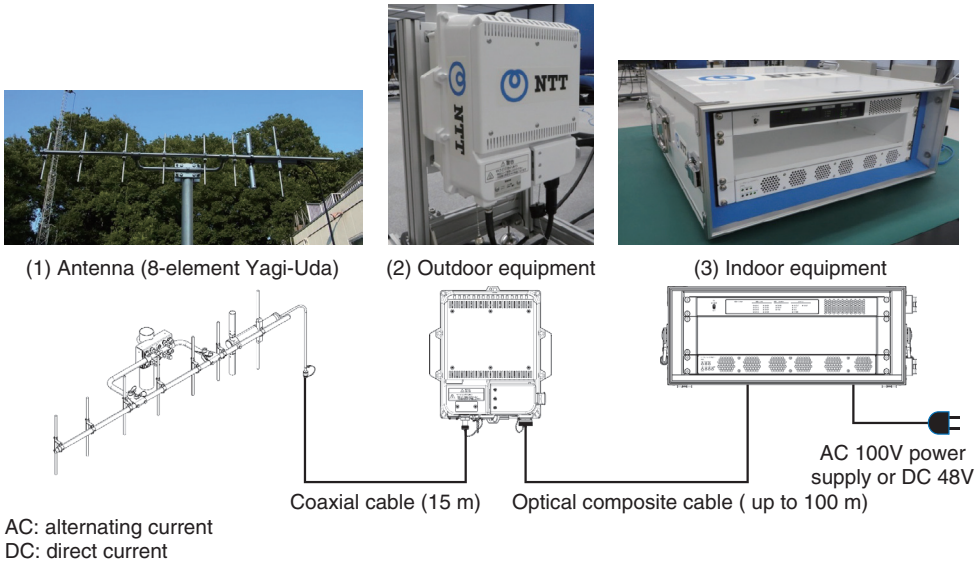


Fig. 3. Equipment appearance.

Furthermore, for the sake of operability, all small parts such as assembly screws feature an anti-dropping mechanism, and only one type of tool is used for assembling the equipment, thereby simplifying the on-site work.

4. Technical features

The technologies used in the TZ-403D system support wide-area disaster relief. They consist of multichannel technology, long-range communications technology, P-MP communications technology, and frequency sharing technology. They are introduced in this section.

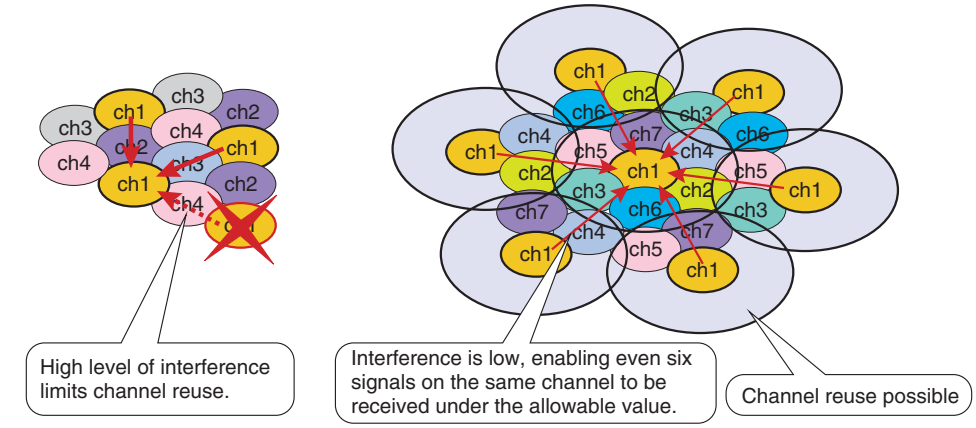
4.1 Multichannel technology

Transmission efficiency has been improved through digitization with the arrangement of more radio

Table 1. Main specifications.

Item	Specification	
Frequency band	400 MHz	
Communication method	FDD	
Multiple access method	TDMA	
Modulation method	OFDM	
Aerial power	40 W	
Channel interval	300 kHz	600 kHz
Interference prevention function	The system has a function for preventing interference with other radio stations.	

FDD: frequency division duplexing
OFDM: orthogonal frequency division multiplexing
TDMA: time division multiple access



(a) Channel reuse with 4 channels

(b) Channel reuse with 7 channels

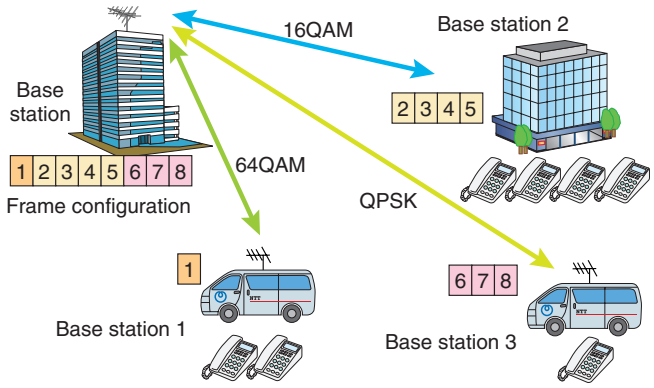
Fig. 4. Multichannel technology.

channels within limited frequency resources and enhanced spectrum efficiency. As a result, a narrowband system contracted by approximately 50% compared with the existing system has been achieved, and the number of simultaneously usable channels has been extended from four to seven. Four channels were used in the past, which often led to interference when there was not enough distance between radio equipment using the same radio channel. Consequently, the areas in which such channel reuse could be applied were limited (**Fig. 4(a)**).

In contrast, the use of seven channels enables sufficient distance between radio equipment to be secured, thereby keeping interference within the allowable value and enabling the reuse of radio channels. In this way, multichannel technology enables the system to operate effectively in the event of a wide-area disaster (**Fig. 4(b)**).

4.2 Long-range communications technology

The TZ-403D system can be used in a variety of propagation environments such as mountains, oceans, plains, and urban areas over communication distances from several kilometers to several tens of kilometers. For this reason, the system adopts orthogonal frequency division multiplexing as a modulation method that is robust against long-delay, multipath interference. In addition, adaptive modulation technology, which enables automatic selection of the modulation method and of the code rate of the error-correction code according to signal quality, establishes communications by lowering the data rate even for long distances.



Example of slot allocation

	Slot	Modulation method	Data rate	Distance	Power output
Base station 1	Slot 1	64QAM	182 kbit/s	Short	Low
Base station 2	Slot 2	16QAM	333 kbit/s	Medium	Medium
	Slot 3				
	Slot 4				
	Slot 5				
Base station 3	Slot 6	QPSK	111 kbit/s	Long	High
	Slot 7				
	Slot 8				

QAM: quadrature amplitude modulation
QPSK: quadrature phase-shift keying

Fig. 5. P-MP communications technology.

4.3 P-MP communications technology

In this system, the radio base station adopts time division multiple access to allocate slots divided along the time axis to individual radio terminal stations. This scheme establishes radio connections between the radio base station and multiple radio terminal stations. At this time, a separate data rate can be selected for each radio terminal station by using adaptive modulation technology, and communication speeds can be flexibly set by changing the number of slots allocated to each radio terminal station (**Fig. 5**). In addition, controlling the power output of each radio terminal station according to communication distance avoids the transmission of unnecessary signals, thereby reducing the amount of power consumed while suppressing interference that affects other radio equipment.

4.4 Frequency sharing technology

Deliberations held by the Information and Communications Council of the Ministry of Internal Affairs and Communications resulted in a ruling stating that a 400-MHz portable wireless system for disaster recovery is required to include a function for preventing interference with neighboring systems. The TZ-403D system is equipped with a sliding monitor function that can detect signals of a neighboring system with high accuracy even if the signal bandwidth of that system is unclear (**Fig. 6**). This enables operation without having to establish a guard band with the other system.

Additionally, to prevent interference with other base stations at the time equipment is set up in an emergency, the system is also equipped with a function for monitoring peripheral signal usage and automatically searching for and selecting an available radio channel. This eliminates the need for personnel in the field to survey available channels, which speeds up and simplifies operations so that special lines can be provided to evacuation centers as early as possible.

5. Related legislation

The TZ-403D system has been recognized as an effective countermeasure to wide-area disasters by the Information and Communications Council, which is made up of university professors, experts from related ministries and agencies, and representatives of telecom carriers. It was put into effect on April 27, 2016 as “radio facilities of a radio station in terrestrial mobile business operations using the 400 MHz frequency band” as stipulated in Chapter 4, Section 4.30 of the Ordinance Regulating Radio Equipment.

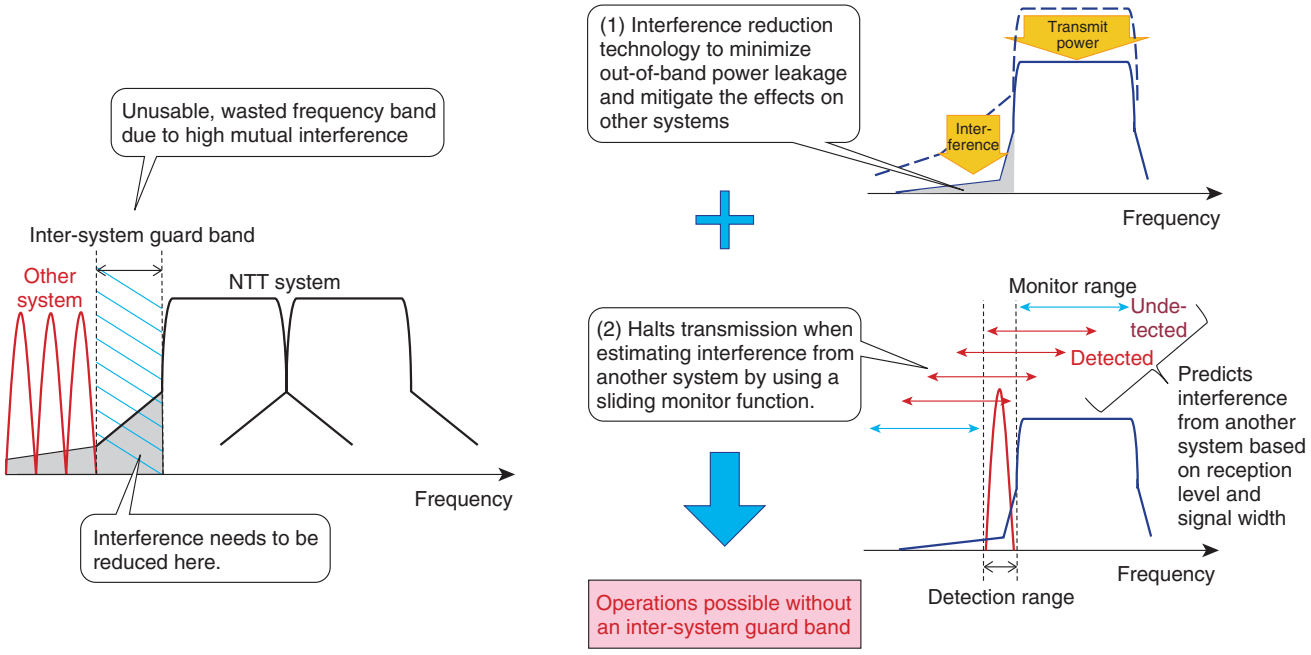


Fig. 6. Frequency sharing technology.

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Cell and Radio Frequency Planning Tool Supporting Wireless Systems for Disaster Recovery

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Abstract

The Great East Japan Earthquake struck Japan in 2011, causing widespread destruction and disrupting communication abilities. It has since been followed by other disasters, reaffirming the importance of having wireless systems available for disaster recovery. Although advances are being made in these systems, station placement design that can optimize the location of radio stations when a disaster strikes is also important. There is also a need for technology that would enable ordinary personnel to design station placement with the same results as that of a skilled designer. This article describes a means of simplifying the design of station placement at the time of a disaster by establishing guidelines and techniques that take disaster recovery into account and developing a tool for their application.

Keywords: disaster recovery, station placement design, cell and radio frequency planning tool

1. Introduction

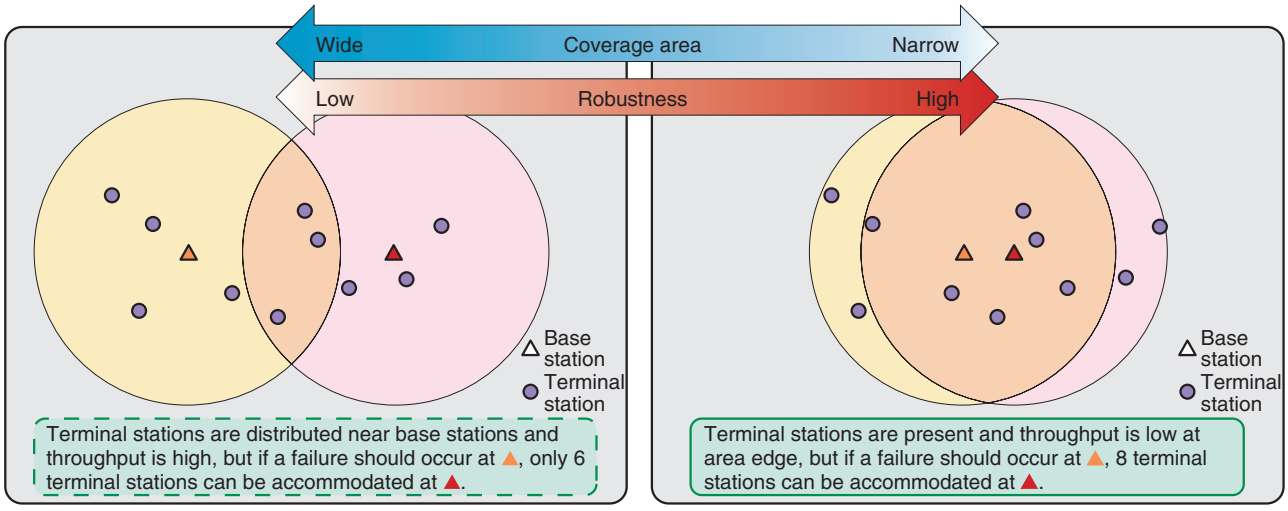
Wireless systems for disaster recovery are especially effective in providing an early recovery thanks to the portability of the equipment and the provision of highly reliable communications using a frequency band oriented to disaster recovery. Various advances have also been made to deal with wide-area disasters that are predicted to occur in the future. These include point-to-multipoint communication, which enables a single radio base station to accommodate multiple radio terminal stations, and narrowband technology that increases the number of channels that can be used simultaneously.

At the same time, it is becoming increasingly important to determine the optimum locations to install radio equipment (generic name applied to radio base stations and radio terminal stations) in order to effectively use an advanced wireless system. However, with the ongoing reduction in the number of personnel having specialized skills and the increasing difficulty of determining optimal locations for equipment installation, there is a growing need for technology that would enable even ordinary personnel to design station placement without needing to have the technical skills of a professional designer.

With the above in mind, we have made it possible to use wireless systems for disaster recovery more effectively by establishing techniques for cell and radio frequency planning that takes disaster recovery into account and by developing a tool for applying them. This tool enables ordinary personnel to easily determine the optimal locations for installing radio equipment.

2. Station placement design policies considering disaster recovery

The locations for installing radio equipment are determined according to policies and guidelines governing station placement design. Typical policies frequently established in mobile communications are set with certain objectives in mind, which include *maximizing the communication area* with as few base



(a) Maximizing communication area

(b) Minimizing unavailability factor of radio terminal stations

Fig. 1. Concept of policies for station placement design.

stations as possible and no dead zones (**Fig. 1(a)**), *maximizing the communication capacity* to accommodate more terminal stations, and *supporting high-speed movement of mobile terminals* to achieve smoother frequency handovers between base stations.

However, station placement design policies that take disaster recovery into account are seldom seen anywhere in the world. At the time of a disaster, two policy objectives usually take on importance: (1) *minimizing the unavailability factor of radio terminal stations* by installing permanent radio base stations in a complementary positional relationship so that if one base station should fail another can accommodate more radio terminal stations, and (2) *accommodating many radio terminal stations by reducing interference* so that more radio terminal stations than usual can be accommodated by reducing the effects of interference. The following station placement design techniques have been established in order to put these policies into effect.

2.1 Minimizing the unavailability factor of radio terminal stations

This highly robust policy (**Fig. 1(b)**) for station placement design aims to minimize the impact of a previously installed radio base station that has become unusable due to disaster-related damage.

An optimal solution exists for determining the locations for installing two radio base stations based on traffic density (distribution density of radio terminal stations) and the probability of failing for each radio base station. In the study model shown in **Fig. 2**, the probability P_t of terminal station accommodation by two base stations can be given by the following equation. Here, x_1 and x_2 denote the locations of the two base stations, while parameter functions $Ps(x_1)$ and $Ps(x_2)$ each denote the probability of terminal station accommodation, and pf_1 and pf_2 denote the unavailability factor of each base station.

$$P_t(x_1, x_2) = (1 - pf_1)(1 - pf_2) \cdot Ps(x_1, x_2) + (1 - pf_1)pf_2 \cdot Ps(x_1) + (1 - pf_2)pf_1 \cdot Ps(x_2).$$

In this equation, base-station unavailability factors pf_1 and pf_2 are determined by past results and by the disaster-recovery levels of the NTT communication buildings where the base stations are installed. Traffic density, meanwhile, is determined by the characteristics of the area in which the disaster has occurred (traffic concentration etc.). Determining x_1 and x_2 so that terminal station accommodation probability P_t is maximized makes it possible to minimize the probability of terminal station unavailability.

2.2 Accommodating many radio terminal stations by reducing interference

A wireless system for disaster recovery, while capable of long-range communications, can experience interference if many units of radio equipment

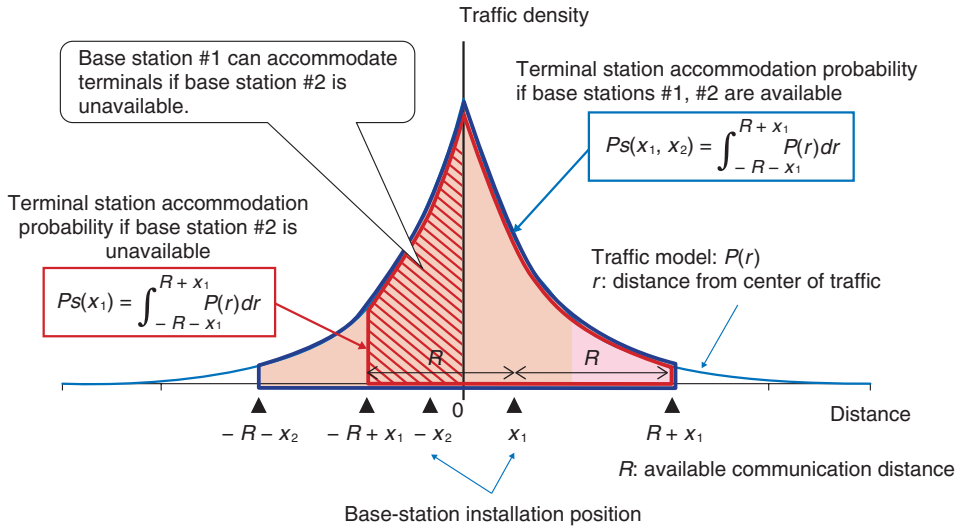


Fig. 2. Study model.

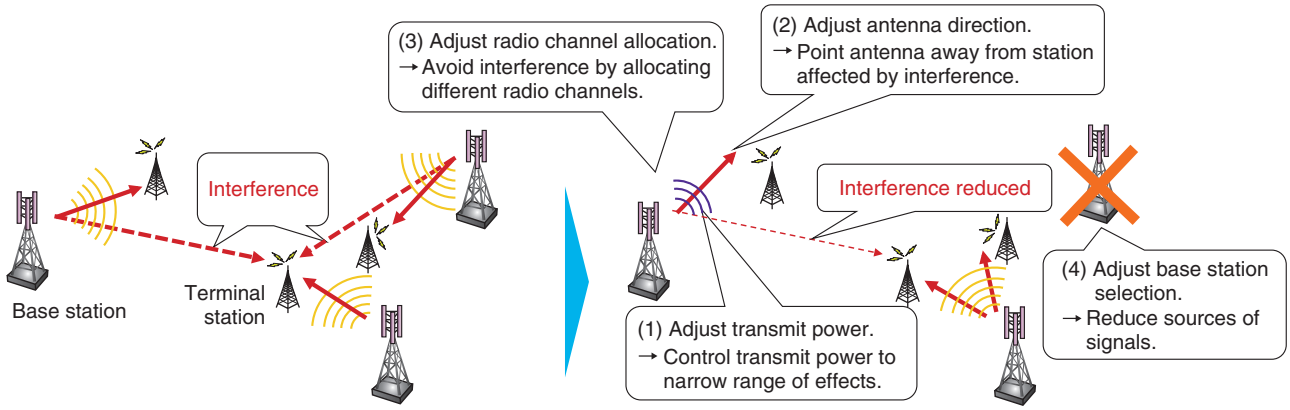


Fig. 3. Methods for reducing interference.

are installed. This is because the number of channels that each unit of radio equipment can support is limited, and failure to establish sufficient distance between radio equipment using the same channels can result in large mutual interference.

There are several measures for reducing the effects of interference. A typical measure is to install a device (e.g., a filter) for reducing interference in the radio equipment itself, but this can increase the size of the equipment. However, interference can sometimes be reduced through operations that do not require the installation of new equipment. This can be done, for example, by (1) controlling transit power to reduce the amount of interference applied to other radio equipment, (2) adjusting the orientation of a directional antenna so it points away from other equipment, (3) allocating different radio channels from those of neighboring radio equipment, and/or (4) reducing the number of radio base stations (**Fig. 3**). However, determining how best to combine these measures is both important and difficult, which is why station placement design techniques are necessary.

To reduce the effects of interference through operations, the same channels must be reused at locations that are as close to each other as possible, which is to say that the amount of mutual interference needs to be reduced by reusing the same radio channels. This can

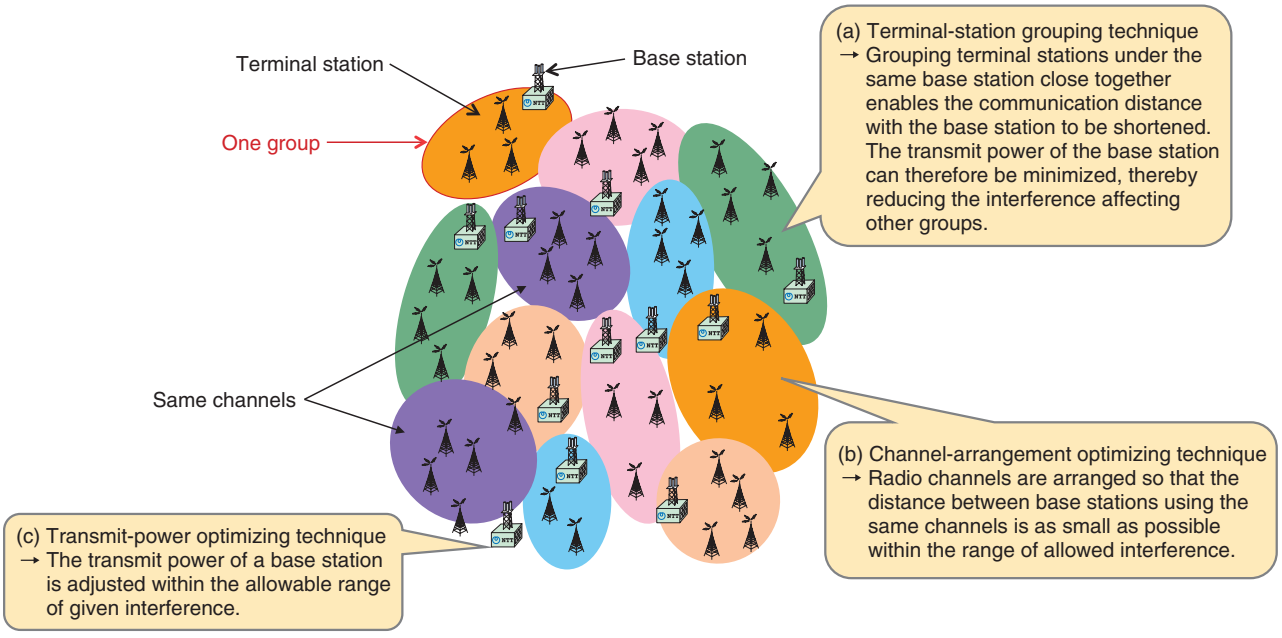


Fig. 4. Station placement design technique.

be achieved by optimizing the combination of measures (1) to (4) above. First, terminal stations communicating with the same base station are grouped together at short distances from the base station so that the transmit power of the base station can be minimized and the interference affecting other groups can be reduced (**Fig. 4(a)**). Next, radio channels are arranged so that base stations using the same channels are placed as close to each other as possible within the allowable range of interference (**Fig. 4(b)**). Finally, the transmit power of each base station is adjusted so as to fall into the allowable range of given interference (**Fig. 4(c)**). These steps are the key elements of station placement design techniques.

3. Tool development

Station placement design traditionally requires advanced knowledge in wireless systems and extensive skills in radio overall. At the same time, determining where to install radio equipment is becoming all the more difficult as wireless systems become increasingly diversified and sophisticated. For these reasons, developing a tool for applying station placement design techniques would be of great benefit since it would enable ordinary personnel to obtain the same results as a professional designer even without advanced skills. The process flow of this tool is shown in **Fig. 5**. With this tool, a designer can perform station placement design by preparing a database of candidate locations for installing radio base stations, a database of installation locations of radio terminal stations, and information on the wireless system.

4. Support of high-accuracy station placement design

For this tool, we have adopted the method described in International Telecommunication Union - Radiocommunication Sector (ITU-R) Recommendation P.1812 for calculating propagation loss, the basis for station placement design. This is a general method for estimating propagation loss in the very high frequency and ultra high frequency bands that takes into account terrain effects such as shielding loss and diffraction loss as well as ducting effects. It is used to calculate the terrain profile and evaluate loss for each propagation path with high accuracy.

Another method uses a building database to calculate propagation loss with a high level of accuracy surpassing that obtained with the ITU-R P.1812 method. The tool that we have developed makes it possible to import calculation results obtained using different propagation-loss-calculation methods by preparing a propagation-loss database with an adjusted

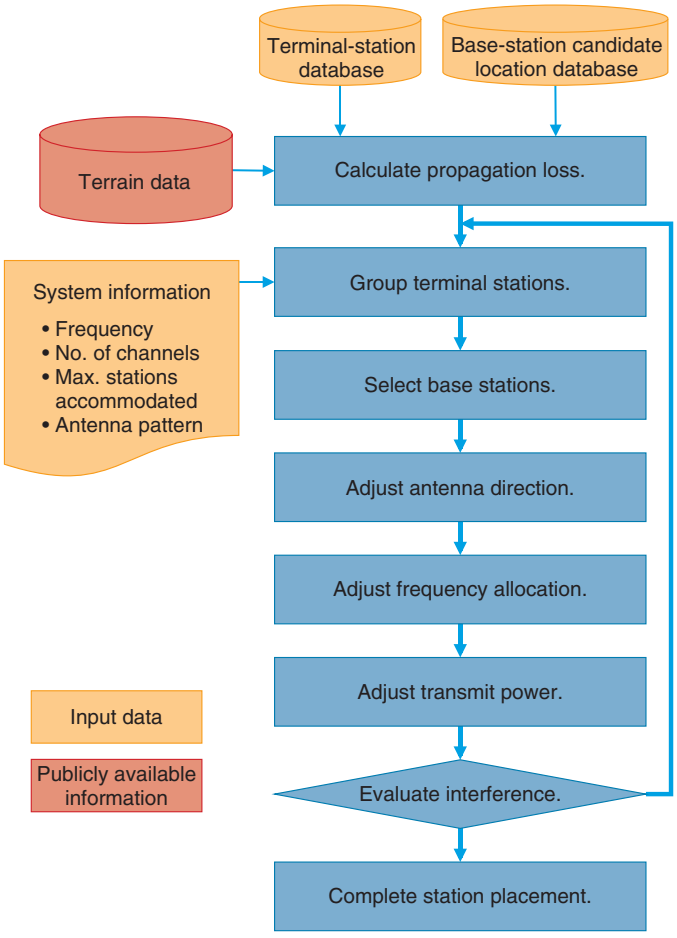


Fig. 5. Process flow of station placement design.

format. This feature enables station placement design with even higher accuracy.

5. Future development

The cell and radio frequency planning techniques and tool have been implemented for use with wireless systems for disaster recovery. The cell and radio frequency planning techniques are independent of the wireless system and can be adopted in various types of systems. In future research, the plan is to apply these techniques to systems other than wireless systems for disaster recovery.

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Color Enhancement by Optimizing the Illumination Spectrum

Masaru Tsuchida, Kaoru Hiramatsu, and Kunio Kashino

Abstract

A method is proposed to enhance color saturation while preserving the color appearance of white by controlling the spectral power distribution (SPD) of illumination. We used a color chart to design the SPD of illumination, which enables the enhancement of several colors concurrently. We experimented with a 16-color LED (light-emitting diode) lighting system as a light source, which can modulate the intensity of each color of light. The SPD of illumination is determined by utilizing three color patches of the X-Rite ColorChecker™. We evaluated the color checker and multicolor woodblock prints on color enhancement and compared the color distributions of these objects before and after changing the SPD of illumination on a chromaticity diagram. The results showed that the three selected colors were well enhanced while maintaining the color balance and metameric white under daylight illumination.

Keywords: color enhancement, spectral power distribution, multiband LED lighting system

1. Introduction

Controlling the spectral power distribution (SPD) of illumination can enhance the colors of an object without requiring any image processing. A tunable multi-wavelength light source can control light intensities of all wavelengths and generate light with various SPDs [1]. However, the total output of this kind of lighting system is currently relatively weak and is not suited for practical use. In contrast, the output of light-emitting diodes (LEDs) has been getting stronger recently, and a color tunable lighting system consisting of various LED colors can be used to control the SPD of illumination.

In this article, we propose a method to enhance several colors concurrently by changing the SPD of illumination while maintaining the metameric white (explained in the following section) and the color balance. The SPD of illumination is designed based on the spectral reflectance of color patches on a color chart. We conducted experiments to observe the enhancement of colors—before and after applying this methodology—against the color chart and old Japanese woodblock prints (*ukiyo-e*) as sample objects.

2. Design of SPD of illumination for color enhancement

We explain here the steps involved in designing the SPD of illumination.

2.1 Synthesis and control of illumination using LEDs

The SPD of illumination can be represented as a linear combination of the SPDs of a monochrome LED. Let us consider a lighting system consisting of N-colored LEDs. The SPD of objective illuminant $I_{obj}(\lambda)$ is described as:

$$I_{obj}(\lambda) = \sum_{i=1}^{N} w_i e_i(\lambda), \quad (1)$$

where λ is wavelength and w_i and $e_i(\lambda)$ are the weight and SPD of the i th color LED of the lighting system. An object's color is enhanced by changing the values of $\mathbf{w} = [w_1, ..., w_N]$. To maintain the color balance of the object under illumination before the SPD of the illumination is changed, let us consider the constraint conditions where the targeted illumination satisfies metameric[*1] white. This means that chromaticity[*2] values of standard white and its luminance are

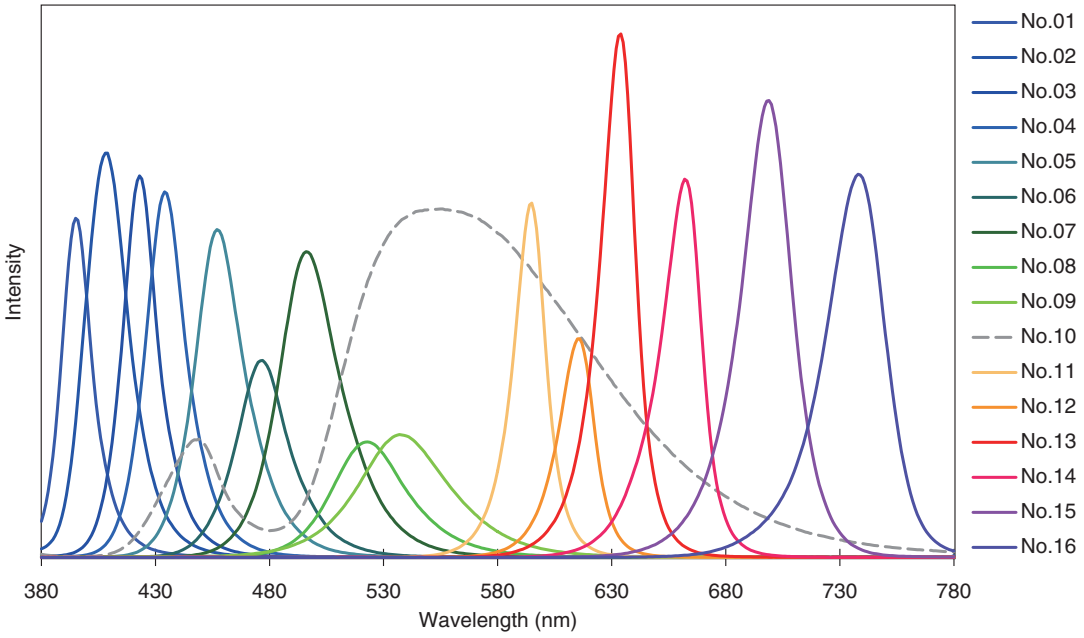

Fig. 1. Spectral power distributions of each LED in the 16-color LED lighting system.

maintained after the SPD of illumination is changed. These conditions are described as:

$$\{f_a(I_{org}(\lambda),1) - f_a(I_{obj}(\lambda),1)\}^2 + \{f_b(I_{org}(\lambda),1) - f_b(I_{obj}(\lambda),1)\}^2 = 0, \quad (2)$$

$$f_L(I_{obj}(\lambda),1) = f_L(I_{org}(\lambda),1), \quad (3)$$

where $I_{org}(\lambda)$ is the SPD of the original illumination. Here, $f_L(I(\lambda), r(\lambda))$, $f_a(I(\lambda), r(\lambda))$, and $f_b(I(\lambda), r(\lambda))$ are functions for calculating CIE-Lab*3 values, where $I(\lambda)$ is the SPD of illumination and $r(\lambda)$ is the spectral reflectance of an object's surface.

2.2 Design of SPD of illumination using color chart

Let us consider the case in which a target color for enhancement is a color patch whose spectral reflectance is $r_{obj}(\lambda)$. The SPD of the objective illumination $I_{obj}(\lambda)$ is obtained by determining weight $\mathbf{w} = [w_1, ..., w_N]$, which fulfills Eqs. (2) and (3) and maximizes ε.

$$\varepsilon = f_a(I_{obj}(\lambda), r_{obj}(\lambda))^2 + f_b(I_{obj}(\lambda), r_{obj}(\lambda))^2. \quad (4)$$

Let the number of target colors be represented as C. Then ε is rewritten as:

$$\varepsilon = \sum_{j=1}^{C} \varepsilon_j, \quad (5)$$

$$\varepsilon_j = f_a(I_j(\lambda), r_j(\lambda))^2 + f_b(I_j(\lambda), r_j(\lambda))^2. \quad (6)$$

When the target colors are blue, green, and red, ε is represented as:

$$\varepsilon = \varepsilon_{blue} + \varepsilon_{green} + \varepsilon_{red}. \quad (7)$$

3. Experiments

We conducted experiments to evaluate the effectiveness of our method. The experiments and results are described in this section.

3.1 Experimental setup

We experimented with a 16-color LED lighting system (Telelumen Light Replicator, TeleLumen LCC) as the light source. The SPDs of each LED are shown in **Fig. 1**; the intensity of light for each color can be modulated. We designed the SPD of illumination using three color patches of the X-Rite ColorChecker™

*1 Metamerism: The phenomenon that occurs due to the ability of human eyes to see two colors as being the same even when the two colors have different spectral power distributions. The two matching colors are called metamers.

*2 Chromaticity: An objective specification of the quality of a color regardless of its luminance.

*3 CIE-Lab: The second of two systems adopted by CIE (International Commission on Illumination) in 1976 as models that better showed uniform color spacing in their values.

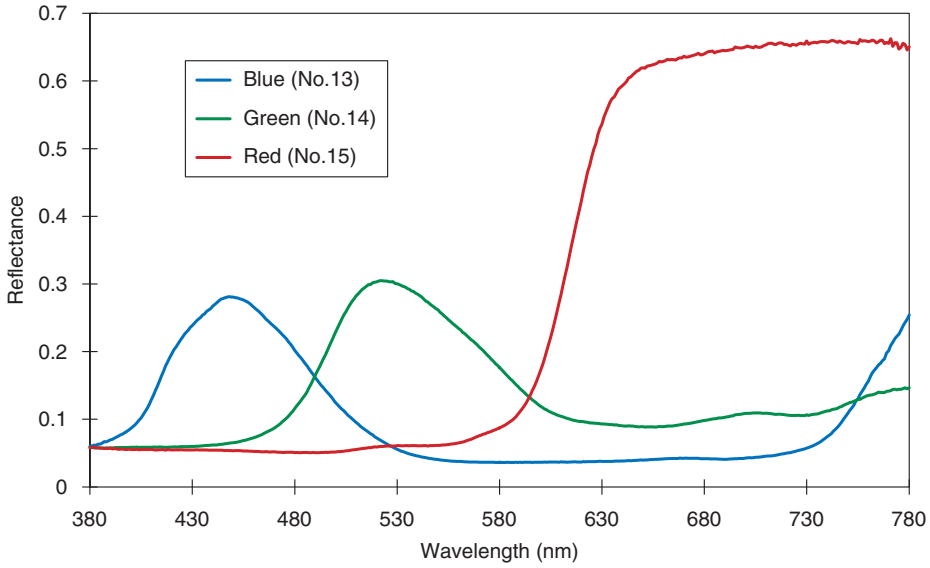

Fig. 2. Spectral reflectance of blue, green, and red patches.

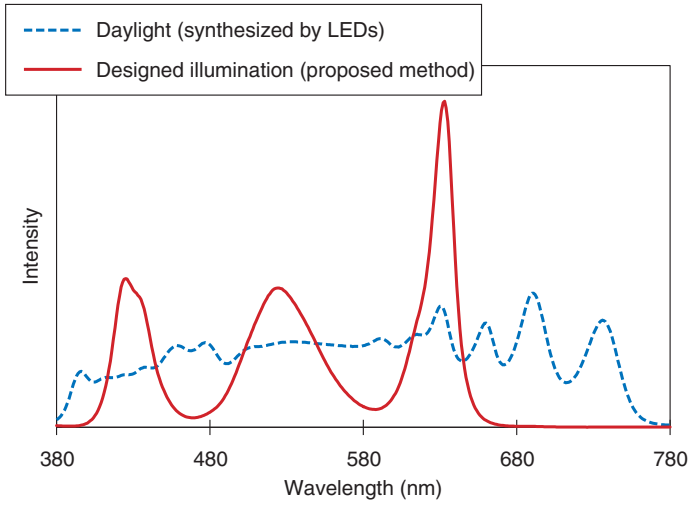

Fig. 3. Spectral power distribution of illumination.

(no. 13 for blue, no. 14 for green, and no. 15 for red); the spectral reflectance of these patches is shown in **Fig. 2**.

We experimented with synthesizing daylight using the lighting system as the reference illumination. First, we used the color chart to design the SPD of the illumination and focused on enhancing the blue, green, and red colors. The weights of each LED were determined using the generalized reduced gradient method. Next, we evaluated the color enhancement results on a chromaticity diagram using the color chart and several old woodblock prints (*ukiyo-e*), which were discolored with degraded color saturation.

3.2 Results of designing SPD of illumination and color enhancement

The SPDs of daylight (blue dashed line) and the designed illumination (red solid line) are shown in **Fig. 3**. The SPD of the designed illumination has

Fig. 4. Captured images of color chart under synthesized daylight (left) and under the designed illumination (right).

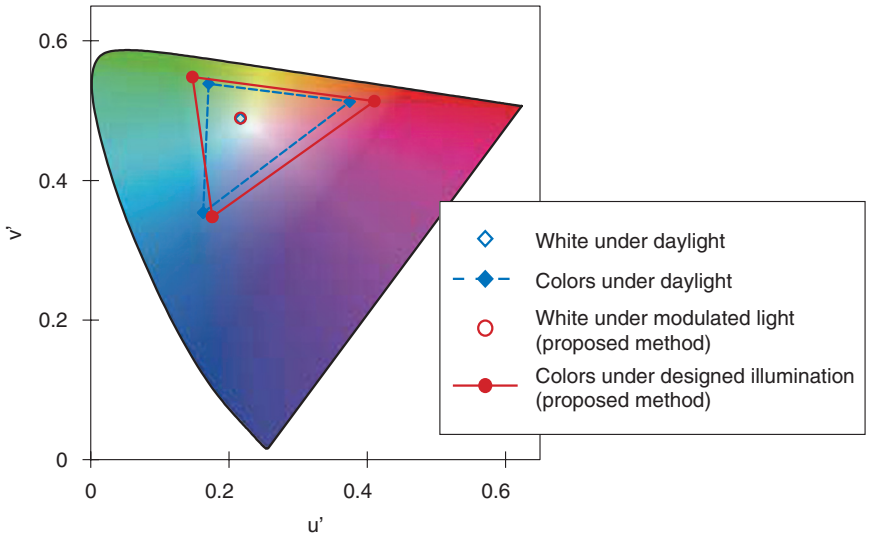

Fig. 5. Color distribution of white, blue, green, and red patches plotted on CIE-u'v' chromaticity diagram.

three peaks whose center wavelengths are 435, 530, and 634 nm. These center wavelengths correspond to the peak wavelengths of the spectral reflectance of the blue and green patches and to the rising wavelength of the spectral reflectance of the red patch.

Images of the color chart captured under synthesized daylight and under the designed illumination are shown in **Fig. 4**. A comparison of color patches along the bottom row indicates that the gradation of white to gray is not different after changing the illumination. However, the saturations of other color patches were enhanced after the illumination changes, especially for the blue, green, pink, orange, and red patches. The color balance of the entire image was also maintained after the illumination change.

Chromaticity values of white, blue, green, and red patches plotted on the CIE-u'v' chromaticity diagram[*4] are shown in **Fig. 5**. The blue diamonds and the dashed line represent colors under the illumination before the SPD was changed, and the red circles and solid line represent colors after the illumination was changed. This diagram shows that u'v' values of white under each kind of illumination are plotted in the same spot; however, the color saturation of the other three color patches is enhanced.

Images of the woodblock print (*ukiyo-e*) captured under daylight (left) and under the designed illumination (right) are shown in **Fig. 6**. In the upper images, the reddish and green parts on the clothes under the designed illumination look more vivid than those under daylight. The pink blossoms also look more reddish, and it is easier to distinguish their shapes.

*4 CIE-u'v' chromaticity diagram: A two-dimensional representation or cross-section of a three-dimensional color space. Here, u' and v' are chromaticity coordinates.

Fig. 6. Observed images under daylight (left) and under the designed illumination (right).

Likewise, the reddish and blue-green parts on the bottom prints are more vivid under the designed illumination. Note that the total color balance of these prints is properly maintained through the SPD illumination change, and the color saturation of some areas on these prints was enhanced.

The colors of the blue, green, and reddish parts on these prints plotted on the CIE-u'v' chromaticity diagram are shown in **Fig. 7**. The circle represents a white point, and the red and blue arrows represent directions of color shifts that were enhanced by changing the SPD of illumination. The color shifts in the diagram also indicate how much the colors represented in the woodblock prints were enhanced.

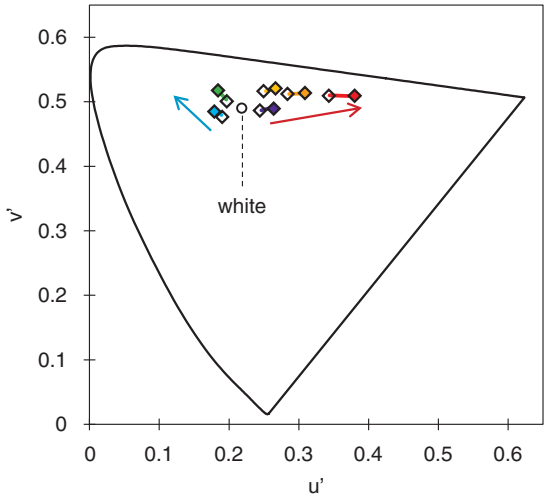

Fig. 7. Color shift on CIE-u'v' chromaticity diagram.

4. Conclusion

We proposed a method for enhancing several colors concurrently by changing the SPD of illumination. In our experiments, blue, green, and red patches of the X-Rite ColorChecker™ were used in designing the illumination, and the designed illumination was synthesized by using a 16-color LED lighting system. We conducted experiments using old Japanese woodblock prints (*ukiyo-e*) discolored with degraded color saturation, in which we illuminated the prints with the designed light. The results showed that the designed illumination enhanced colors while maintaining the metameric white and the color balance under daylight.

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Trademark notes

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Activities toward TM Forum Frameworx 17.0 and TM Forum Live! 2017 Report

Aya Suzuki, Kenichi Kashibuchi, and Takayuki Nakamura

Abstract

TM Forum is the global industry association related to telecom business operations. It specifies standard business processes, information models, applications (function deployment), and interfaces for achieving digital services in a reference model called Frameworx. The NTT Group conducts surveys and gathers information on putting TM Forum specifications to practical use. It also proposes requirements necessary to provide B2B2X (business-to-business-to-X) services and to manage end-to-end processes including virtualized environments and reflects those requirements in TM Forum documents. This article provides an overview of TM Forum and introduces the activities of the NTT Group at TM Forum including those at TM Forum Live! 2017.

Keywords: TM Forum, Frameworx, Catalyst

1. Introduction

TM Forum [1] is a non-profit industry association founded as the Open Source Initiative/Network Management (OSI/NM) Forum in 1988. The organization presently has more than 850 member companies and brings together more than 90,000 engineers and technicians to study industry standards in the field of operations and to promote interoperability. Specifically, TM Forum biannually releases a revised edition of documents called Frameworx that compiles business processes, information models, applications (function deployment), and interfaces as standards related to business operations. Furthermore, TM Forum specifies Business Metrics compiling key performance indicators and key quality indicators in the field of operations and Open Application Programming Interfaces (Open APIs) to enable collaboration between operators and other industries in the ecosystem as documents related to Frameworx. The most current release is Frameworx 17.0, with Frameworx 17.5 scheduled for release in December 2017.

In the past, the projects making up Frameworx dominated discussions, but in more recent years, related projects have come to be actively studied to support telecom operators and partners in other industries faced with the challenges of digital transformation. The results of discussions on those projects will be reflected in Frameworx.

TM Forum is also hosting proof of concept projects called Catalyst projects developed by telecom operators and software vendors. The purpose of Catalyst projects is to demonstrate that certain models and specifications formulated by TM Forum can be practically applied in real-world environments.

2. Overview of TM Forum projects

This section presents brief descriptions of the key TM Forum projects underway.

2.1 Work on Frameworx

Frameworx projects have been carried out focusing on the different areas below.

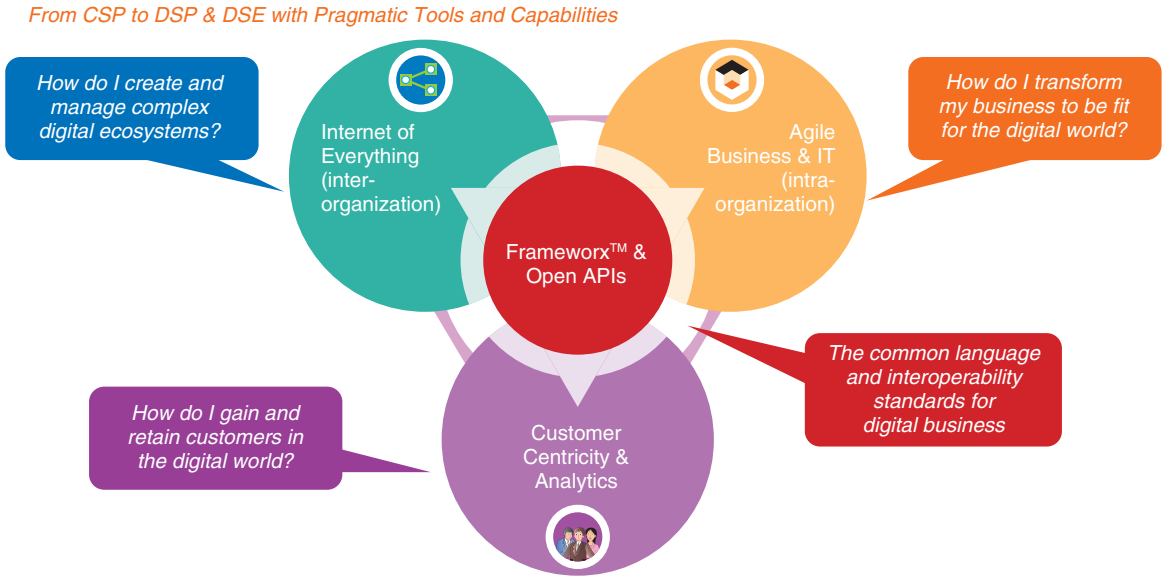


Fig. 1. Frameworx and related projects.

(1) Business Process Framework (eTOM)

The enhanced Telecom Operations Map (eTOM) organizes the business processes of an information-communications service provider on a matrix based on phases along the time axis and management domains.

(2) Information Framework (SID)

The Shared Information/Data model (SID) systematizes the information managed and circulated in a system as an information model rather than a specific data model.

(3) Application Framework (TAM)

The Telecom Application Map (TAM) is a standard framework for organizing and mapping the functions in the operations support system/business support system (OSS/BSS) using relationships between eTOM and SID. Here, the focus in business processes is not only on tasks performed during operations known as FAB (fulfillment, assurance, and billing) but also on strategy (decision-making) and readiness (migration, procurement) from the viewpoints of agility and virtualization.

(4) Integration Framework

The Integration Framework has traditionally contained standards supporting integration and interoperability between applications defined in TAM. These standards are used widely today in the telecom industry, but recent industry trends are now driving the standardization of Digital Services Reference Architecture (DSRA) related to both support and management functions on platform services and APIs based on Representational State Transfer (REST) for achieving collaboration between operators.

2.2 Related projects

Three strategic programs were launched four years ago as a framework for studying the direction of Frameworx extensions (**Fig. 1**) [1]. These programs are based on trends in the telecom industry and are focused on providing business support for introducing virtualization, providing business-to-business-to-X (B2B2X) services, and improving customer value. These three strategic programs are summarized below.

(1) Agile Business & IT (information technology)

This program is centered on operations and security in a virtualized environment. In particular, the Zero-touch Orchestration, Operations and Management (ZOOM) project is focused on exploiting network functions virtualization (NFV) and software-defined networking (SDN) in the operation of virtual networks.

(2) Internet of Everything

This program concerns architecture for achieving

an open digital ecosystem and scenarios such as smart cities based on linked services as typified by IoT (Internet of Things).

(3) Customer Centricity & Analytics

This program explores customer experience management using customer-experience evaluation indices (Business Metrics) and the big data analytics to analyze those metrics.

TM Forum members consider the requirements established in these strategic programs to cross-sectionally discuss the standardization of REST-based APIs in the area of operations of API projects at the implementation level in collaboration with related industry organizations.

2.3 Catalyst projects

At TM Forum, Catalyst projects are organized to demonstrate the effectiveness of TM Forum standards and to refine them. These projects are focused on scenarios created by two or more service providers, including telecom carriers. Catalyst projects are aimed at testing the dynamics of scenarios that are given form by four or more software vendors using TM Forum standards. Catalyst projects are demonstrated at TM Forum events. Project members can receive comments and feedback on their projects there and can promote their reflection in Frameworx and implementation as standards.

Demonstrations of 32 Catalyst projects from the above strategic programs were presented at the TM Forum Live! 2017 conference (a conference featuring keynote speakers, general lectures, Frameworx presentations, Catalyst demonstrations, workshops, and corporate exhibits) [2] held in Nice, France, in May 2017. As a result of these demonstrations, the concerns in standardization activities shifted from reference models to implementation.

3. Activities toward Frameworx 17.0

Discussions were held within the various TM Forum projects on the establishment of Frameworx 17.0 released in September 2017. These efforts, including trends at TM Forum Live! 2017, are summarized in this section.

3.1 Standardization activities in NTT Group

The NTT Group recognizes the weight that TM Forum carries in commercializing OSS products and has therefore been working at TM Forum to reflect NTT Group requirements in TM Forum standards while promoting the improvement of environments (covering technology, deployment, and operation) that can utilize TM Forum-compliant products on the NTT Group side. These activities are centered on the treatment by the NTT laboratories and NTT COMWARE of the Internet of Everything and Agile Business & IT as NTT Group priority areas from the respective viewpoints of B2B2X business and end-to-end (E2E) management including virtualized environments.

The NTT Group expert committee on TM Forum consists of expert members from NTT Group operating companies, with a member of the NTT laboratories serving as head and NTT COMWARE as secretariat. This committee supports NTT Group participation in TM Forum projects, consolidates opinions with respect to TM Forum documents, and shares information on studies and trends at TM Forum.

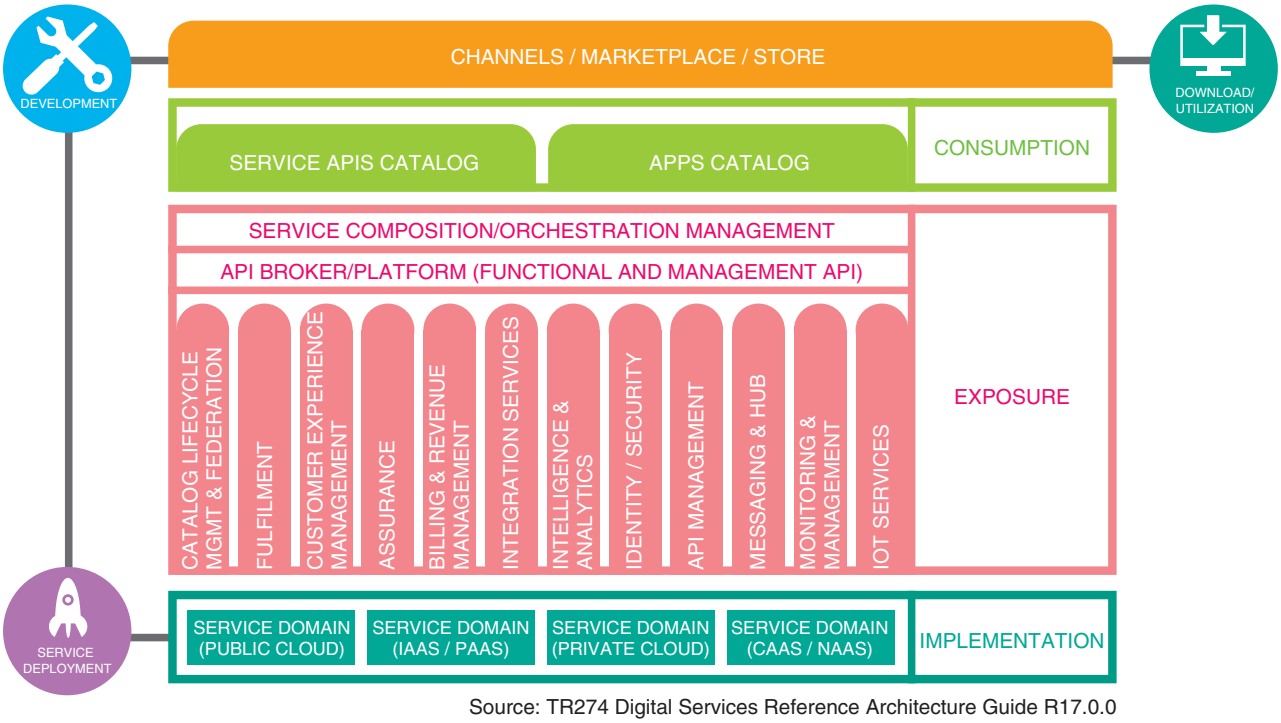
(1) APIs

Studies on REST-based API standardization called TM Forum Open APIs began three years ago at TM Forum as a result of anticipation of the shift in the carrier business model to B2B2X services. As the number of TM Forum members studying APIs increased, API requirements for OSS/BSS intermodule linking came to be reflected in standards in addition to inter-operator APIs. In addition, API standardization based on virtualization requirements has recently been gaining momentum in studies.

The NTT Group, meanwhile, has been active in standardizing API requirements within the NTT Group with the aim of establishing common operations (one-stop operations) for the provision of services linking multiple operators [3]. During the time of TM Forum Live! 2017, the scope of API studies with regard to NTT requirements (resource pool management) was adjusted in discussions with knowledgeable individuals. The plan going forward is to continue working to reflect these requirements in standards.

(2) DSRA/DPRA

At TM Forum, discussions are underway on DSRA (**Fig. 2**) as an architecture for achieving collaboration among multiple services under the B2B2X model and on APIs for completing those links. At the NTT laboratories, we incorporated the authentication federation function necessary for collaboration between multiple services (service federation) into the business scenarios in DSRA Guide R17.0. Additionally, a preliminary survey was conducted at TM Forum Live! 2017 with the aim of generating proposals for more functions, and the importance of various functions was evaluated.



Source: TR274 Digital Services Reference Architecture Guide R17.0.0

CAAS: communication as a service
IAAS: infrastructure as a service
MGMT: management
NAAS: network as a service
PAAS: platform as a service

Fig. 2. DSRA.

Digital Platform Reference Architecture (DPRA), which is based on DSRA, was also explored as a reference architecture for functional requirements in environments requiring collaboration among multiple partners. This architecture envisions hybrid infrastructure management spanning multiple carriers consisting of fixed/mobile networks, legacy networks, and virtualized environments in which vendor/carrier proprietary elements are treated as black boxes and operability is achieved through TM Forum Open APIs. At TM Forum, the aim is to provide integrated operations in an environment having different network technologies.

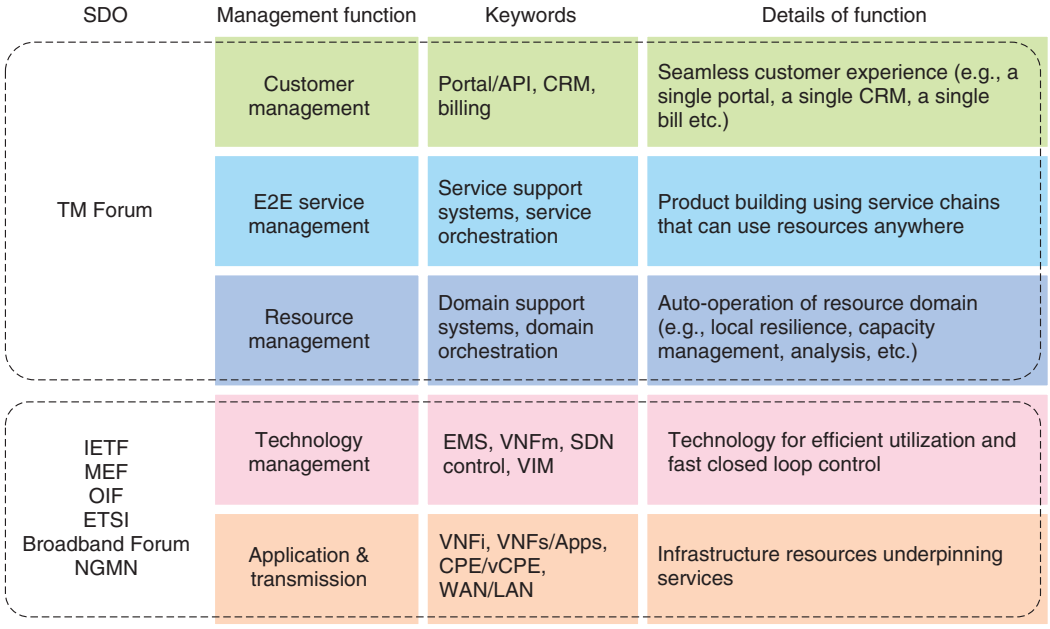
(3) ZOOM

One of the most enthusiastically discussed themes in virtualization-related studies is network slicing in fifth-generation mobile communications systems (5G). Network slicing refers to dividing up a network in a virtual manner so that individual networks can be provided in a more efficient manner tailored to service requirements. At TM Forum, attention is focused on how the business layer—the axis of studies—drives the provision and use of network slices between operators. A white paper was prepared by TM Forum on high-level requirements for network slicing based on the definition of slicing by Next Generation Mobile Networks (NGMN) and on TM Forum study assets accumulated to date such as those concerning common operations in a hybrid environment, a premise of network slicing. The NTT laboratories have made contributions to network slicing from the viewpoint of use cases based on the output from Catalyst projects.

In parallel with preparing this white paper, studies on API requirements toward operations in a hybrid environment are progressing with an eye to API standardization while aiming for consistency with related standards developing organizations (SDOs) (**Fig. 3**). There is now a move toward API standardization studies related to closed-loop, policy-based service and resource management, which is a topic focused on optimizing a hybrid environment. This movement will be a highlight of future discussions.

3.2 Catalyst activities in NTT Group

Of the 32 Catalyst projects presented at TM Forum



Source: TR262 Hybrid Network Management Platform Blueprint R17.0.0

Apps: applications
CPE: customer premises equipment
CRM: customer relationship management
EMS: element management system
ETSI: European Telecommunications Standards Institute
IETF: The Internet Engineering Task Force
LAN: local area network
OIF: The Optical Internetworking Forum
vCPE: virtual CPE
VIM: virtualized infrastructure manager
VNFi: virtual network function infrastructure
VNFm: virtual network functions manager
WAN: wide area network

Fig. 3. Achieving consistency with SDOs.

Live! 2017, the NTT Group participated in 4 of them, which are described below.

(1) Connected Citizen: Life in a Green, Clean, Smart City

This Catalyst led by Orange S.A. aims to commercialize a platform for smart cities. It has constructed a prototype platform based on use cases (building cities through citizen participation, transportation measures, healthcare) covering seven European cities. For implementation, NTT COMWARE contributed its FlexibleEntry [4] product as a user interface for local governments and an API to link with BearingPoint's Infonova R6 [5] business support system. (This project was evaluated as a TM Forum standardization activity and received a Catalyst award.)

(2) New Business Models with Mobile Sponsored Data

This Catalyst project focuses on the use of sponsored data to offer free communication services to mobile-device users. Such users would receive free services, which they would normally be charged for, through the delivery of ads or special messages sent by the service provider. At TM Forum Live! 2017, a demonstration of this project was conducted reflecting use cases involving collaboration among multiple carriers.

(3) 5G Service Operations - Leveraging Open Source Innovation

This Catalyst aims to provide 5G and existing network functions as a network-as-a-service to multiple industries by leveraging the benefits of open source. The demonstration focused on dynamically and automatically achieving business operations that satisfy carrier-grade assurance.

(4) Real Virtuality - Phase II

With a hybrid network spanning multiple digital service providers, this Catalyst aims to achieve E2E processing that includes both virtualized networks (NFV/SDN) and non-virtualized networks. The demonstration at TM Forum Live! 2017 featured high-function, self-managing operations based on the concept of policy control.

3.3 Global carrier trends

Nine themes including keynote presentations were covered at TM Forum Live! 2017. The following is a summary of the presentations on three themes that received particular attention.

(1) API Manifest

This keynote presentation reported on case studies in digital transformation in various companies and confirmed that positive developments were taking place both inside and outside the telecom industry. The TM Forum secretariat shared the news that the number of companies promoting TM Forum Open APIs as a means of achieving this digital transformation had increased from 9 to 28 (NTT Group is one of the original members).

(2) Future OSS

An example of digital transformation at various carriers was given in this keynote presentation, which announced a white paper on Future OSS from Orange and reported that discussions were progressing not only on the NFV/SDN network layer but also on the OSS/BSS layer including micro-services and APIs and that requirements of future OSS/BSS were starting to be specified. In particular, studies on APIs for virtual network environments and on network management automation based on the operational agility of NFV are progressing to the testing stage. To this end, leading carriers in Europe and the United States have been actively applying open source to virtual network management such as AT&T's Open Network Automation Platform (ONAP) and Telefonica's OSM, that is, Open Source MANO (Management and Orchestration).

(3) Platform Economy

Detailed studies led by BT, Vodafone, and other firms on DPRA in relation to the linking of operator platforms as advocated by TM Forum are starting to take shape as application examples related to the Smart City concept that highlights collaboration between carriers and other industries. This trend was reflected in some of the Catalyst projects exhibited at TM Forum Live! 2017. Additionally, given that local governments have much in common with respect to the problems they face, collaborations and joint projects among local governments adopting Smart City ideas are now underway. TM Forum recommends that cities construct Smart City platforms based on a common architecture and establish mutual links via these platforms.

3.4 Global vendor trends

During the time of TM Forum Live! 2017, the NTT Group was engaging in technical discussions with global vendors and collecting information on product trends. We report here on NFV products and compliance with TM Forum standards.

(1) NFV products

There was an emphasis on service orchestration products that go beyond the integration of existing networks with virtual networks and enable linkage with a variety of digital services, that is, non-network functions. It was also revealed that a multivendor virtual network environment was becoming mainstream for operators, and the successful results of linking NFV products with the products of other companies drew interest.

Telecom operators are concerned with the increasing complexity of recovering from failures in a virtual environment that requires an awareness of the physical environment. Vendors are taking the stance that linking their products with service assurance products enables auto-healing, but no clear solution in cases of major physical failures caused by a natural disaster, for example, could be seen. The NTT Group will continue to keep an eye on standards-related technologies and product trends that take this into account.

(2) Compliance with TM Forum standards

We have confirmed that some vendors adopting TM Forum Open APIs use testing tools (conformance test kits) to check the conformance of API specifications and that they have products that expose TM Forum Open APIs. TM Forum standards have traditionally not required a level of conformance as strict as that of other standards, but against a background of interoperability with other companies' products in a multivendor era, they are moving in the direction of requiring strict conformance with API specifications, especially TM Forum Open APIs. Making it easy to reflect TM Forum standards in vendor products will make standardization activities all the more important.

4. Future outlook

As we work towards promoting virtualization and B2B2X services in the NTT Group, we are carrying out standardization efforts to achieve early reflection of our requirements for these priority areas in TM Forum programs. To this end, we are keeping a close watch on those areas at TM Forum in which lively discussions are being held. We will also continue to participate in Catalyst projects and assess the feasibility of those technical requirements.

The NTT Group can reference and use TM Forum standards when exposing functions as APIs and managing operations in a virtualized environment. Also, through the TM Forum expert committee within the NTT Group, we will continue to engage in activities beneficial to the use of TM Forum standards by the NTT Group by sharing information on technical studies and industry trends at TM Forum.

References

[1] TM Forum, https://www.tmforum.org/
[2] TM Forum Live! 2017, http://www.tmforumlive.org/
[3] Y. Soejima, M. Nakajima, and K. Takahashi, "One-stop Operation Technology," NTT Technical Review, Vol. 14, No. 10, 2016. https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201610fa5.html
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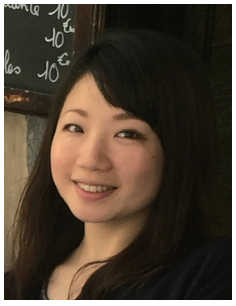

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She received a B.E. and M.E. in engineering from Waseda University, Tokyo, in 2012 and 2014. She joined NTT Network Service Systems Laboratories in 2014. She has been researching and developing API architectures for the B2B2X business model. She has also been involved in standardization work for promoting B2B2X business models in TM Forum since 2016.

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He received a B.E. in information engineering and an M.S. and Ph.D. in information sciences from Tohoku University, Miyagi, in 2005, 2007, and 2010. From 2007 to 2010, he was a research fellow with the Japan Society for the Promotion of Science. After joining NTT Network Service Systems Laboratories in 2010, he was involved in research and development focused on exposing APIs from a call session control server. He is currently researching an API provision framework required for the B2B2X business model, while referencing TM Forum assets. Dr. Kashibuchi is a member of the Institute of Electrical and Electronics Engineers (IEEE) and the Institute of Electronics, Information and Communication Engineers (IEICE).

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He received a B.E. and M.E. from Tokyo Institute of Technology. He joined NTT in 1996. He has been working on the design, deployment, and management of platform based services. He also has experience in OSS/BSS optimization. He has been involved in TM Forum as a member of the API project since 2014 and received the "Outstanding Contributors Award" in September 2017.

External Awards

Achievement Award
Winner: Koyo Nitta, NTT Device Innovation Center; Ken Nakamura, NTT Media Intelligence Laboratories; Takayuki Onishi, NTT Media Intelligence Laboratories
Date: June 1, 2017
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE)

For their contribution to the development and practical application of MPEG-2/H.264/H.265 codecs.

MIRU Excellent Paper Award
Winner: Kota Yamaguchi, CyberAgent, Inc.; Takayuki Okatani, Tohoku University; Takayuki Umeda and Kazuhiko Murasaki, NTT Media Intelligence Laboratories; Kyoko Sudo, Toho University
Date: August 9, 2017
Organization: The 20th Meeting on Image Recognition and Understanding (MIRU2017)

For "End-to-end Learning Potentials for Structured Attribute Prediction."
Published as: K. Yamaguchi, T. Okatani, T. Umeda, K. Murasaki, and K. Sudo, "End-to-end Learning Potentials for Structured Attribute Prediction," MIRU2017, OS2-1, Hiroshima, Japan, Aug. 2017.

Best Paper Award
Winner: Munekazu Date, Hiroshi Fujii, and Hideaki Kimata, NTT Media Intelligence Laboratories
Date: August 31, 2017
Organization: The 9th International Conference on 3D Systems and Applications (3DSA 2017)

For "Full Parallax Visually Equivalent Light Field 3D Display Using Linear Blending."
Published as: M. Date, H. Fujii, and H. Kimata, "Full Parallax Visually Equivalent Light Field 3D Display Using Linear Blending," Proc. of 3DSA 2017, Digest version, p. 521, Busan, South Korea, Aug. 2017.

IEICE 100-Year Memorial Paper Award Competition, Best Paper Award
Winner: Seishi Takamura, NTT Media Intelligence Laboratories
Date: September 15, 2017
Organization: IEICE

For "The Future of All Nature Simulation by Machine."
Published as: S. Takamura, "The Future of All Nature Simulation by Machine," J. IEICE, Vol. 100, No. 12, Dec. 2017 (in Japanese).

IEC 1906 Award
Winner: Makoto Shimokozono, NTT Device Technology Laboratories
Date: October 23, 2017
Organization: International Electrotechnical Commission (IEC)

For his role as a key project leader in IEC TC 86/SC 86C/WG3 and WG4, where he guided two projects on optical amplifiers (IEC 61291-2) and on laser modules for telecommunication (IEC 62572-3) to publication. As secretary of WG4, he demonstrated his excellent technical and organizational skills.

Papers Published in Technical Journals and Conference Proceedings

Design of a Temporary Optical Coupler Using Fiber Bending for Traffic Monitoring
T. Uematsu, H. Hirota, T. Kawano, T. Kiyokura, and T. Manabe
IEEE Photonics Journal, Vol. 9, No. 6, December 2017.

We designed a temporary optical coupler that extracts 1.25-Gbps optical signals for traffic monitoring. The temporary optical coupler employs a fiber bending technique that uses a receiving fiber to receive leaked signal light from a bent fiber. We optimize the bending condition and the receiving fiber to obtain a high extraction efficiency while keeping the bending loss below 2 dB. We also measure the bit error rates for the 1.25-Gbps signals and reveal that our temporary optical coupler extracts the 1.25-Gbps optical signals without any deterioration in signal quality. Finally, we confirm experimentally that we achieved traffic monitoring using a traffic monitoring system and our temporary optical coupler in a fiber-to-the-home access network system based on a gigabit Ethernet passive optical network.