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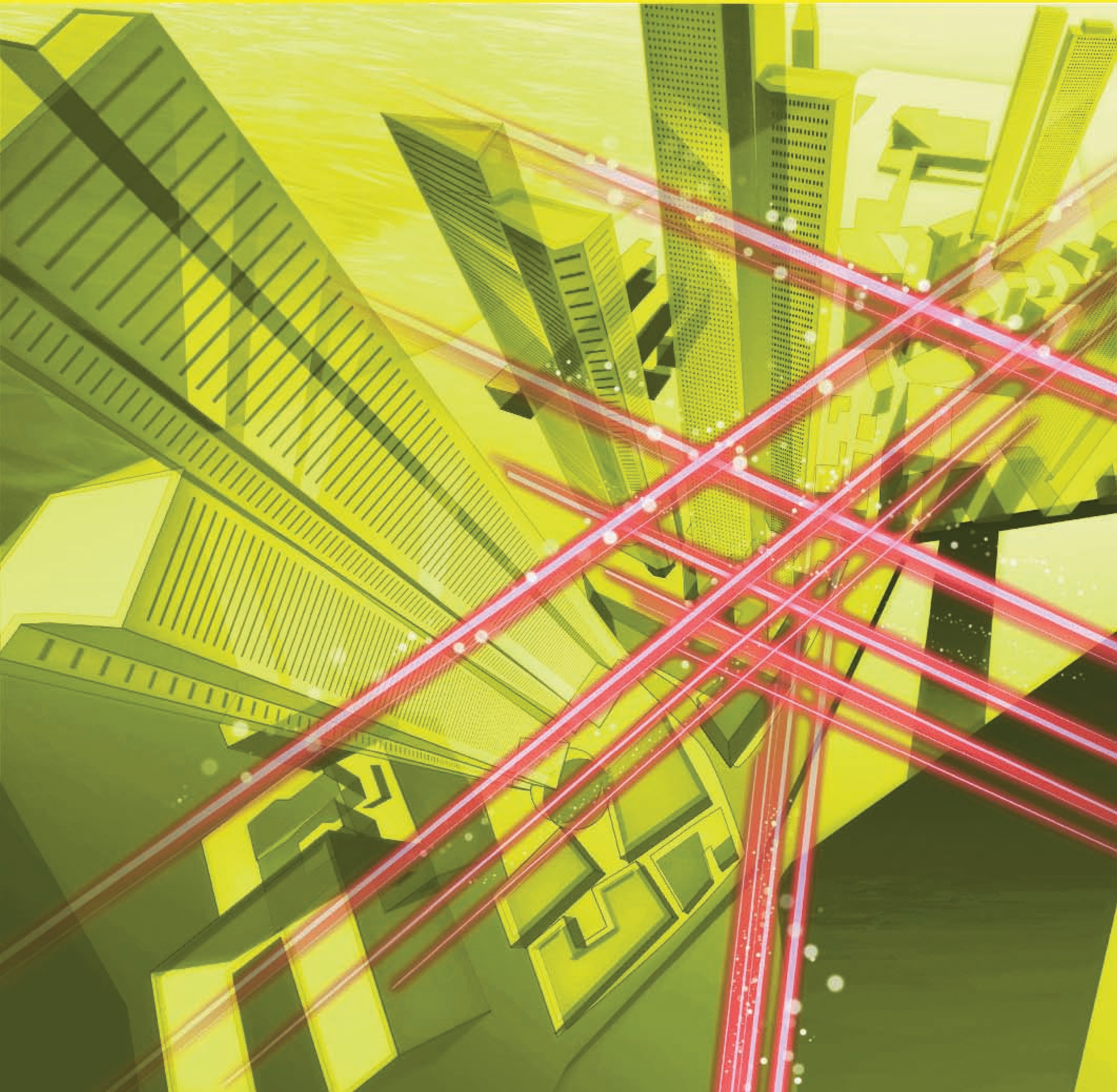

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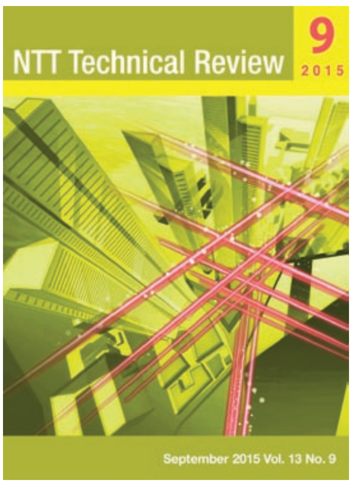

Recognizing the Importance of Dissemination Skills after 10 Years of Combating Malware

Makoto Iwamura
Distinguished Researcher,
NTT Secure Platform Laboratories

Combating malware has become a global issue. The black market for malware, which threatens the integrity of even state secrets, is turning into a robust organization that presents an ongoing challenge to researchers. Since 2005, when the word *malware* came into common use, NTT Secure Platform Laboratories has been working around the clock to collect, analyze, and combat malware. We asked Dr. Makoto Iwamura, NTT Distinguished Researcher, to tell us about research achievements to date, future issues, and approaches to establishing an anti-malware system and training program for security personnel.

Keywords: cyber security, malware, honeypot

Wide-ranging need for cyber security, from personal information to state secrets

—Dr. Iwamura, please tell us about your research activities.

My work involves the collection and analysis of malware and the creation of mechanisms for solving malware-related problems. Malware is a portmanteau of the words *malicious* and *software* and refers to software with malicious intent. For example, when malware infects a computer, it may result in unintended operations or information leaks and can even disable the computer itself.

It has become commonplace to hear about damage caused by malware attacks, such as the leak of confidential documents from a personal computer or monetary loss from a transfer of funds to an unintended account during an Internet banking transaction. Today, however, malware is also coming to be known as a cyber weapon that can be used as a means of mounting a military-like attack on a foreign government.

In the past, malware was mainly used to mount attacks indiscriminately on an unspecified number of people. Recently, however, malware that mounts targeted attacks on specific individuals or organizations has come into existence. These types of attacks may infect a personal computer by attaching a document to email or by exploiting vulnerabilities in a web browser to direct the user to visit a specific URL (Uniform Resource Locator).

Malicious scanning that exhaustively attacks vulnerable computers in Internet space (by *knocking on doors* to find vulnerable areas of computers) and spreads an infection if successful was reported to

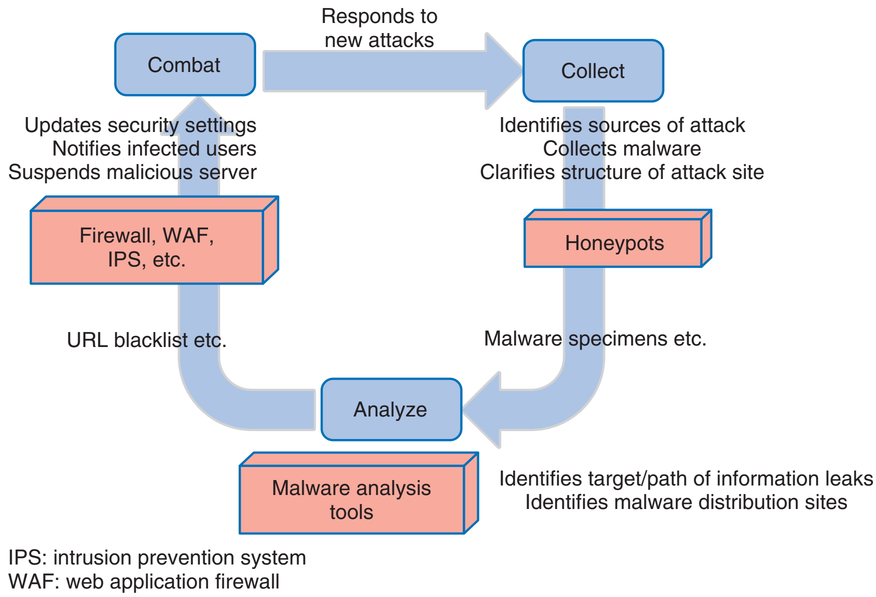

Fig. 1. Anti-malware approach using honeypots.

have occurred about 25.6 billion times in 2014.

These attacks have been mounted to obtain personal information, confidential corporate information, and state secrets, and when such information is obtained, it has consequently been traded on the black market, resulting in undeserved profits for perpetrators. We researchers combat cyber attacks day and night to prevent such damage from becoming a daily occurrence, but the truth is that there are more than a few countries and companies that have been the victim of malware.

—What specifically does your work entail?

Well, to begin with, we create decoy computer systems called *honeypots* to collect malware (**Fig. 1**). Honeypots are placed at a variety of locations to make malware collection more efficient such as on a customer's network or in Internet space where vulnerable software or browsers are present. Honeypots can be broadly divided into four types: high-interaction honeypots and low-interaction honeypots based on the level of interaction, and server honeypots and client honeypots based on the path of infection. I am particularly involved with two high-interaction honeypots called DenDenHoney and Marionette that have high camouflaging ability.

DenDenHoney uses technology for identifying and safely collecting the sources of attacks by accurately detecting attacks that exploit vulnerabilities in Windows OSs (operating systems) (**Fig. 2**). It can also collect the malware itself in a restricted environment called a *sandbox*.

Marionette, on the other hand, is technology for detecting malware via the web and for discovering malicious websites. Using a web browser with vulnerabilities, Marionette crawls through Internet space actively collecting information on malicious websites and capturing malware itself.

Next, in terms of malware analysis, there are two types of analysis techniques: dynamic analysis that actually executes the collected malware and analyzes its behavior, and static analysis that analyzes only the program code of malware without running it. The former monitors malware behavior in detail and clarifies its communication patterns and functions. The latter, meanwhile, disassembles program code to obtain an overall view of the malware including latent functions that operate only under certain conditions. The above malware analysis is conducted manually and consequently requires considerable labor, but it can be made more efficient by identifying similarities with past malware and concentrating on those elements that are different.

Through my involvement in developing cyber security measures over a period of about ten years, I have found that attackers are continuously thinking up and implementing new attack techniques reflecting a very

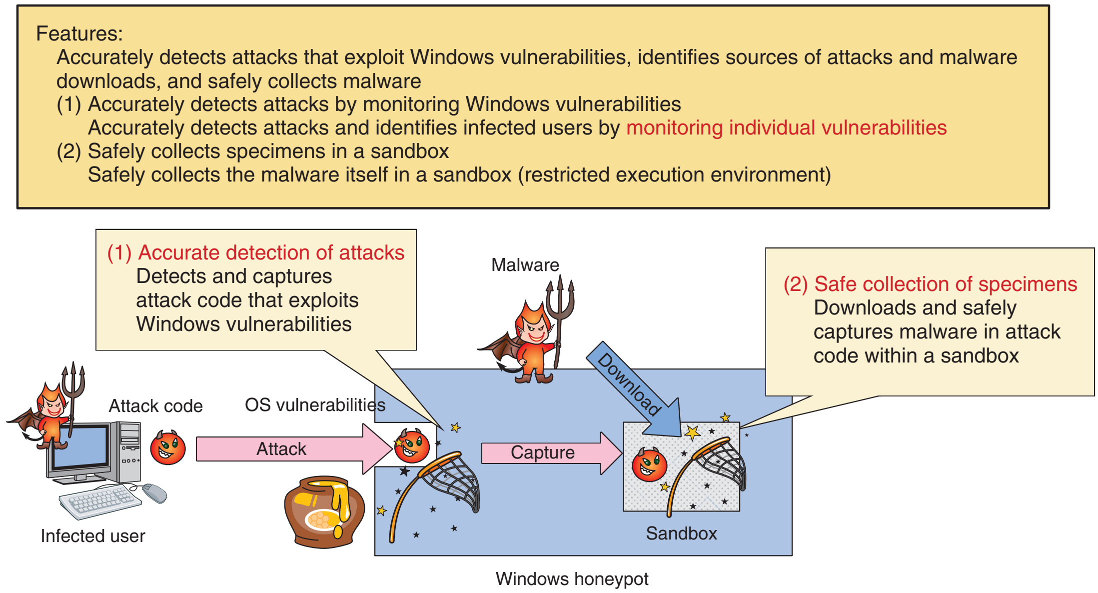

Fig. 2. Malware attack detection approach of DenDenHoney.

high level of creativity.

In contrast, the side that provides security has been taking a more passive stance in which it tries to determine how best to respond to a customer that has been infected by malware. With this approach, however, I cannot help but feel that we are simply chasing after malware endlessly, so I would like to promote research and development on techniques for anticipating and preempting malware.

Just like magic! Continuing the never-ending battle against cyber attacks after hearing the words of a fellow student

—In your ten years of combating highly creative attackers on a daily basis, have there been any momentous events?

We started our work on DenDenHoney in 2005, around the time when malware was turning into a social problem. Since then, publicly available honeypots in open source or other formats have existed, but most of them have been easily recognizable to attackers. As a result, they are not useful for malware collection, and we therefore took it upon ourselves to develop our own honeypots.

The inspiration for this idea came early, but it took us more than a year to implement the idea. The mechanism itself for collection was very simple, but there were very high technical hurdles that we had to overcome to implement it, and the entire team had to improve its skills in this field. However, once malware issued by attackers began to flow into our honeypot, indicating that our collection mechanism was working, we responded joyously by exclaiming "We've done it!"

If malware is analyzed in a haphazard manner, such analysis can become noticeable to attackers. To prevent this from happening, our team created virtual software specialized for malware called Stealth Debugger, which was another momentous experience for me. This software is currently becoming a base technology for a mechanism that can quickly identify malware that causes information leaks.

—Why did you choose the life of a researcher?

When I was in elementary school, I loved inventions. At that time, there was no such thing as a *staple-free* stapler, so I wanted to create one, and I devoted myself to that task. Additionally, because my family home had a bicycle shop, I also developed an interest in mechanical things. If I weren't doing what I'm doing now, I would probably be a watchmaker. Later, however, on encountering computers, I felt that "You can do anything with a computer!" and I became seriously committed to computing. Then, during my university studies, I heard a senior of mine say "You can wrest control from a server by causing its buffer to overflow." At that time, I had no idea what that meant—I could not understand how a commonplace event like a buffer overflow could be used to rob control from a server. It seemed like magic to me!

In an attempt to understand the mechanism behind this, I turned my attention to operating systems, compilers, and machine language and became captivated by discovering countermeasures to security holes. Needless to say, buffer-overflow attacks still exist, and countermeasures to them are in force, but attackers continue to come up with ever-ingenious attacks of this type. Technically speaking, I believe there are still elements of these attacks that we have to investigate further.

The need for dissemination skills in an unexplored field

—What kind of stance must the security-provision side take from here on?

I believe that the side that provides cyber security must be knowledgeable about social trends, that is, about the likes and preferences of people, and it must also strive to build relationships based on trust. In this regard, dissemination skills are essential. By this, I mean one must be able to communicate information to a wide audience. Now, after ten years, I feel strongly that the cyber security business cannot fully function if the people involved simply focus on their own research.

Although the need for a system of mutual information-sharing is recognized, it will be difficult for the security-provision side to become united if some of us are hesitant about admitting a breach into one's system and revealing a flaw in one's security measures. However, if we do not change this mindset and we refuse to cooperate, we will not be able to stand up to the cyber-attacking side. It is said that "Information accumulates around people that disseminate information," and I would like to expand cooperation by disseminating information myself.

For my part, to help expand the security network both inside and outside the NTT laboratories, I am involved in bringing together talented researchers and security engineers on the security-provision side while also helping to train the next generation of security engineers. I also actively participate in outside activities such as speaking at national security camps held by the Information-Technology Promotion Agency (IPA), supervising security contests, and giving lectures at universities (**Photo 1**).

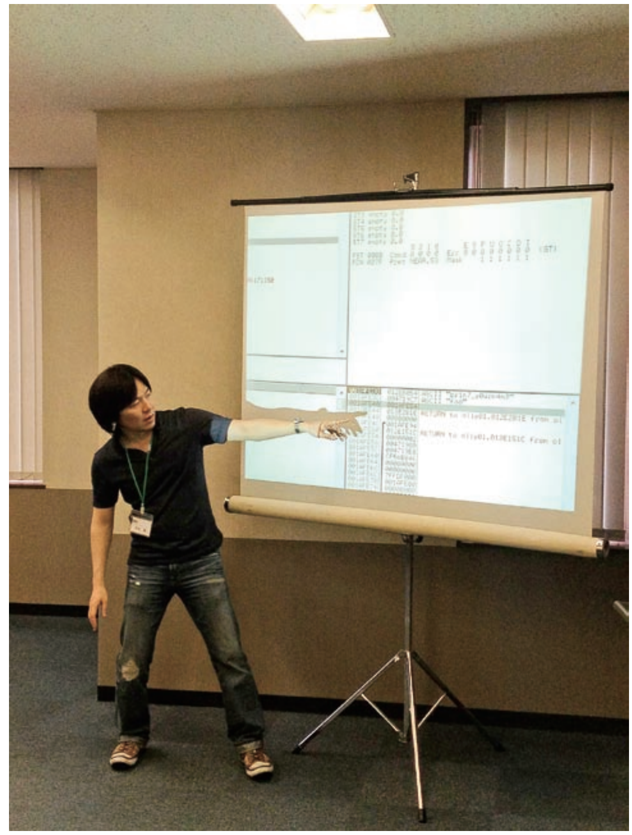

Photo 1. Delivering a lecture at a national security camp.

Additionally, I recently participated in a DEF CON CTF (Capture the Flag) contest, in which participating teams use their cyber security-related skills, that is, hacking skills, to compete against each other. In this contest, I competed shoulder-to-shoulder with young engineers I had mentored at security camps. My aim here was to grow as an engineer above and beyond what I could accomplish by simply disseminating information. For a full two days and two nights, these young engineers were faced with very challenging problems, and I found them clinging to their computers even while I was taking a break. In my daily work, I am usually involved in several tasks and have few opportunities to devote all my energy to one endeavor, so seeing the way they approached these problems reminded me of the importance of facing a technical problem head-on until a solution is reached.

In my free time, I enjoy playing popular computer games and watching hit movies, but I've come to realize that what I'm really interested in is keeping up with social trends. In other words, I have been unconsciously following what people like and dislike in the real world as opposed to the closed world of the cyber security industry.

—I assume that a wide range of measures are required for solving unprecedented problems such as cyber attacks.

Today, we may be entering a period in which people that create programs will be required to have essential skills and be responsible for creating safe and secure programs. There may be a need for establishing certifiable qualifications in much the same way as a medical license. This is not simply a matter of teaching an engineer the technical skills needed for analyzing malware. It is also important to develop programmers who have a good understanding of security while simultaneously educating managers who have decision-making power in implementing countermeasures to cyber security-related problems.

Furthermore, through my daily work and on-site activities in training security personnel, I strongly feel that we have a shortage of qualified personnel. A genuine problem today is that companies that have suffered damage from malware, while recognizing the importance of security engineers, nevertheless tend to respond to the occurrence of problems with stopgap measures. The placement of qualified personnel and the development of personnel with a forward-looking mindset tend to receive low priority.

It is said that personal happiness comes about through engagement, relationships, meaning, and achievement. For me, I can say that I am truly happy when I am completely engaged in creating something or in collecting or analyzing malware. Many of the young engineers I encounter at DEF CON and security camps feel joy in much the same way.

To counter the creativity of attackers, we must be able to make best use of this special character in young researchers who excel in combating cyber attacks. This, I believe, is the responsibility of those of us in corporate organizations whose job is to nurture people with talent.

Young researchers such as these find value in devoting themselves to research without focusing on its meaning or significance. For those of us who supervise such talent, we should perhaps set up environments for them in which they can discover at least some minor goals to aim for. Looking 10 or 20 years into the future, I myself plan to devote more energy to developing personnel for an active career in the cyber security industry and setting up venues for security-related activities.

First and foremost, I would like to be actively involved in disseminating information to gain the trust of people so that they too will share information. In addition, I hope to increase the number of my colleagues on the security-provision side both inside and outside NTT and collaborate with them in developing countermeasures to cyber attacks.

■ Interviewee profile
Makoto Iwamura

Distinguished Researcher, Senior Research Engineer, Cyber Security Project, NTT Secure Platform Laboratories.

Dr. Makoto Iwamura received his B.E., M.E., and D.Eng. in science and engineering from Waseda University, Tokyo, in 2000, 2002, and 2012, respectively. He joined NTT in 2002. He is currently with NTT Secure Platform Laboratories, where he is engaged in the Cyber Security Project. His research interests include reverse engineering, vulnerability discovery, and malware analysis.

Approach to Network Science—Solving Complex Network Problems through an Interdisciplinary Approach

Kohei Shiomoto

Abstract

As networks come to be used in diverse ways and become increasingly complex and massive in scale, it is becoming difficult to support networks using only existing network technologies aimed at achieving complete control of individual network elements. At NTT Network Technology Laboratories, we are researching and developing network science as an interdisciplinary approach that combines existing network technologies with new technologies from other fields. We are also carrying out research and development (R&D) on technologies that apply network science to enable service providers and end users to use networks in more intelligent ways. This article provides an overview of these R&D efforts at NTT.

Keywords: interdisciplinary approach, communication traffic management, communications-service quality management

1. Introduction

Broadband access has become widely available through both fixed-line and wireless means, and information and communication technology (ICT) has become a vital social infrastructure in our daily lives. The NTT Group has made global cloud services the cornerstone of its business operations and has simultaneously taken up the challenge of improving the competitiveness and earning power of its network services. Furthermore, as reflected by its Hikari Collaboration Model announced in May 2014 [1], the NTT Group seeks to stimulate the ICT market by assisting a wide array of players in creating new value and to contribute to solving social problems and fortifying Japan's industrial competitiveness. In short, the NTT Group aims to build up the earning power of its network services while making extensive cost reductions and providing high-value-added services in collaboration with operators in a variety of industrial fields. At NTT Network Technology Laboratories, we are researching and developing network science to support the network infrastructure that the NTT Group needs to advance the above initiatives.

The issues to be resolved and goals to aim for in constructing the future network are shown in **Fig. 1**. Network usage patterns are changing as ICT becomes entrenched as a social infrastructure. Numerous video and movie services are now being provided, and mobile services over smartphones and tablets are proliferating. At the same time, the diversification of terminals looks to intensify in the years to come with the advent of wearable terminals and advanced sensors, and the 5th generation of mobile network technology appears to be ready for rollout in 2020. Improving not only transmission speeds but energy and spectrum efficiencies as well will enable users to enjoy high-definition video services in all kinds of places using all sorts of mobile terminals. In addition,

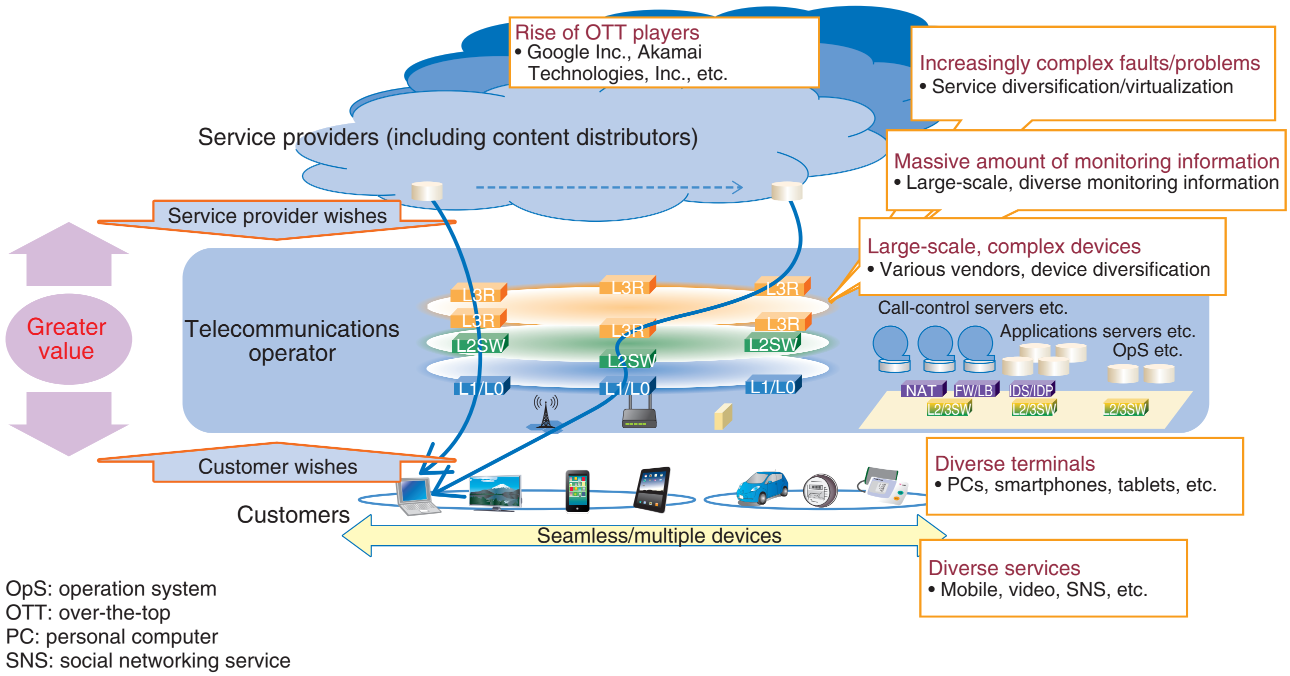

Fig. 1. Issues and goals toward the future network (service co-creation network).

the diffusion of Internet of Things (IoT)*1 technologies and machine-to-machine (M2M) communications will enable many and varied devices to be interconnected via the network (Fig. 1). The provision of services using the cloud will also expand, and services that cannot be imagined under present conditions will be introduced one after another in the future. This diversification of services will naturally be accompanied by a wide variety of traffic patterns. In an era dominated by cloud and mobile services, the network must be able to maintain a stable level of quality so that customers can enjoy a satisfactory quality of experience (QoE)*2 just about anywhere.

Today's network consists of transfer/transmission facilities such as L3 (layer 3) routers, L2 switches, and L1/L0 transmission equipment, server facilities such as call-control servers and application servers, and other types of facilities and functions such as network address translators, firewalls, load balancers, and intrusion detection and prevention systems. As such, the configuration of the network is becoming increasingly complex and diversified (Fig. 1). As a consequence, the operation of the network consisting of such many and varied constituent elements is likewise becoming increasingly complex.

Furthermore, in addition to network operations, end-to-end operations including the cloud are also important, and they are becoming a factor in this rise in complexity. Additionally, the introduction of virtualization technologies such as software-defined networking (SDN)*3 and network function virtualization (NFV)*4 will enable the design of logical configurations independent of physical configurations, although this can have the effect of making responding to problems all the more complicated.

The network structure is also becoming increasingly complicated. Operators of content delivery networks (CDNs) are constructing content delivery platforms that connect cache servers over the network on a global scale. Even service providers that are expanding their services throughout the world, for example, Google Inc., are beginning to construct networks. Service providers and CDN operators such as these are called *Hyper Giants*, and they can have a huge impact on traffic flow by controlling content

*1 IoT: Technology for giving all sorts of things communication functions to enable Internet/cloud connections, mutual control, etc.

*2 QoE: The level of quality experienced by a user of communication services.

*3 SDN: Generic term for technology that enables centralized management of network communication devices and alteration of network configuration/settings via software.

*4 NFV: A method for implementing network functions by software on general-purpose servers using virtualization technology.

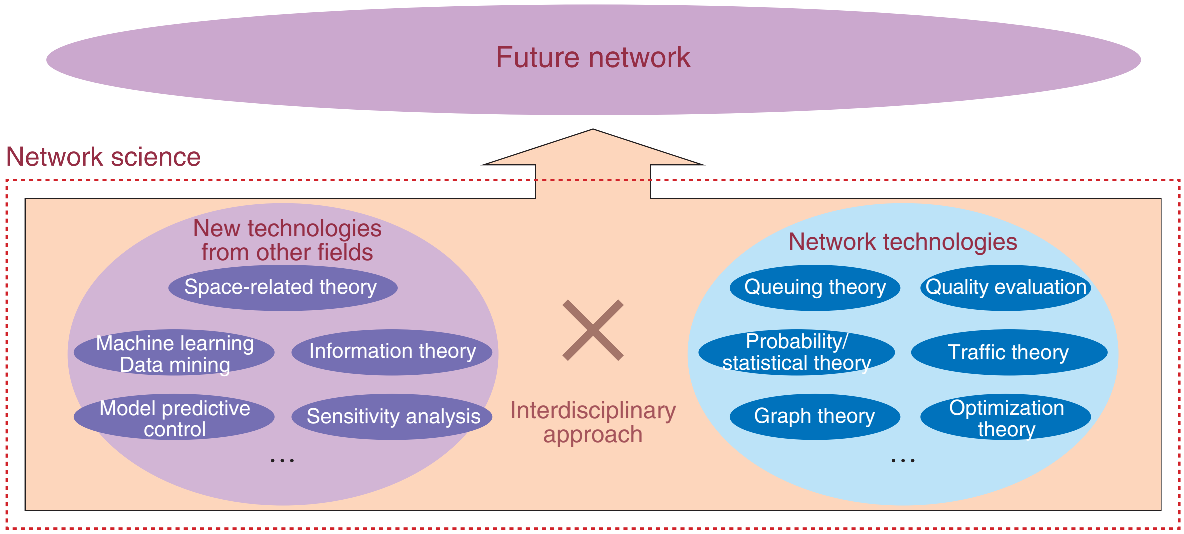

Fig. 2. Interdisciplinary approach to network science.

delivery on a global scale [2]. In fact, mutual interference between content control by Hyper Giants and network control by telecommunications operators is becoming a problem.

Furthermore, a variety of operators are becoming involved in the network. In addition to service providers that provide services to general customers and telecommunications operators that construct and operate networks, CDN operators that provide efficient delivery of content can be found between telecommunications operators and content providers. Telecommunications operators must be able to support service providers and CDN operators and not just general customers. It is essential that they provide high-value-added services in collaboration with all kinds of players.

Consequently, as network usage scenarios become increasingly diverse and as networks themselves become increasingly complex and massive as described above, it is becoming all the more difficult to cope with a network using only existing network technologies that aim to have complete control of individual network elements. At NTT Network Technology Laboratories, we are researching and developing network science as an interdisciplinary approach that combines existing network technologies with new technologies from other fields. We are also researching and developing technologies that apply network science to enable service providers, end users, and other operators to use the network in more intelligent ways.

2. Network science

The existing approach assumes that the target system is to be faithfully modeled and analyzed using stochastic and statistical techniques so that the individual elements making up the system can be well understood. In the existing network, however, obtaining complete control of individual elements making up the system is in itself becoming extremely difficult. With this in mind, we are researching and developing an interdisciplinary approach called network science that combines new technologies from other fields with existing network technologies (**Fig. 2**).

A variety of domains can be considered as new technologies from other fields, but at present, we are exploring the application of technologies such as space-related theory, machine learning and data mining, information theory, and model predictive control.

2.1 Space-related theory

Space-related theory deals with spatial information against the background of academic demands and social trends. Up to now, traffic theory has targeted stochastic behavior along a time axis, but in space-related theory, the focus is on a theory that targets stochastic behavior along a space axis. Integral geometry forms some of the foundation for this theory; given that the area and perimeter length of certain objects are known, the probability that their shapes overlap can be calculated. This principle can be used, for example, to calculate the probability that spatially and stochastically distributed objects overlap [3]. Application examples of this theory include the analysis of measurements taken by sensors and the design and control of networks that are robust to natural disasters. Constructing an actual physical network involves designing a network highly resistant to disaster by calculating the probability of being hit by a disaster based on a hazard map showing the likelihood of such an event (an earthquake, for example). This theory can also be applied to network control in a virtual network in which the logical configuration of the network can be controlled independently of its physical configuration. For example, the ever-changing probability of being hit by a disaster can be calculated based on forecasts of typhoons, torrential rains, or other extreme weather conditions, so that network servers can be switched to an arrangement with a low probability of being affected by such a disaster.

At NTT Network Technology Laboratories, we are also studying base-station design using homology. The use of conventional mathematical programming to calculate an optimal arrangement of sector antennas can result in an explosive number of combinations that hinders problem solving. Homology-based modeling, however, can drastically reduce computational complexity in such cases, enabling a solution to be found [4].

2.2 Machine learning and data mining

The combined approach of machine learning and data mining enables the discovery of features and regularities in large volumes of data. For our purposes, the target of analysis is traffic collected from the network and data related to service quality. This type of data is not limited to numerical data. It can include, for example, atypical messages in logs generated by equipment and devices. Specifically, we use machine learning and data mining to analyze large volumes of data and discover the relationship between two types of numerical data (regression), to discover groups of data having similar properties from large volumes of data (clustering), and to sort data into predetermined categories based on training data (classification). We are also using machine learning and data mining to achieve advanced network operations [5].

2.3 Information theory

Information theory includes a technique called compressed sensing [6]. Because the elements of an observation vector can be expressed as the product of an unknown vector and a known matrix, compressed sensing can be used to infer the unknown vector. Specifically, if the structure of the known matrix is sparse—that is, if many of the elements of the matrix are zero—the unknown vector can be inferred. Compressed sensing is a technique originally developed in fields such as image processing and signal processing, but its application to network operations is progressing. Here, assuming that end-to-end quality on a variety of network paths can be measured, we consider a situation in which quality deterioration has been detected on several paths. Compressed sensing can then be used to determine which interval in the network is the source of this deterioration. In mobile communications, compressed sensing can be applied to techniques for isolating locations of quality deterioration [7].

2.4 Model predictive control

Model predictive control can be used in cases where predicting the response to a network control operation such as changing transmission paths is difficult. This technique was originally developed for controlling plant processes. Model predictive control iteratively solves an optimization control problem while shifting forward an N-step interval at every step of the process. It applies only the first operation step of the optimization input sequence to the control target (**Fig. 3**). An optimization control problem that takes N forward steps into account makes predictions N steps into the future and solves an optimization control problem with control conditions attached at every input step at that time. Model predictive control theory has so far been applied to traffic engineering, where it was found to be effective [8]. It is now being studied for use in resolving the problem of mutual interference in control operations between telecommunications operators and Hyper Giants.

3. Application of network science

With the aim of applying network science, we are researching and developing (1) network data analysis, (2) proactive network control, (3) QoE-centric operation, and (4) Disaster-free Networks, as summarized below.

3.1 Network data analysis

In network data analysis, we mainly use machine learning and data mining to formulate effective countermeasures to faults in network services. We study in particular each step making up a fault countermeasure, namely, fault detection, root cause

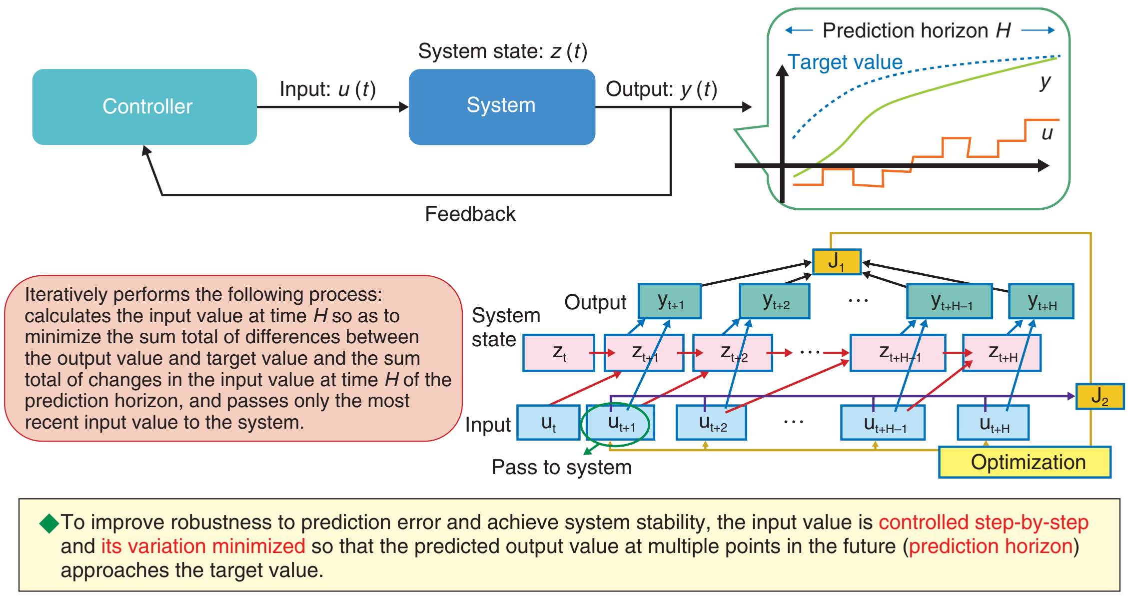

Fig. 3. Model predictive control.

analysis, and service restoration. First, for the fault detection step, we are developing technologies for visualizing service status, supporting visual monitoring, detecting silent faults, performing predictive detection, and other tasks. For the root cause analysis step, we are developing technologies for identifying the root cause and location of a fault and for determining the impact of a fault on services. Finally, for the service restoration step, we are developing technologies for formalizing and automating restoration tasks.

In developing these technologies, we apply machine learning and data mining, information theory (compressed sensing etc.), and optimization theory to diverse types of data related to network operations such as syslog[*5] data, Twitter[*6] data, numerical data, response histories, and workflow data [9]. For example, network devices generate syslog data in great quantities, but the messages that are output are in formats that differ from one device to another and from vendor to vendor. As a result, using this information in on-site maintenance operations can be difficult. However, machine learning and data mining technology can be used to discover regularities in such a huge quantity of syslog messages such as messages that tend to be issued simultaneously, and it can also be used to visualize network operations [10]. Additionally, this technology can be used to detect and comprehend service failures by analyzing Twitter data. The idea here is to train the system beforehand using previous tweets posted at the time of service failures and to then identify tweets related to service failures during real-time monitoring of Twitter feeds. These failure-related tweets can then be extracted and used to clarify the nature of a service failure [11].

The network of the future will have an increasingly complicated and diverse configuration, and network operation will be all the more complex. Furthermore, if we include the cloud when talking about the network, we can expect even greater complexity. In light of this complexity, the detection of faults and failures, troubleshooting and factor clarification after detection, and failure recovery after troubleshooting will become increasingly difficult. Moreover, in addition to simply determining whether a service interruption has occurred, it will also be necessary to deal effectively with service flaws that are difficult to quantitatively evaluate such as deterioration in the customer's QoE. Such service flaws are sometimes called obscure faults whose reproducibility is low, and solving them may require a relatively long time as a result. The introduction of SDN, NFV, and other virtualization technologies is expected to make problem response even more complicated, so we can expect

*5 Syslog: Log information consisting of software/hardware operating conditions periodically recorded by network devices such as switches, routers, and servers.

*6 Twitter is a registered trademark of Twitter, Inc.

network data analysis to become increasingly important going forward.

3.2 Proactive network control

Proactive network control is a network control technique that optimizes the network configuration based on traffic predictions [12]. To make traffic predictions, it is important to clarify the latent mechanisms involved in generating traffic.

The ways in which users use the network are also diversifying, so it is also important to understand for what purposes users use the network in order to make reliable traffic predictions. Additionally, there is a need to be aware of mobile traffic arising from the increasing popularity of smartphones and tablets. Here, it is important to understand how users move through both cyberspace and physical space. We are developing technologies to solve the above problems by making use of space-related theory and machine learning and data mining.

Controlling traffic based on traffic predictions requires that the error arising in those predictions be minimized. However, when performing network control as in changing transmission paths, it is becoming increasingly difficult to predict the response to such a control operation. This difficulty is reflected by the mutual interference that can occur between content control by a Hyper Giant and network control by a telecommunications operator. A Hyper Giant may change the servers it uses to deliver content based on measurements of network quality. This can have the effect of changing traffic flow on the telecommunications operator's network and generating congestion. The telecommunications operator may then change network transmission paths to deal with that congestion, but from the Hyper Giant's point of view, this may mean a change in communications quality. It is in this way that mutual interference arises between content control by a Hyper Giant and network control by a telecommunications operator. It has consequently become difficult for a telecommunications operator to predict the result of its own control operation to change transmission paths. Model predictive control is considered to be an effective technique under such conditions.

3.3 QoE-centric operation

In the operation and management of network services, there is a growing need to consider the user's QoE in addition to simply determining whether a service interruption has occurred [13]. Although QoE is a subjective matter involving such characteristics as *beautiful* (e.g., for images) and *natural* (for sound), quantifying such subjective characteristics should enable QoE to be inferred based on indicators measured on the network side. The QoE so obtained could then be used in the operation and management of network services.

Until recently, the main approach to quantifying QoE has been to conduct experiments with multiple subjects seated in evaluation booths. However, it is now becoming important to ascertain user QoE in the field though the use of crowdsourcing with smartphones and other novel means. Furthermore, to facilitate estimation of QoE, we can model the correspondence between data that can be directly measured within the network such as throughput and delay and QoE related to video, voice, and data-communications services. As for video, we are researching and developing HTTP/TCP (Hypertext Transfer Protocol/Transmission Control Protocol)-based progressive-download video services that have recently become popular as well as 4K/8K high-definition video services. Next, in terms of voice, we are researching and developing mobile VoIP (voice over Internet protocol) applications such as LINE*7 and Skype*8 and IP-based voice services in a mobile environment such as voice over LTE (VoLTE)*9. Finally, in the area of data communications, we are targeting web browsing in our research and development (R&D) efforts.

As described above, QoE can be understood on the basis of data measured by the network and used in the operation and management of network services. At the same time, such data can be provided to service providers to assist them in adding value to their services. A quality-related application programming interface (quality API) is one means of providing such data, and we are conducting field tests in collaboration with service providers using such a quality API [14].

3.4 Disaster-free Networks

We are researching and developing Disaster-free Networks applying space-related theory [15]. A Disaster-free Network is a network whose design and control methods are robust to natural disasters and other calamities. Space-related theory can be used to calculate the probability that areas in which natural

*7 LINE is a trademark or registered trademark of LINE Corporation.

*8 Skype is a trademark of Skype Limited.

*9 VoLTE: Service that provides voice communications in packet form using Long Term Evolution (LTE).

disasters may occur overlap with the network. In short, when deploying network facilities, the probability that those facilities will be affected by a disaster can be calculated based on a hazard map that indicates the likelihood of earthquakes occurring. The results of those calculations can then be used to design a network highly resistant to disasters. Space-related theory can also be applied to network control in a virtual network focusing on the fact that the logical configuration of the network can be controlled independently of its physical configuration. For example, the ever-changing probability of being hit by a disaster can be calculated based on forecasts of typhoons, torrential rains, and other weather events so that the current arrangement of network servers can be switched to one with a low probability of being affected by such a disaster.

4. Conclusion

As network usage formats diversify and as the network itself becomes increasingly complex and massive, it is becoming all the more difficult to support the network by using only existing network technologies that attempt to achieve complete control of individual network elements. In the face of this problem, NTT Network Technology Laboratories is promoting R&D of network science as an interdisciplinary approach that combines technologies used in diverse fields. In the coming cloud era, we can expect the network to become an increasingly essential infrastructure. We can also expect to see quantum leaps in mobile technologies that will enable users to enjoy a wide range of services wherever the users may be. At the same time, we can envision the penetration of IoT and M2M technologies and the interconnection of many and varied devices over the network. Security too will become increasingly vital as the importance of the network as a social infrastructure grows. In addition, the introduction of virtualization technologies such as SDN and NFV will enable the design of logical configurations that are independent of physical configurations and will help satisfy the need for advanced network construction and operation techniques. Going forward, we aim to create a new academic discipline to support the further evolution of the network through the embodiment and realization of network science.

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Basic Theory of Network Science—the Network, Spatial Characteristics, and Spatial Information

Hiroshi Saito

Abstract

NTT Network Technology Laboratories is researching a new theory to support networks that focuses on spatial information handled by networks. This article discusses an evaluation of geometric probability based on integral geometry and the design and control of new network characteristics.

Keywords: spatial characteristics, spatial information, geometric probability

1. A brilliant theory is timeless

Traffic theory, which is said to originate in a paper written by A. K. Erlang, the renowned Danish telephone engineer, has been subsequently expanded by many theorists in this field and in the field of queuing theory in applied mathematics. It has been a theoretical pillar supporting the operations of information and communication networks for about 100 years and has become essential not only in the design of telephone networks but in the design of computer systems as well. At NTT, research in the field of traffic theory has also led to some brilliant achievements such as Takagi's theorems*, which provide a theoretical basis for determining an optimal architecture for switch channels.

Today, however, there are fewer areas in which traffic theory can be applied. One reason for this is that the unit of facility design has become larger. Another reason is the wide use of best-effort policies; that is, there is no longer a need for detailed design. The third reason is that resources themselves have become cheaper. It has been shown in NTT's Interconnection Accounting Reports and elsewhere that the book-value ratio of traffic-dependent network facilities (facilities that either increase or decrease in number according to traffic volume) has been decreasing greatly. This is making traffic design as well as traffic control and quality control within the network less meaningful and is diminishing the fruits of traffic theory.

2. Space-related theory

The introduction of theories that support the network is the responsibility of the network operator through research and development efforts. In light of the present situation, there is a need for theoretical development along a new direction. We have decided, in particular, to target a theory that deals with spatial information against the background of academic demands (expansion of existing theory, which is based mainly on probability theory and theory of stochastic processes along the time axis, to a theory that incorporates spatial phenomena) and social trends (enhancement of physical/spatial information-gathering capabilities in conjunction with the proliferation of mobile devices and sensors). Actually, in the field of networks, space-related theories already exist, for example, radio propagation theory in mobile communications. The theory targeted by our current research, however, covers the entire network or all information related to the space handled by the network. As such, we expect this research to be the first

* Takagi's theorems: A series of theorems presented around 1970 dealing with link connections and switch-channel connections, including results related to optimal connections.

of its kind in the world.

3. Integral geometry and geometric probability

Probability related to the positional relationships of geometric figures is called *geometric probability*, and the theory that derives this probability is called *integral geometry*. Here, defining the probability related to the spatial relationship of two objects in terms of geometric probability can give rise to a variety of discussions. For example, if we let one object represent the network and the other a disaster area, we can talk about the probability that the network will pass through that disaster area. Of course, it would be convenient if the position of the disaster area could be predicted, but even if it cannot, this probability can still be obtained provided that information can be given on the occurrence of a disaster area of a certain size in a specific region.

This situation is similar to our experience in traffic theory; although we cannot predict the arrival of individual calls or packets, we can calculate the call-loss rate or buffer-overflow rate in traffic theory. Next, if we let one of two objects represent a target of detection and the other object represent detectors such as sensors, this theory can give rise to discussions on the handling of spatial information collected by the network. These may include ideas such as “How would the arrangement of sensors affect the detection probability?” or “If we collect a lot of detection results, to what extent can we learn something about the target object such as its shape?”

4. A new world

For example, the above probability that the network will pass through a disaster area can provide knowledge on a new method for configuring networks. Integral geometry, moreover, enables concrete and quantitative discussions to be held on the network. These may include the geographical shape of a communication-path network that would minimize or reduce the probability of passing through a disaster area, or the geographical and spatial arrangement of servers that would minimize the probability that servers providing services to a certain area would be cut off due to a disaster. A network achieved by design and control methodologies based on the above theory is called a *Disaster-free Network* [1–3].

A Disaster-free Network is just one application example of this theory. It should also be possible to discuss a relationship between the network and spatial phenomena unrelated to natural disasters so that network measures other than those for anti-disaster readiness can be improved.

5. Future developments

Similar to the way in which traffic theory enables network traffic design and control, the new theory introduced here will make it possible to design and control network characteristics that up to now have not been targeted in design and control efforts. As a result, we can expect the development of a safe and secure network and the provision of new network services.

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QoE-centric Operation for Optimizing User Quality of Experience

Takanori Hayashi

Abstract

NTT Network Technology Laboratories has been researching indices for evaluating user quality of experience (QoE) for a variety of services. Our aim is to achieve QoE-centric operation for optimizing QoE using information that can be monitored during the provision of services. This article introduces the elemental technologies of QoE-centric operation.

Keywords: QoE, operation, quality API

1. Introduction

The recent proliferation of high-functionality and high-performance mobile terminals such as smartphones and tablets has made the Internet into a social infrastructure that is essential to our daily lives. The services made possible by Internet technologies, as well as their usage formats, have been diversifying year by year, and in addition to voice calls, video delivery, and web browsing, the recent trend toward the Internet of Things (IoT)*1 has begun to drive the creation of new services in a variety of industries.

At the same time, studies are progressing on the application of virtualization technologies such as software-defined networking (SDN)*2 and network function virtualization (NFV)*3 to carrier networks. The aim here is to create an economical software-based execution environment that can achieve both scalability and reliability given a network that must handle a plethora of diverse services.

Against this background, providing a wide array of services over the network at a satisfactory level of quality will require more than simply monitoring network device operations as in the conventional approach. That is, it will also be important to implement maintenance operations that can monitor user quality of experience (QoE)*4 and detect any emerging signs of problems. There is particular concern in the era of network virtualization that it will become increasingly difficult to determine how network faults and quality degradation affect different types of services.

Additionally, factors affecting QoE have expanded beyond the network to elements such as servers, terminals, and applications, so achieving high QoE simply by ensuring network quality will likewise become difficult. It can therefore be considered that determining the state of the network from information collected from both inside and outside the network and sharing that information with service providers and end users should enable service provision conditions and service usage methods to be optimized according to the state of the network.

At NTT Network Technology Laboratories, we are promoting research and development that includes a network-science based approach called QoE-centric operation [1]. This approach consists of a maintenance

*1 IoT: Technology for giving all sorts of things communication functions to enable Internet/cloud connections, mutual control, etc.

*2 SDN: Generic term for technology that enables centralized management of network communication devices and alteration of network configuration/settings via software.

*3 NFV: A method for implementing network functions with software on general-purpose servers using virtualization technology.

*4 QoE: The level of quality experienced by a user of communication services.

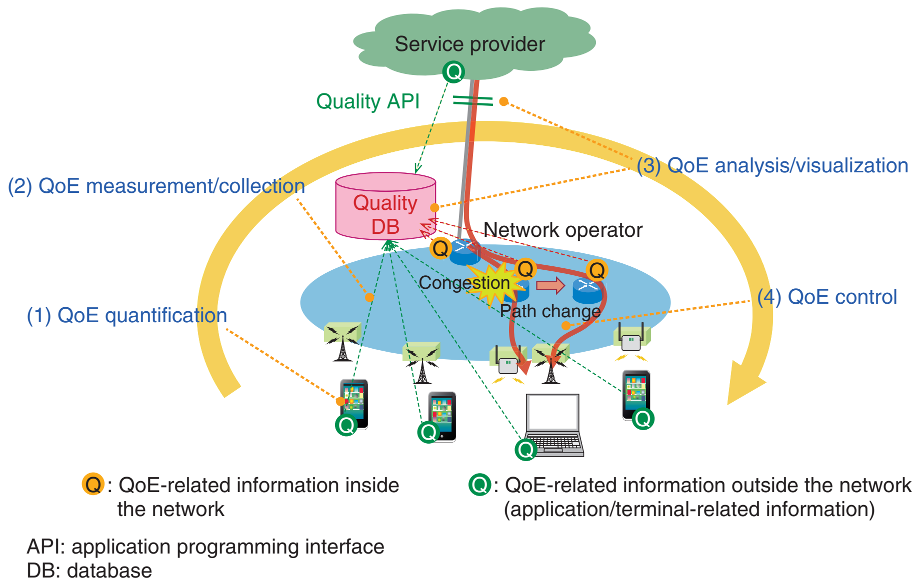

Fig. 1. Achieving QoE-centric operation.

operations cycle that quantifies QoE from parameters that can be monitored during service provision and optimizes QoE accordingly.

2. Elemental technologies of QoE-centric operation

There are four steps to achieving QoE-centric operation: (1) QoE quantification, (2) QoE measurement and collection, (3) QoE analysis and visualization, and (4) QoE control (**Fig. 1**). First, in QoE quantification, the task is to clarify the relationship between QoE and network-quality measures (packet loss/delay, delay fluctuation, etc.) and application-quality measures (sound quality, picture quality, response time, etc.) and to quantify QoE by such objective measures using information that can be monitored during service provision. Next, in QoE measurement and collection, the aim is to efficiently measure and collect quantified QoE information to facilitate the uniform management of this information, and then, in QoE analysis and visualization, to speed up maintenance operations by comprehending the state of service provision, isolating the causes of QoE degradation, and detecting signs of QoE degradation. Finally, the QoE control step uses this analyzed and visualized QoE information to optimize QoE according to network conditions by allocating network resources appropriately and controlling policy and content delivery as needed. The following provides a more detailed explanation of each of these elemental technologies making up QoE-centric operation.

2.1 QoE quantification

The QoE quantification step clarifies service quality design and service management guidelines by elucidating human perceptive and cognitive characteristics with respect to the quality of communication services. This step also establishes a methodology for estimating QoE using quality-related information from the network, servers, and terminals—that is, information that can be monitored during service provision. NTT has been promoting the study of QoE quantification with a focus on voice calling via voice over Long Term Evolution (VoLTE)*5 and VoIP (voice over Internet protocol) applications, video delivery including ultrahigh-definition television (4K/8K) [2], and web browsing and cloud-based business applications. In view of the desirability of achieving QoE on the basis of a globally uniform index, QoE-related discussions are proceeding within the ITU (International Telecommunication Union) and other international standardization bodies. For example, discussions have recently been held on a

*5 VoLTE: Service that provides voice communications using an ultrahigh-speed communication service (LTE).

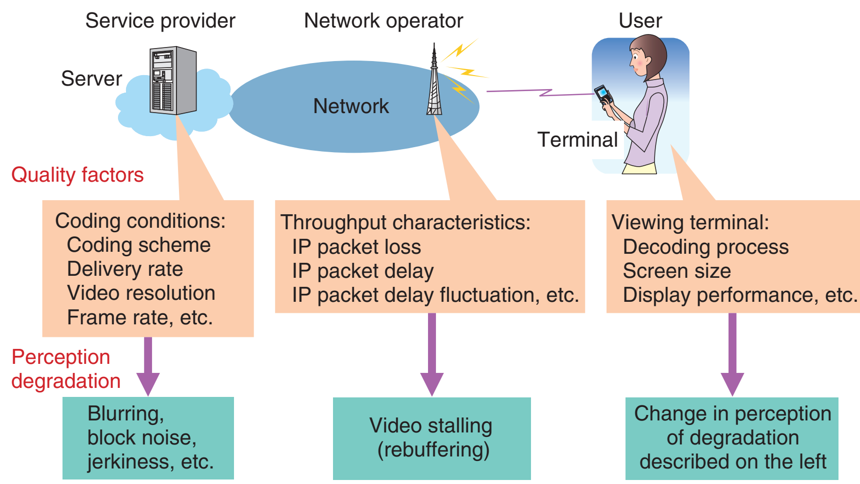

Fig. 2. Quality degradation factors in video delivery services.

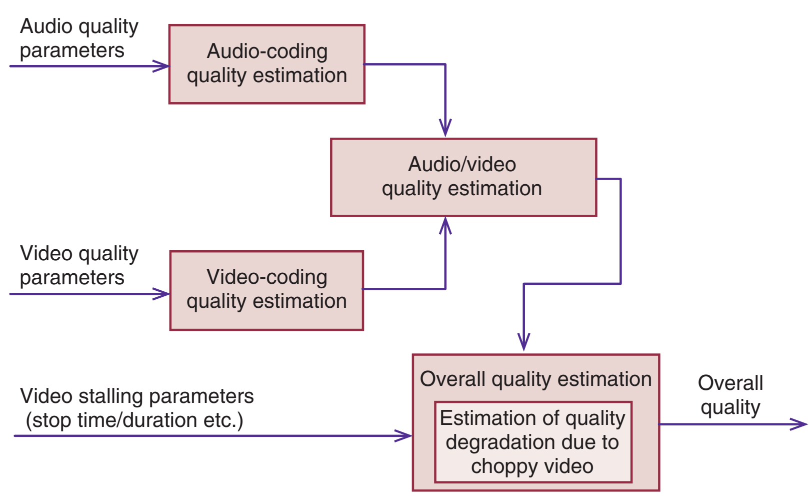

Fig. 3. Framework of QoE estimation algorithm for video delivery services.

method for estimating QoE with respect to progressive-download video delivery[*6] services. Specifically, studies have been done on an algorithm for estimating QoE from IP packet information that can be obtained during service provision. This algorithm will target quality degradation factors particular to video delivery services such as temporal fluctuation in coding quality and video stalling (**Fig. 2**).

The framework of this QoE estimation algorithm is shown in **Fig. 3**. The ITU Recommendation in question is being studied under the provisional name of P.NATS (Parametric non-intrusive assessment of TCP (Transmission Control Protocol)-based multimedia streaming quality, considering adaptive streaming). The plan is to finalize the Recommendation in 2016 after comparing algorithms proposed by multiple institutions in a technical competition.

2.2 QoE measurement and collection

To use QoE information effectively in operations, information needed in the next step of QoE analysis/visualization must be efficiently measured and collected and uniformly managed. Since QoE is affected

*6 Progressive-download video delivery: A delivery method that enables viewing while downloading a video file.

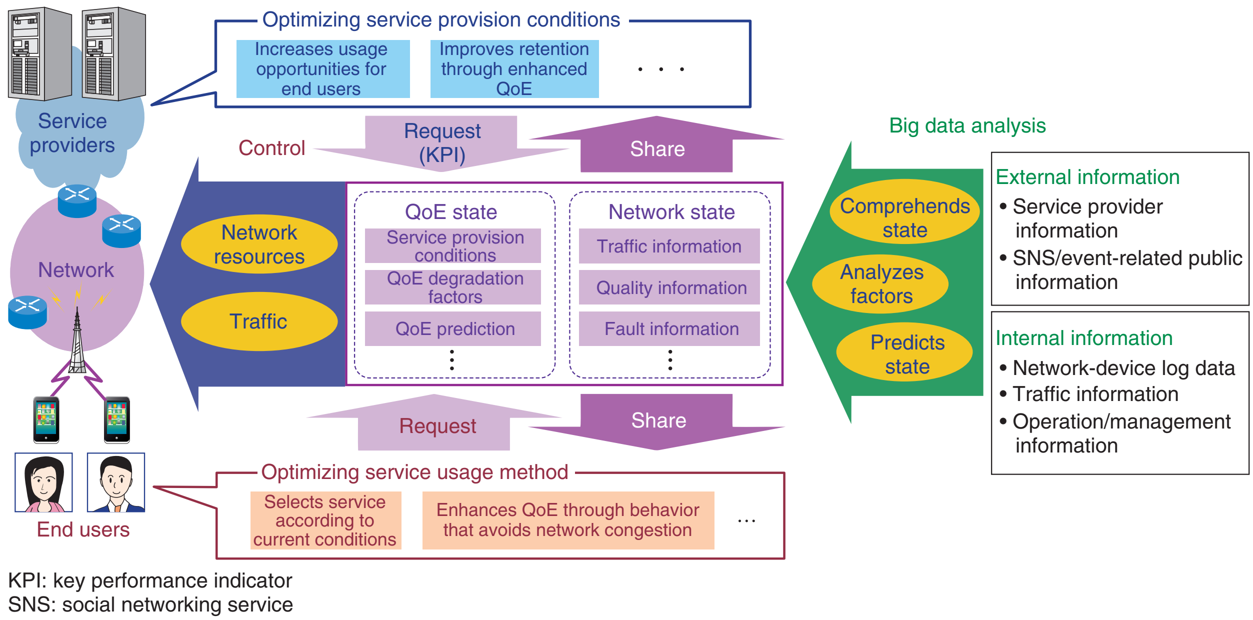

Fig. 4. Effects of QoE analysis/visualization and QoE control.

by quality factors both inside and outside the network, information on the user's service usage environment and terminal conditions is necessary in order to identify and deal with QoE degradation factors on a user-by-user basis. In mobile communications in particular, it is necessary to determine the temporal and spatial fluctuation characteristics of quality. An effective approach to achieve this is to obtain the cooperation of users in a crowdsourcing*7 manner to collect quality information on communication services and on the network and terminals as measured by users' mobile terminals.

2.3 QoE analysis and visualization

Useful information for improving customer satisfaction and network value can be visualized by making full use of information collected from both inside and outside the network and applying big data analysis techniques such as machine learning. This information includes the degree of network congestion, state of service provision, signs of service faults, quality degradation factors, and the scope of quality degradation on services. Visualization of QoE information in this way can support network quality improvements and initial assessments when responding to faults and can play a role in reducing the cost of maintenance operations and in raising customer satisfaction (**Fig. 4**).

2.4 QoE control

QoE control refers to actions taken when detecting QoE degradation or its signs by QoE analysis/visualization with the aim of improving QoE or avoiding such degradation. However, QoE optimization is difficult in a best-effort type of network in which network resources are shared between users and services. Thus, the network operator requires a new form of network-resource and traffic control to support service providers in providing services. To this end, the goal is to optimize QoE by sharing with service providers and end users the state of the network and QoE as analyzed and visualized from information inside and outside the network and by controlling network resources and traffic in accordance with network and QoE conditions (Fig. 4).

3. Specific example of QoE-centric operation

We consider here a specific example of QoE-centric operation targeting a progressive-download video delivery service.

As described above, the main factors in the degradation of quality in video delivery services also exist outside the carrier network, so QoE control performed

*7 Crowdsourcing: A process for performing a task by obtaining the cooperation of a large group of people.

by the network operator and service provider in a collaborative manner is an effective means of optimizing QoE. Even when delivering video at a high coding bit rate with the aim of providing users with high-quality video, a congested network may prevent a sufficiently high level of throughput from being obtained, resulting in video stalling and a significant drop in QoE. An effective response to such a situation would be to deliver the video at a coding bit rate for which QoE could be optimized taking network congestion into account. In other words, delivering the video at a coding bit rate for which choppy playback does not occur would be an appropriate action to take from the viewpoint of QoE even if video quality should drop by some degree.

For the service provider and end user, this form of control improves QoE, while for the network operator, it can reduce traffic that does not contribute to improving QoE, while achieving a reduction in network load (i.e., a reduction in the required facilities). In short, controlling the network in this manner can result in a win-win relationship. Such a QoE optimization measure linking the service provider and network operator has been proposed [3].

NTT is studying an interface called quality API for exchanging quality-related information between operators [4]. Joint experiments are being performed with Dwango Co., Ltd., the provider of the Niconico video streaming service, to test the effectiveness of this quality API.

4. Future developments

In this article, we proposed QoE-centric operation as a new operation framework based on user QoE and introduced the elemental technologies needed for its implementation.

Current QoE quantification technologies are based on studies that focus on human perception and cognition with respect to the media quality of audio and video. Going forward, we envision the further application of network science, the use of sensitivity analysis and behavior theory, and the development of techniques for clarifying and modeling the way in which QoE affects user satisfaction and user behavior. In this way, we aim to achieve network design and management directly connected to key performance indicators (KPIs)*8 of service providers.

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*8 KPI: An index for assessing performance and for quantitatively measuring progress toward corporate goals.

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Proactive Network Control

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Abstract

Development of virtualization technologies has enabled proactive network control and flexible resource optimization, which promise to help preempt reductions in service quality due to congestion and to increase network utilization rates. In this article, we introduce a method of traffic prediction that considers the mechanisms causing the traffic, and a means of control that is tolerant of unpredicted traffic, contributing to proactive network control.

Keywords: proactive, optimization, control

1. Introduction

It is difficult to predict from past traffic data, sudden changes in traffic that occur due to causes such as users gathering for an event, software updates on smartphones or other mobile terminals, or changes in how services are used. Nevertheless, networks need to be able to provide stable communication even when such changes occur. Generally in the past, after sudden changes in traffic caused network congestion, a reactive control scheme was used such as diverting some or all traffic on the affected network segments to other routes. With network virtualization, resource allocation and changes can be done flexibly, so reactive control is no longer necessary, even when there are sudden changes in traffic, and proactive resource allocation schemes can now be used to achieve both maximized utilization of resources and network stability. Technology that controls network resources and traffic based on traffic prediction in this way is called *proactive network control*. We are conducting research and development on traffic prediction technologies that consider the mechanisms producing the traffic and control technologies that tolerate unpredicted traffic, toward implementing proactive network control (**Fig. 1**).

2. Traffic prediction considering mechanisms producing the traffic

Most conventional traffic prediction technologies analyze observed traffic volumes over time and make predictions by extrapolating from past data. However, it has recently become more difficult to predict traffic volumes from past observations when the factors that generate the traffic change dynamically such as when new applications or content are introduced, or when large numbers of people gather due to a special event. To predict traffic based on such traffic-generating factors, we are advancing network traffic prediction technologies that analyze the flow of human traffic in physical spaces. In particular, we are studying how to predict and control network traffic by predicting the flow of human traffic during large-scale events such as the Olympics/Paralympics, in order to avoid congestion when such events lead to people concentrating in a particular area. In the future, we intend to develop more sophisticated prediction technologies by combining this with analysis and prediction of traffic behavior in cyberspace.

3. Control that is tolerant to unpredicted traffic

There are two stages involved in handling traffic fluctuations: more accurate prediction, as discussed above, and control technology that is tolerant to unpredicted traffic. We are currently developing two

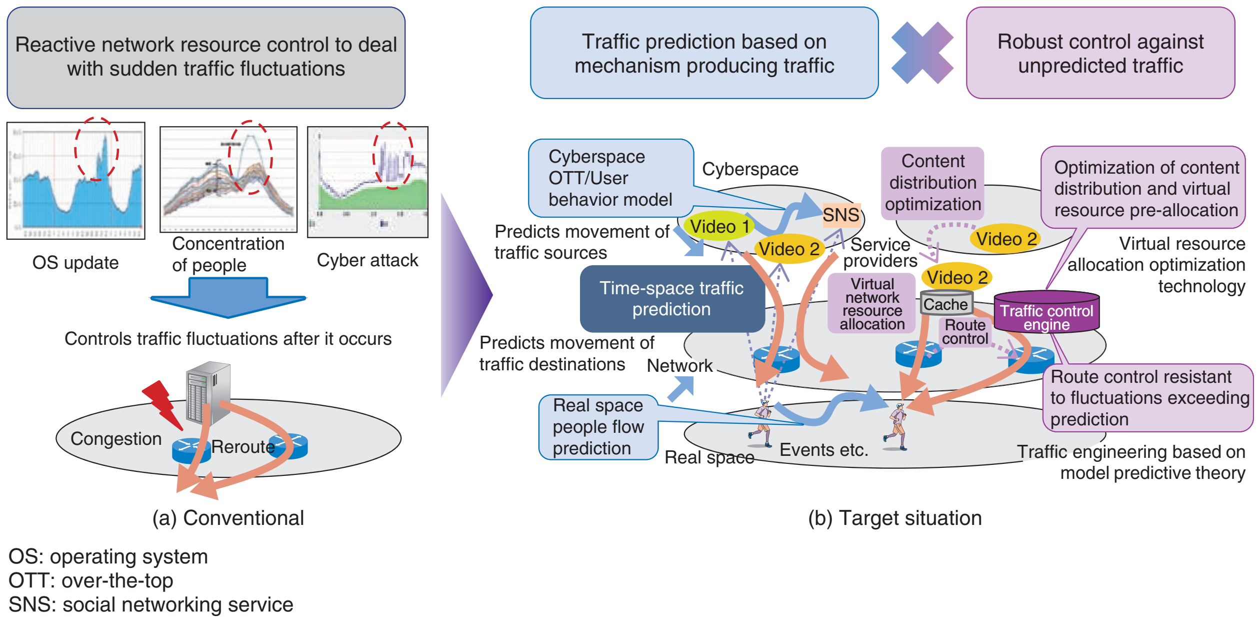


Fig. 1. Proactive network control.

technologies to achieve tolerance of unpredicted traffic, as described below.

- Virtual resource allocation optimization technology: Maximizes the ability to handle sudden changes in traffic and new demands from service providers by optimizing the management of idle physical resources.
- Traffic control using model predictive control technology: Classifies the predictability of traffic and applies different control policies for each classification.

We describe these control technologies below.

3.1 Virtual resource allocation optimization technology

Virtual networks need to be able to allocate resources with flexibility according to the demands of service providers. We have established a resource allocation technology that maximizes available resources based on the assumption that it is difficult to predict demand from service providers, maximizing the ability to accommodate future demand [1]. At the same time, we also minimize the reallocation of resources in order to increase quality for service providers [2]. The main strategy is that if resources on a link can be used up and there is a domain that cannot communicate without that resource, resources from other routes are allocated so as not to involve the domain in question (**Fig. 2**).

Also, if multiple routes can be selected, priority is given to unpopular routes that are only used between a limited number of domains, so that popular routes that can be used from more domains are kept available as much as possible. In the example in Fig. 2, with conventional mechanical routing, all neighboring links are used up, creating an isolated node, and resource reallocation is necessary when the next request occurs. In contrast, our proposed method uses less direct routes so that such reallocation of resources can be avoided. In the future, we will study optimization of resource allocation with network virtualization technologies, incorporating factors such as reliability, QoE (quality of experience) optimization, and minimizing power consumption, and we will work to achieve overall optimization of networks combining these multiple elements.

3.2 Traffic control using model predictive control technology

Traffic engineering is a way of actively controlling routes to accommodate more traffic using limited network resources. Conventional predictive traffic engineering technologies were developed assuming that predictions were accurate. Consequently, if the actual traffic differed largely from the predictions, ineffective routes could be selected based on the erroneous predictions. Routing was also controlled with the objective of optimizing utilization of the network

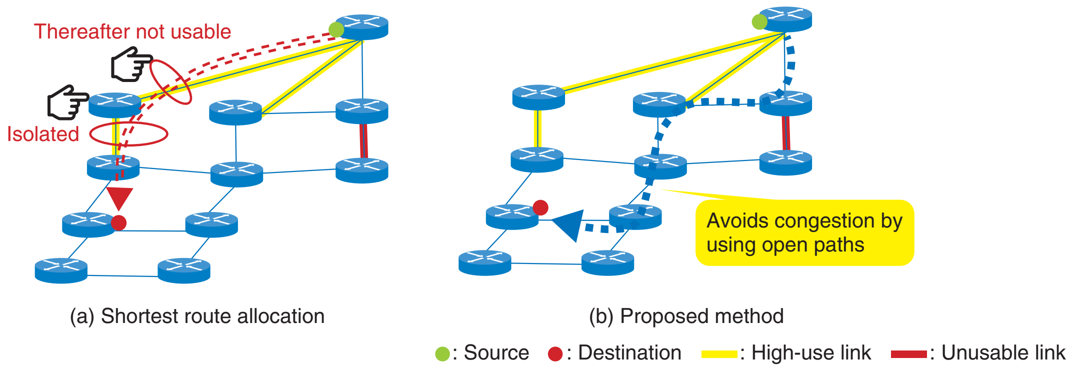
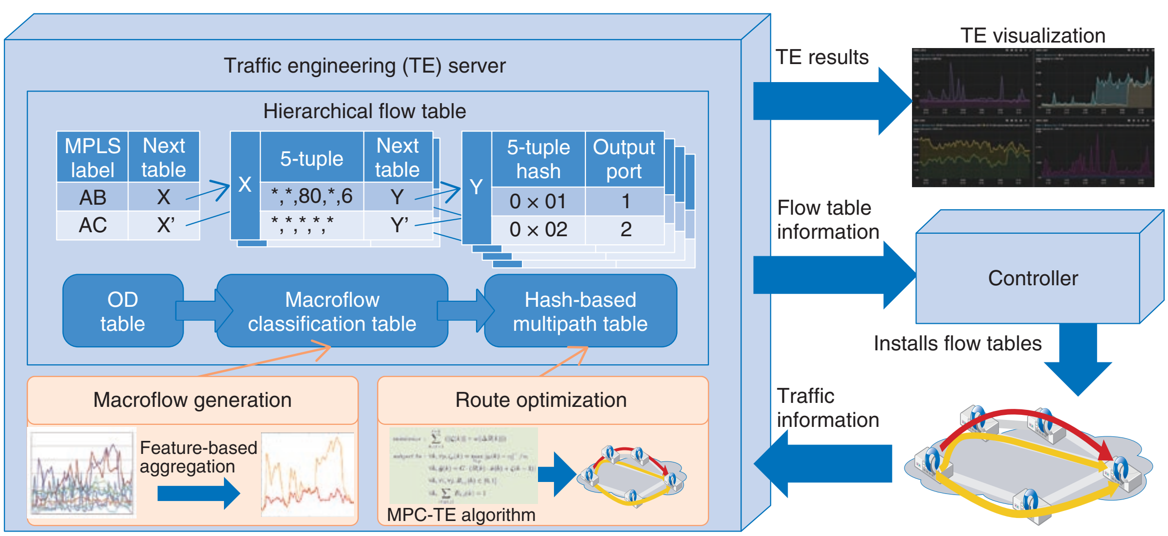


Fig. 2. Virtual resource allocation optimization technology.



MPC: model predictive control
MPLS: multiprotocol label switching
OD: origin-destination

Fig. 3. Experimental environment.

[3]; therefore, as traffic fluctuated, routes could fluctuate greatly with each control period. This could result in large changes in transmission delay with each control change, reducing communication quality.

To resolve such issues, our research group is working on traffic engineering technology that applies model predictive control, which is a type of control theory for systems that include interference that is difficult to predict. It is a practical control method that has been applied in the field of plant control. To avoid erroneous control, it represses the amount of control applied during each control cycle, approaching the target value in steps.

We applied the model predictive control idea to traffic control, avoiding erroneous control due to unpredicted traffic and implementing route control robust against prediction errors. Specifically, we formulated a new mathematical optimization problem by building model predictive control characteristics that repress the amount of route changes into the conventional problem of computing optimal routes in predictive traffic engineering. To evaluate the proposed method, we built an environment reproducing the topology, link delay, and flow data of the Internet2 test network in the USA (**Fig. 3**). The per-link

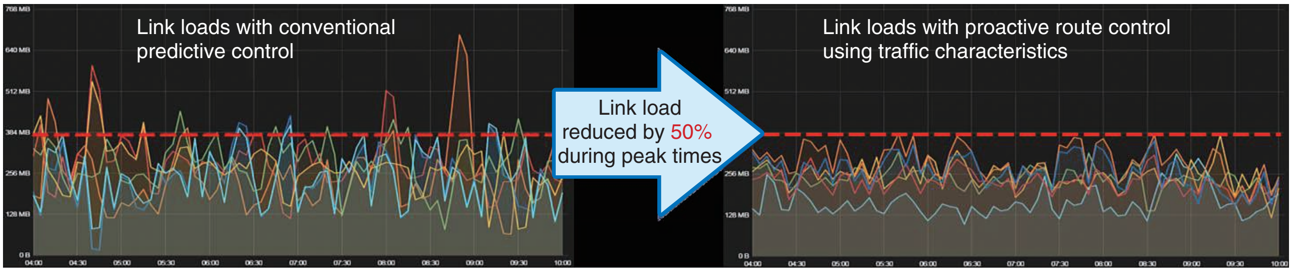


Fig. 4.   Per-link traffic fluctuation.

traffic fluctuations over time for the cases using conventional predictive route control and cases using route control combined with model predictive control are shown in **Fig. 4**. With the conventional method, traffic is concentrated on specific links in several time bands, resulting in network congestion. With the proposed method, traffic spikes are distributed, reducing concentration of traffic on specific links. A comparison of maximum link loads during peak time periods confirmed that maximum link loads with the proposed method were approximately 50% of those with the conventional method.

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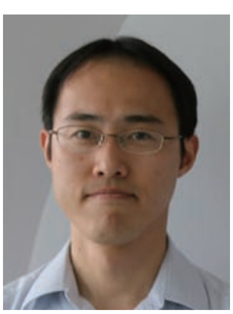

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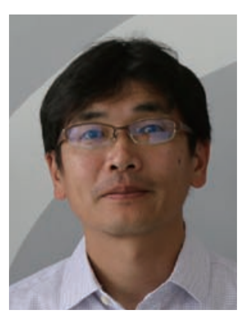

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Analytics-based Operation for Implementing Service Co-creation Networks

Keisuke Ishibashi

Abstract

At NTT Network Technology Laboratories, we are working on ways to accelerate the speed of responding to network faults, as well as to increase accuracy and save labor when doing so. This includes analyzing data obtainable within and outside the network such as equipment logs, traffic, and trouble tickets, in order to achieve service co-creation networks. A key method to achieve this is analytics-based operation, which we introduce in this article.

Keywords: fault detection, cause identification, recovery automation

1. Introduction

At NTT Network Technology Laboratories, one of our objectives is to accelerate the speed of responding to network faults, and to do so with greater accuracy and with less labor. The ultimate goal is to realize service co-creation networks, which will enable us to achieve safe, secure, and easy-to-handle end-to-end service management [1]. As networks have become larger and more complex, it has become more difficult to detect network faults, isolate the causes, and understand their effects on services. As a result, the longer times needed for recovery work and the increasing amounts of recovery work are becoming problems. Although progress is being made in formulating responses to frequent, stereotypical faults and automating them to increase speed and save labor, there are also cases for which recovery is taking longer, particularly silent faults, which are faults detected through user reports, and unique faults that occur infrequently.

However, the developments in big data and machine learning technologies in recent years may be useful in detecting faults, identifying their causes, and estimating their effects on services by inferring the underlying network state from data obtained within and outside the network. NTT Network Technology Laboratories is conducting research and development on network operation methods, which we call analytics-based operation, that can be used to respond to faults more quickly and accurately and save labor by inferring the network state from network data using machine learning technology.

2. Elemental methods of analytics-based operation

We are studying recovery of network service faults in the three stages of detection, cause analysis, and recovery. For the detection stage, we are developing methods such as service state visualization, support for visual monitoring work, silent fault detection, and predictor detection. For the cause-analysis stage, we are developing methods to identify the causes of faults, identify the locations, and understand their effects on services. For the recovery stage, we are developing methods to formulate recovery tasks and automate recovery work (**Fig. 1**).

For detection, we infer the network state from data within and outside the network and detect whether it is a fault or a predictor of a fault by determining whether that state is associated with a past fault and whether it is an unusual or abnormal state. For cause analysis, particularly for silent faults not detected by

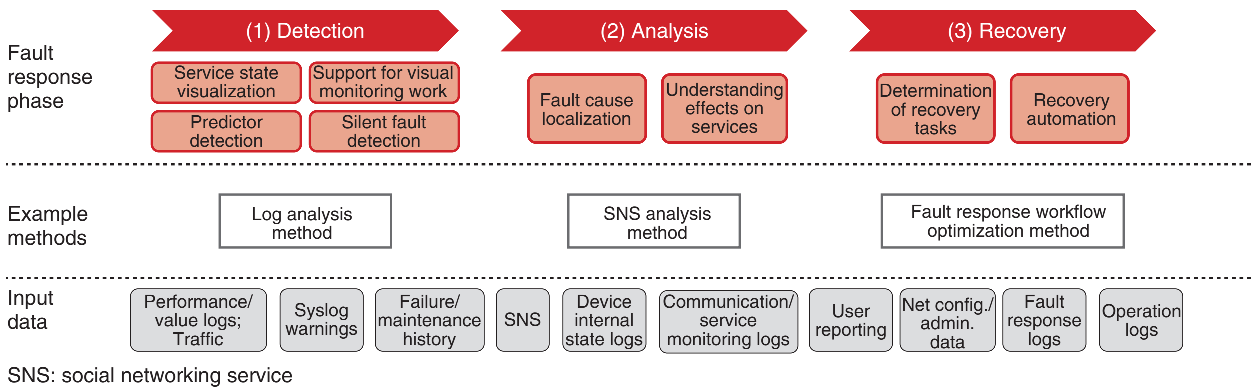

Fig. 1. Elemental methods of analytics-based operation.

device alerts, we identify the location and cause. At the same time, we evaluate the level of urgency in responding to the fault by estimating any effects on services. Finally, for recovery, we take recovery measures such as replacing or restarting components based on the causes determined by the analysis. We give an overview of these elemental methods used for implementing analytics-based operation below.

2.1 Detection

Data sources that can be used to infer the network state include alerts issued by equipment, syslogs indicating state changes, and performance logs indicating usage of resources such as links and the CPU (central processing unit). Data from outside the network such as service monitoring data from test calls, customer reports, and data from Twitter* can also be used to infer the network state. We combine these data sources to infer the network state.

However, syslogs are text logs with vendor-specific formats, so they are difficult to process statistically. They also generally have one message per line, while state changes result in multiple messages. Thus, detecting state changes is a matter of grouping multiple messages. We are studying machine learning approaches to handling this issue. Specifically, we have established a vendor-independent method for creating templates that do not require prior knowledge by estimating parameter settings from multiple syslogs and by grouping logs of the same type by ignoring parts that are the same. We have also established a method for extracting events, which groups messages likely to occur at the same time [2] (**Fig. 2**).

We can also detect faults by inferring the state from these data sources. Conventionally, faults have been detected using rules such as those indicating when particular strings appear in the syslog or when threshold values are exceeded in performance logs. However, in some conditions it is difficult to determine whether or not a fault exists, and false positives and false negatives can be a problem in these cases. Such problems can potentially be resolved using machine learning.

Fault detection with machine learning can be broadly divided into supervised approaches that learn states related to faults that have occurred in the past and that use those states to detect faults or predictors of faults, and nonsupervised approaches that detect abnormalities by finding statistical deviations from the normal state. The latter is advantageous in that it can apply to previously unknown faults, although it can be difficult to identify specifically what happened. For the latter approach, we have established a way of detecting abnormalities by using a dual approach of extracting occurrences in syslogs that are unique to faults, and also extracting those faults that occur periodically or infrequently [3].

2.2 Identifying fault causes and understanding effects on services

To recover or otherwise handle faults that are detected, the causes must be isolated and identified, and the effects on services must be understood. This consists of estimating both the causes and results of the phenomenon. For faults that occur frequently in a set manner, procedures can often be defined for isolating and identifying them, but unique and unknown

* Twitter is a registered trademark of Twitter, Inc.

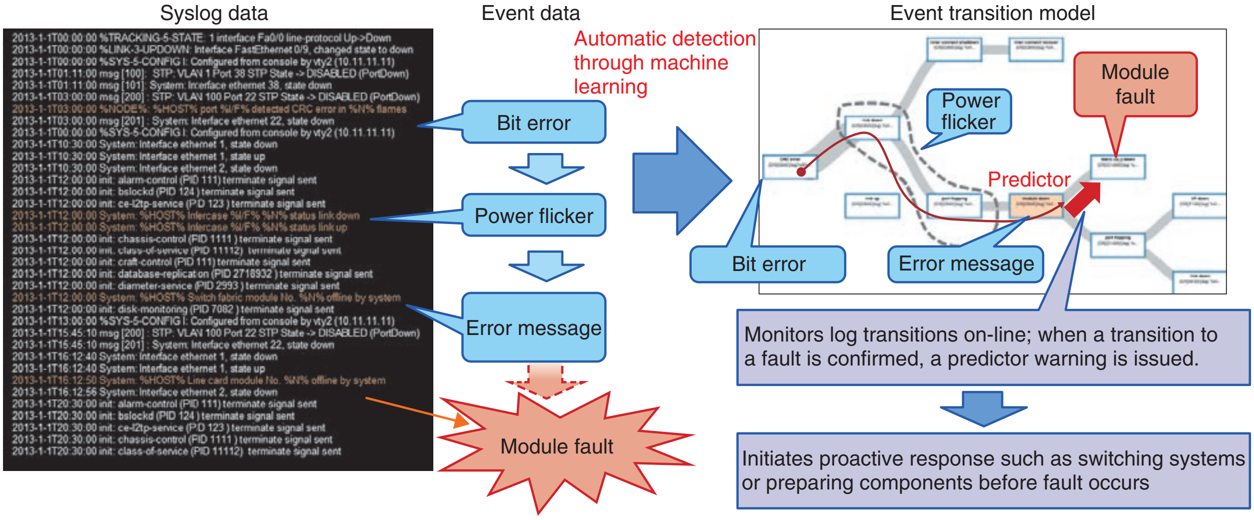

Fig. 2. Method for extracting events.

faults can take longer to isolate and identify. One potentially effective way to handle this is to use the machine learning results described earlier in the opposite direction to infer the fault that is the cause of the observed state. Also, to estimate the effects on services, it can be useful to obtain information outside the network such as service monitoring data using test calls, customer-reported information, or Twitter data [4], although the coverage of test calls and the relation between faults and customer reports is not always reliable. As such, it is possible that effects on services may be understood more accurately by using methods for estimating the state from sampled, incomplete, or noisy data.

2.3 Fault recovery

To reduce the operations workload and the amount of down time, procedures for handling faults must be clarified. If such procedures are not clear, operators can decide how to respond to the fault from the response history, which describes how abnormalities have been handled in the past (trouble-ticket data). However, reading and understanding the response history, which contains large amounts of mixed information, and deciding how to deal with the fault requires a great deal of work by the operator and prolongs the time that the fault is occurring. Therefore, to formulate and automate the work of fault recovery, we examined the free-form descriptions in the fault-response records (trouble-ticket logs) and developed techniques to extract task items from these records, generate work flows based on tasks identified in multiple records, and extract branch points of workflows using clustering, in order to establish an overall fault response workflow visualization method [5] (**Fig. 3**).

3. Future development

In this article, we described technical problems and potential ways to solve them using data analysis in fault detection, analysis, and recovery procedures to achieve more sophisticated fault handling. We also introduced related technologies that NTT Network Technology Laboratories is working on. We will continue our technical development in the future using a diversity of data to improve quality for customers and reduce operational workloads.

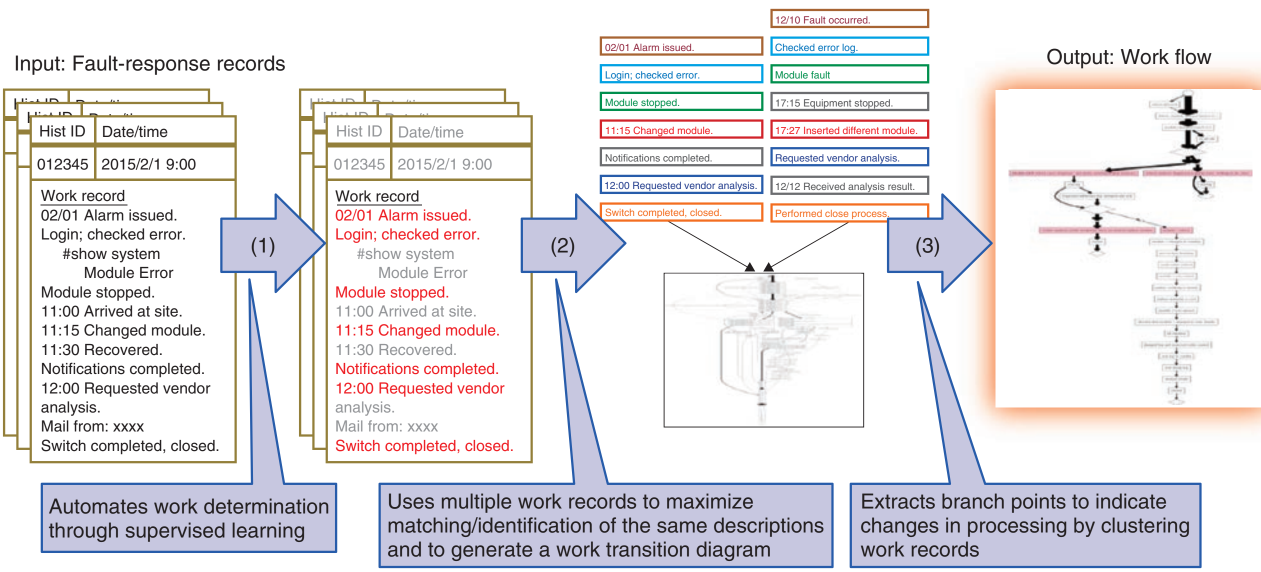

Fig. 3. Workflow visualization method.

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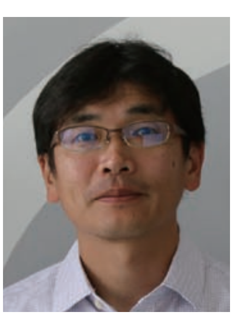

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Report of ASTAP-25 and 1st APT Preparatory Meeting for WTSA-16

Yoshinori Goto, Noriyuki Araki, and Makoto Murakami

Abstract

The 25th meeting of the Asia-Pacific Telecommunity (APT) Standardization Program (ASTAP), which refers to the regional standardization activities of APT, was held in Bangkok in March 2015. This article reports the major outcomes of this ASTAP meeting, including the new structure of ASTAP, results of discussions on networks and systems, which are of interest to telecom operators, and the preparatory activities for the WTSA (World Telecommunication Standardization Assembly) meeting to be held in 2016.

Keywords: APT, ASTAP, WTSA-16

1. Introduction

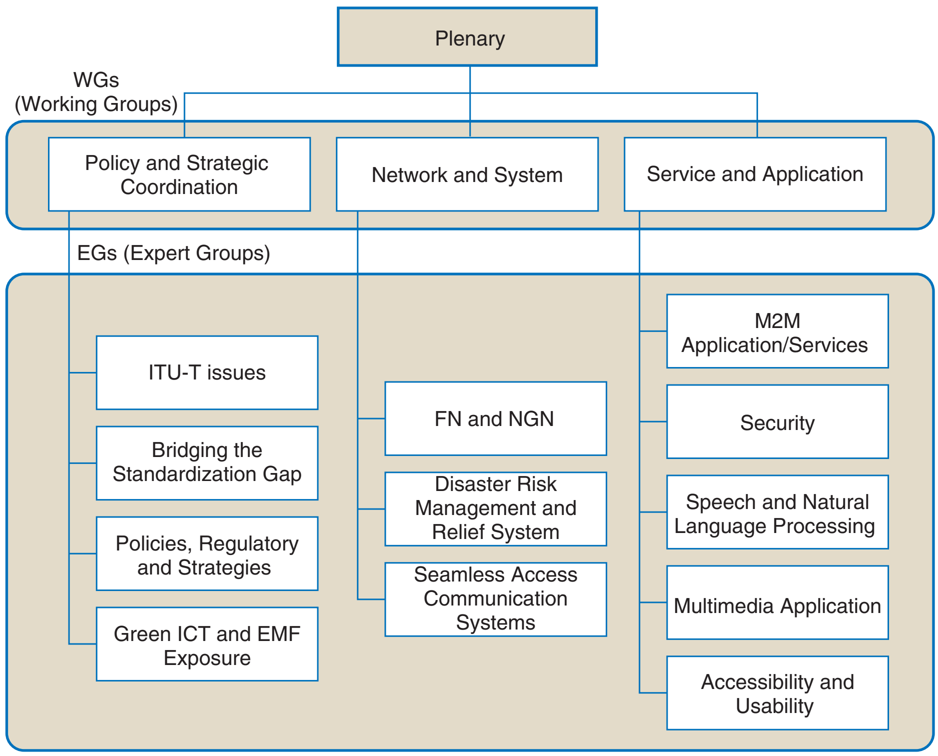
The Asia-Pacific Telecommunity (APT) is an international organization promoting the development of telecommunication services and infrastructure in the Asia-Pacific region. Currently, 38 counties are members of APT, and there are also 4 associate members and 131 affiliate members. APT serves as a platform for carrying out preparatory activities for making regional common proposals for high level conferences and assemblies of the International Telecommunication Union (ITU) such as the ITU Plenipotentiary Conference, and it plays an important role in promoting the voicing of member opinions in this region. In addition to the preparatory activities for high level conferences and assemblies of ITU, APT also conducts regional standardization work through ASTAP (Asia-Pacific Telecommunity Standardization Program) activities [1]. ASTAP usually holds two plenary meetings every year. The meeting in March 2015 was the 25th meeting.

2. Structure of ASTAP

Previously, ASTAP was a two-layer structure in which all the Working Groups (WGs) and Expert Groups (EGs) were positioned at the same level under the top plenary level. Although this structure was advantageous in its simplicity, it resulted in many output documents being brought into the plenary meeting without having been examined by a wider group of participants. Therefore, a lot of time was usually needed at the plenary meeting to clarify several points. It was pointed out that this structure could be improved by introducing an intermediate process between the EGs and the plenary meeting to sort out minor contentious issues. The new structure consists of three layers: the plenary meeting, WGs, and EGs (**Fig. 1**). The actual technical discussions take place in the EGs, and the WGs then check all of the output documents so they are ready for presentation at the plenary meeting, where decisions about them are made. With this new structure, the plenary meeting is reserved for strategic discussions and decision-making.

Three WGs, namely, those for Policy and Strategic Coordination (WG PSC), Network and System (WG NS), and Service and Application (WG SA), were established to respectively address policies and regulations, network infrastructure, and service issues. This structure of the WGs is aligned with the structure of the Telecommunication Standardization Sector of ITU (ITU-T) Study Groups (SGs), which enables efficient collaboration with ITU-T.

Twelve EGs are positioned under the WGs, and they conduct detailed technical discussions on



EMF: electro-magnetic field
FN: future network
ICT: information and communication technology
M2M: machine-to-machine
NGN: Next Generation Network

Fig. 1. The structure of ASTAP.

relevant issues. Many of the EGs are a continuation of former EGs in the previous structure, while minor adjustments were made to some of the EGs in order to align them with current activities. In today's international standardization efforts, most standardization work is conducted in global standardization bodies such as ITU-T. To complement such global activities, ASTAP focuses on information exchanges and regional activities utilizing global standards such as technical trials rather than establishing its own regional standards that might compete with global ones. Many Asian countries are coming late to the global standardization table, and their presence is still weak, although Japan, China, and Korea are increasingly influential. Assisting these newer members to be global players in standardization activities not only benefits them but also benefits us by creating future partners in global standardization.

3. Network system

This part mainly reports the activities of WG NS and the Expert Group on Future Network and Next Generation Network (EG FN&NGN), in which NTT is active. As a regional standardization body, ASTAP is responsible for establishing a regional coordination mechanism in the Asia-Pacific region for the World Telecommunication Standardization Assembly (WTSA). This coordination mechanism was utilized when the standardization of Multiprotocol Label Switching-Transport Profile (MPLS-TP)—a highly reliable packet transport technology—was debated in ITU-T. NTT played a leading role in coordinating the APT common proposal to WTSA-12 by bringing a contribution co-signed by Japan, China, and Korea to the APT preparatory meeting for WTSA-12. The draft recommendations on MPLS-TP were brought to WTSA due to a particular difficulty in obtaining approval for them via the usual approval procedure utilizing the SG meeting of ITU-T, and they were

Table 1. Structure, chairs, and vice-chairs of APT preparatory meeting for WTSA-16.

Plenary/WGs	Chairs/Vice-chairs	
Plenary	Chair	Mr. Yoichi Maeda (TTC, Japan)
	Vice-chairs	Dr. Hyoung Jun Kim (Korea)
		Ms. Weiling Xu (China)
WG1 Working Methods	Chair	Mr. Kaoru Kenyoshi (NEC, Japan)
	Vice-chair	Mr. Muhammad Neil El Himan (Indonesia)
WG2 Work Organization	Chair	Dr. Seungyun Lee (Korea)
	Vice-chairs	Mr. Noriyuki Araki (NTT, Japan)
		Mr. Abdul Karim Abdul Razak (Malaysia)
WG3 Standardization Issues	Chair	Mr. Si Xianxiu (China)
	Vice-chairs	Ms. Michiko Fukahori (NICT, Japan)
		Dr. Seyed Mostafa Safavi (Iran)
		TBD (Vietnam)

successfully approved. The approved recommendations on MPLS-TP are now ready to use as international standards.

Furthermore, NTT led the proposal on the vision of the next generation highly reliable packet transport technology including the network structure, implementation, and operation to ASTAP in collaboration with China Mobile and ETRI in Korea. The proposal was approved as an APT report by which NTT's vision of the next generation transport network is shared by other members in the Asia-Pacific region.

WG NS and EG FN&NGN have launched new study items on cloud computing and NFV (network function virtualization) in order to make communication and the processing of information more efficient, taking into account the advent of big data, and to encourage the development of related technologies and information-sharing among countries in the Asia-Pacific region. At this ASTAP meeting, NTT submitted contributions on advanced transport technologies for future flexible and high quality services such as advanced MPLS-TP packet transport network technology suitable for high resolution video distribution such as 4K and 8K, transport software-defined networking (SDN) utilizing SDN technology for transport networks to realize network virtualization, and high resolution time synchronization technology to be used for high quality mobile services and applications. These proposals were accepted as a work plan for further discussion including a survey in the Asian region, and were recognized as important ASTAP study items.

4. First APT preparatory meeting for WTSA-16

The first APT preparatory meeting for WTSA-16 was held after ASTAP-25. WTSA is the highest-level meeting of ITU-T and addresses strategic issues including SG restructuring. This preparatory work in APT is important for a member state to be successful at the WTSA because its proposals can gain the support of 38 APT countries by making an APT common proposal. The negotiating power of an APT common proposal is so high that the proponents of APT common proposals can debate issues equally with other regions such as North America, Europe, the Middle East, and Africa. The delegations of this preparatory meeting recognize this particular benefit and try to coordinate their opinions for presentation at WTSA.

This meeting is the first meeting for WTSA-16. Therefore, the major issues were the appointment of a chair and vice-chairs, the approval of a group structure including WGs, and the appointment of the chairs and vice-chairs of the WGs.

Mr. Maeda of the Telecommunication Technology Committee (TTC) was appointed as the chairman of the preparatory meeting, which consists of the plenary and three WGs. WG1 is responsible for establishing the ITU-T work method. WG2 is responsible for organizing the ITU-T work, including SG restructuring. WG3 is responsible for discussing standardization-related issues including policies and regulatory issues. The structure of the APT preparatory meeting for WTSA-16 and the appointed chairs and vice-chairs are indicated in **Table 1**. In the agreed structure, Japan, China, and Korea lead as chairs and vice-chairs of the plenary and WGs. This balanced structure among the major countries in the region encourages coordination. The participants of the preparatory meeting will work on producing APT common proposals, taking into account the discussions of TSAG (Telecommunication Standardization Advisory Group) and the Review Committee. The second meeting is planned for October 2015.

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He received his B.E. and M.E. in electrical and electronic engineering from Sophia University, Tokyo, in 1993 and 1995, respectively. He joined NTT Access Network Service Systems Laboratories in 1995. He then worked on the research and development (R&D) of operation and maintenance systems for optical fiber cable networks. Since 2006, he has been engaged in work on outside plant standardization in ITU-T SG6. He was the Rapporteur of Question 6 of ITU-T SG6 from 2006 to 2008, and the Rapporteur of Question 17 of ITU-T SG15 from 2008 to 2012. He served as the Chairman of ITU-T FG-DR&NRR (Focus Group on Disaster Relief Systems and Network Resilience and Recovery). He has been the vice-chairman of ITU-T SG15 since 2013. He also contributes to the activities of IEC (International Electrotechnical Commission) Technical Committee 86 (fibre optic systems). He received the ITU-AJ award from the ITU Association of Japan in 2012. He is a member of IEICE.

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External Awards

TAF Telecom System Technology Award

Winner: Hiroshi Sawada, NTT Service Evolution Laboratories; Shoko Araki, NTT Communication Science Laboratories; Shoji Makino, Tsukuba University
Date: March 23, 2015
Organization: The Telecommunications Advancement Foundation (TAF)

For "Underdetermined Convolutive Blind Source Separation via Frequency Bin-wise Clustering and Permutation Alignment."

This paper presents a blind source separation method for convolutive mixtures of speech/audio sources. The method can even be applied to an underdetermined case where there are fewer microphones than sources. The separation operation is performed in the frequency domain and consists of two stages. In the first stage, frequency-domain mixture samples are clustered into each source by an expectation-maximization (EM) algorithm. Since the clustering is performed in a frequency bin-wise manner, the permutation ambiguities of the bin-wise clustered samples should be aligned. This is solved in the second stage by using the probability on how likely each sample belongs to the assigned class. This two-stage structure makes it possible to attain a good separation even under reverberant conditions. Experimental results for separating four speech signals with three microphones under reverberant conditions show the superiority of the new method over existing methods. We also report separation results for a benchmark data set and live recordings of speech mixtures.

Published as: H. Sawada, S. Araki, and S. Makino, "Underdetermined Convolutive Blind Source Separation via Frequency Bin-wise Clustering and Permutation Alignment," IEEE Trans. Audio, Speech, and Language Processing, Vol. 19, No. 3, pp. 516–527, Mar. 2011.

The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, the Prize for Science and Technology (Research Category)

Winner: Shin'ya Nishida, NTT Communication Science Laboratories
Date: April 15, 2015
Organization: Ministry of Education, Culture, Sports, Science and Technology

For research on the mechanism of human perception that is achieved through the mutual interaction of different kinds of sensory attributes such as an object's color, shape, and movement, as well as sensory modalities such as visual, auditory, and tactile perception.

Published as: S. Nishida and A. Johnston, "Influence of Motion Signals on the Perceived Position of Spatial Pattern," Nature, Vol. 397, pp. 610–612, Feb. 1999, and as S. Nishida and A. Johnston, "Marker Correspondence, Not Processing Latency, Determines Temporal Binding of Visual Attributes," Current Biology, Vol. 12, No. 5, pp. 359–368, Mar. 2002.

Papers Published in Technical Journals and Conference Proceedings

Uncompressed 8K-video System Using High-speed Video Server System over IP Network

H. Kimiyama, M. Maruyama, M. Kobayashi, and M. Sakai

Proc. of APMediaCast2015 (1st Asia Pacific Conference on Multimedia and Broadcasting), pp. 99–105, Bali, Indonesia, April 2015.

We developed a scalable high-speed video server system to deliver high-quality video, including uncompressed HD and uncompressed 4K video, streams over IP networks and a synchronization method for it that combines multiple 4K transmission systems and video servers. We demonstrated the method's validity by implementing and testing an uncompressed 8K video real-time transmission system and an uncompressed 8K video on-demand system. Through experiments performed on both systems via commercial 100-Gbit/s Ethernet, we succeeded in achieving the world's first bidirectional uncompressed 8K video transmission and 8K video on-demand systems.

Multi-resolution Signal Decomposition with Time-domain Spectrogram Factorization

H. Kameoka

Proc. of ICASSP 2015 (40th International Conference on Acoustics, Speech and Signal Processing), pp. 86–90, Brisbane, Australia, April 2015.

This paper proposes a novel framework that makes it possible to realize non-negative matrix factorization (NMF)-like signal decompositions in the time domain. This new formulation also allows for an extension to multi-resolution signal decomposition, which was not possible with the conventional NMF framework.

L_p-norm Non-negative Matrix Factorization and Its Application to Singing Voice Enhancement

T. Nakamura and H. Kameoka

Proc. of ICASSP 2015, pp. 2115–2119, Brisbane, Australia, April 2015.

Measures of sparsity are useful in many aspects of audio signal processing including speech enhancement, audio coding, and singing voice enhancement, and the well-known method for these applications is non-negative matrix factorization (NMF), which decomposes a non-negative data matrix into two non-negative matrices. Although previous studies on NMF have focused on the sparsity of the two matrices, the sparsity of reconstruction errors between a data matrix and the two matrices is also important, since designing the sparsity is equivalent to assuming the nature of the errors. We propose a new NMF technique, which we called L_p-norm NMF, that minimizes the L_p norm of the reconstruction errors, and we derive a computationally efficient algorithm for L_p-norm NMF according to an auxiliary function principle. This algorithm can be generalized for the factorization of a real-valued matrix into the product of two real-valued matrices. We apply the algorithm to singing voice enhancement and show that adequately selecting p improves the enhancement.

Generative Modeling of Voice Fundamental Frequency Contours

H. Kameoka, K. Yoshizato, T. Ishihara, K. Kadowaki, Y. Ohishi, and K. Kashino

IEEE/ACM Transactions on Audio, Speech, and Language Processing, Vol. 23, No. 6, pp. 1042–1053, June 2015.

This paper introduces a generative model of voice fundamental frequency (F_0) contours that allows us to extract prosodic features from raw speech data. The present contour model is formulated by translating the Fujisaki model, a well-founded mathematical model representing the control mechanism of vocal fold vibration, into a probabilistic model described as a discrete-time stochastic process.

Motion Estimation for Dynamic Texture Videos based on Locally and Globally Varying Models

H. Sakaino

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Motion estimation, i.e., optical flow, of fluid-like and dynamic texture (DT) images/videos is an important challenge, particularly for understanding outdoor scene changes created by objects and/or natural phenomena. Most optical flow models use smoothness-based constraints using terms such as fluidity from the fluid dynamics framework, with constraints typically being incompressibility and low Reynolds numbers (*Re*). Such constraints are assumed to impede the clear capture of locally abrupt image intensity and motion changes, i.e., discontinuities and/or high *Re* over time. This paper exploits novel physics based optical flow models/constraints for both smooth and discontinuous changes using a wave generation theory that imposes no constraint on *Re* or compressibility of an image sequence. Iterated two-step optimization between local and global optimization is also used; first, an objective function with varying multiple sine/cosine bases with new local image properties, i.e., orientation and frequency, and with a novel transformed dispersion relationship equation are used. Second, the statistical property of image features is used to globally optimize model parameters. Experiments on synthetic and real DT image sequences with smooth and discontinuous motions demonstrate that the proposed locally and globally varying models outperform previous optical flow models.

Development of Wireless Systems for Disaster Recovery Operations

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This paper presents wireless systems for use in disaster recovery operations. The Great East Japan Earthquake of March 11, 2011 reinforced the importance of communications in, to, and between disaster areas as lifelines. It also revealed that conventional wireless systems used for disaster recovery need to be renovated to cope with technological changes and to provide their services with easier operations. To address this need, we have developed new systems, which include a relay wireless system, subscriber wireless systems, business radio systems, and satellite communication systems. They will be chosen and used depending on the situations in disaster areas as well as on the required services.
