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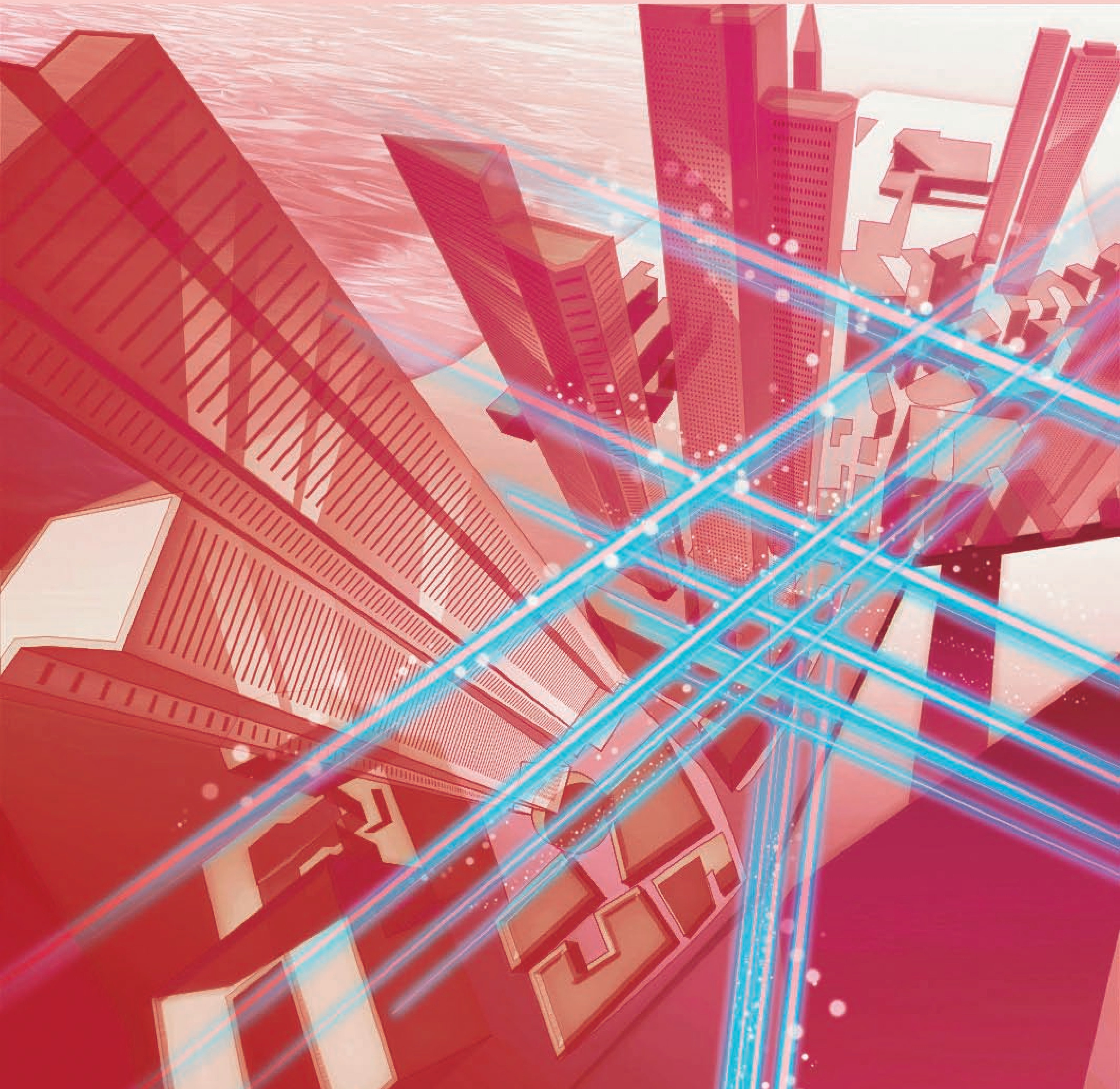

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Innovation and Collaboration: Ride a Big Wave, Create a Big Wave —Towards the Next Stage in 2014

Yasuyoshi Katayama
Senior Executive Vice President, NTT

Overview

Technical innovation in the world of information and communications technology has certainly been amazing, especially in cloud computing, big data, and security. Today, the telecommunications industry is looking for even more technological leaps, and the NTT Group is playing a hub-like role in this endeavor. We asked Yasuyoshi Katayama, NTT Senior Executive Vice President, about the company's objectives for 2014 "towards the next stage."

Keywords: innovation, collaboration, telecommunication industry

Towards the next stage: a revolutionary era for all of society

—Mr. Katayama, what was last year like for the telecommunications industry?

It's been no more than a year or so since the NTT Group announced its Medium-Term Management Strategy "Towards the Next Stage" in the fall of 2012, but I can already see that a variety of technical and social trends have taken root, which makes me feel that the move "towards the next stage" has truly begun.

Beginning with advances in individual technical fields such as the cloud and big data, information and communications technology (ICT) has grown to a point where it is now beginning to generate new value overall.

In the field of smart grids, for example, electric power companies have begun to introduce smart meters in earnest, and in the field of cloud computing, orders from our customers to have their internal systems moved to our cloud have been accelerating. Furthermore, in the field of big data, the Internet and ICT are coming to generate new value by applying big data in a common-sense manner to the analysis of Twitter posts, to data analysis in elections, etc.

The use of ICT in a wide variety of fields is coming under the spotlight even as a matter of national policy—I believe that society on the whole is looking for change in this direction.

—Amid these changes, what has the NTT Group achieved and how does it plan to face the challenges of 2014?

Since last year, we have been focusing our attention on the global cloud business, and one achievement here is that NTT Group companies that have been expanding overseas through M&A (merger and acquisition) activities have begun to generate a synergetic effect with each other and enter new markets.

Furthermore, the great potential of the NTT Innovation Institute, Inc. (NTT I^3) established in May 2013 in Silicon Valley is materializing, and concrete results even in business terms are beginning to take shape. The feeling is that NTT I^3 has already established a strong foundation and that the seeds of new business are beginning to sprout in many areas.

Cloud, big data, and security: today's growth fields

We can expect the field of cloud computing to continue growing into the future. At present, we are providing individual companies with means of entrusting their systems to us and making full use of the advantages of cloud computing through cost controls and flexible mechanisms tailored to the scale of their businesses. But looking to the future, we see our cloud as playing the role of an intermediary that connects information between company A and company B that have so far had no point of contact. In this way, we think that we can create new services and industries as a new movement in cloud computing.

Our aim is to provide a place where such business activities can blossom and to support the businesses of individual customers and the businesses born out of customer tie-ups. Of course, we are just one player among many in the field of cloud computing, but we believe we can help our customers in various industries and fields to manifest their full abilities by providing them with an extensive ICT infrastructure. For example, we created a group called "Japan Connected-free Wi-Fi" that interconnects operators that provide open Wi-Fi at airports, train stations, and other locations. Up to now, the word "connect" in our business implied the provision of communications such as by connecting two telephones. As we go forward, I would like the NTT Group to expand upon this role by helping companies, businesses, and services to connect with each other, that is, to collaborate.

Meanwhile, big data technology is making it possible to deal with data that up until recently was not very manageable. For example, smartphones are equipped with a variety of sensors such as those for handling GPS data, and the network connection provided by smartphones has made it easy to collect and store data at low cost. In addition, the detailed analysis of information has become possible thanks to greater computer processing power and advanced software techniques. As a result, information that had previously been treated as obscure and out of reach is now being targeted for creating real value.

This capability is being applied in the field of marketing too. While the answer to the question "What do I need right now?" can be inferred from that person's purchase history, we might be entering an era in

which big data analysis techniques will be able to determine what those needs are more accurately than the person in question (smiles).

As for network security, this is a major issue of concern. In addition to requesting individual customers to change their passwords frequently to prevent malicious behavior such as spoofing (impersonation), we still must provide a solid guarantee of safety on the network above and beyond such safe practices.

From the beginning, it has been difficult to predict security threats, and while threats have traditionally been of the mischievous type, they have recently been morphing into those associated with crime, terrorism, and other heinous activities. We must therefore construct systems that can stand up to attackers, but given that new technologies are constantly being developed and promptly incorporated into attacking schemes, it would be hard to say that any set of security measures could cover all threats completely. It is said that we have entered an era in which attacks on users must be prevented through the collaboration of multiple players since no single operator can deal with all threats to its users.

With this in mind, my plan is to promote research and development efforts in security while listening to our customers' comments and opinions, and in addition to developing world-leading security technologies, I would like to see a higher level of interaction among our global operations in regards to security.

Furthermore, when talking about security, attention must be paid to the value of the information in question. For example, a terrorist attack on a country's smart grid can halt the supply of power and simply paralyze the social functions of that country, and an attack on a hospital's computer system can corrupt information related to medical care and put patients' lives at risk. Research and development (R&D) must proceed taking into account the abilities of attackers, the vulnerabilities of systems, and the value of target information.

Creating an ICT environment for stress-free sharing by customers

—Can you give us some uplifting words as 2014 begins?

We expect 2014 to mark a full-scale recovery of the Japanese economy while being a year of much activity including the launch of preparations for the *big event* in 2020.

At NTT too, we see 2014 as being an auspicious year. We aim to provide new technologies and to create an environment in which customers can access the information they need in a stress-free manner and jointly experience a deeper level of feelings and emotion through ICT.

Let me give an example in relation to high-definition television (TV), which is a technology familiar to all of us. At the current level of resolution, the true worth of high-definition TV comes out in scenes involving movement, as in a program broadcasting a sports event. But at 4K or 8K levels of ultrahigh definition, such scenes invoke feelings or emotions completely new to us. In fact, even in a program having little movement, as in the broadcast of a Japanese chess match (shogi), ultrahigh-definition images can convey even the tension felt by the players. Similarly, in videoconferencing, it has not been possible up to now to observe fine points in the other party's facial expressions such as detailed eye movements, but ultrahigh-definition technology makes that possible.

When the era of ultrahigh-definition video truly arrives, telecommunication operators will be obliged to support the transmission of such video over the network. According to forecasts made by IDC, the market research company, the global amount of information will increase by more than 30 times the present level by 2020. How will we deal with this explosive growth in traffic? This is not simply a matter of increasing and enhancing our telecommunication facilities.

Up to now, we have been able to handle increases in the amount of network traffic as content expanded from email to images and video by developing technology from a hardware perspective. Our problem here was how to increase the capacity of a single optical fiber to carry more information. Going forward, however, we must work to enhance network capabilities from both hardware and software points of view. We must implement without delay such mechanisms as efficient data transmission using the HEVC (High Efficiency Video Coding) format and proactive, predictive type of network control using SDN (Software Defined Networking), which enables flexible control by converting network processes to software. This is what I believe is our mission in 2014.

It has been said that locations such as Singapore and Hong Kong have served as Asian hubs, but I can envision Japan becoming a world hub using advanced ICT such as the 4K/8K ultrahigh-definition technology that I just mentioned. It has also been said that Japan is a country at the frontier of emerging social issues, and in this sense, I would like to see Japan solve its agricultural and medical-care problems through ICT originating in Japan and thereby fulfill its role as a member of the global community. I truly believe that ICT has the power to solve such key social problems that affect many developed nations.

Taking the lead with a sense of balance and an acceptance of collaboration

—What are your hopes for R&D?

The network control and security measures that I just talked about are the conditions that must be met for ICT to be an *enabler*, to perform its functions correctly. Though we take great pride in being one of the top companies in the telecommunications industry even on a global basis, getting these technologies to a level where they can actually be used to provide services to our customers will require that we first implement the results of R&D in our business operations and create a rock-solid network.

In this regard, we are not yet at the point where we are confident enough to introduce, for example, this advanced network control technology on a global level, so I don't think that we have to be alone at the head of the pack as long as we maintain our standing as a top-level player.

NTT personnel involved in R&D have never worked with a catch-up frame of mind. They have always set their goals high with the aim of developing world-leading technologies. For this reason, I would like to see our researchers feel their way forward and undertake their work with a firm sense of direction. I want them to make NTT a global driver of technology.

Even if we were to be "running in the lead," we could never do everything on our own. For example, when requesting a vendor to manufacture certain equipment, costs could escalate and create havoc if we did not procure that equipment under the condition that many other parties must be able to use it and not just ourselves. To prevent such havoc, I think that it's very important that we disseminate our R&D results widely and provide equipment and technologies that everyone can use while collaborating with other operators in the world. On the other hand, I would like NTT to be number one in the advanced research of translation technology. However, it won't work to adopt a self-centered attitude here. In the end, it all comes down to having a sense of balance in our R&D endeavors.

The Japanese economy is now regaining its health and spirit. With the big event in 2020 as a target, I feel that a big wave is coming, in which Japan's presence in the world will reach new heights through the power of ICT.

Accordingly, to help invigorate society even more, I ask our researchers to work with the aim of riding this wave, and if possible, to even create a wave of their own.

By all means, let's use ICT to create a movement in a positive direction. Let's bring about change—we can't just stay still.

"My best work is my next movie!"
—Charlie Chaplin

—Mr. Katayama, can you say a few things to everyone in the NTT Group?

Of course. It's not just a matter of providing services on our own. There are a variety of players in the industry, and we must find out what they are doing and what they are thinking, and we must pursue tie-ups with them.

Charlie Chaplin famously said "My best work is my next movie!" It's important that we think about what we will do next. Let's take up the challenge of doing something new. Instead of going deeper into things that we already know about, let's undertake new things going forward.

To grow as a group that is recognized by society for its innovation, collaboration is essential. For example, NTT and Dwango formed a business alliance in July 2013. I would also like to promote collaboration with people in genres new to the NTT Group to stimulate ideas and create new value.

Customer needs play a big role here, and there are many things that can be created to satisfy those needs. Since we don't know in advance what value can be found where, we should attach great importance to interacting with people in fields that are new to us.

Interviewee profile

■ Career highlights

Yasuyoshi Katayama joined Nippon Telegraph and Telephone Public Corporation (now NTT) in 1976. He became Senior Vice President and Executive Manager of the Fundamental Services Department and Executive Manager of the Plant Planning Department of NTT WEST in 2004, Senior Vice President and General Manager of Networks of NTT WEST in 2006, and NTT Senior Vice President and Director of the Technology Planning Department in 2008. After serving as NTT Director and Executive Vice President and as Director of NTT's Technology Planning Department from 2009, he took up his present position in June 2012.

Taking on Pioneering Research with a Worldview as a Specialist in Cryptographic Theory

Masayuki Abe
Senior Distinguished Researcher,
Research Group Leader, NTT Secure Platform Laboratories

Masayuki Abe, an NTT Senior Distinguished Researcher, has been researching cryptography for over 20 years. He has played an important role in this special field even at an international level having written a number of papers on cryptographic theory and having served as executive committee chairman and program committee member for various international conferences. The origin of this active life is no doubt the personal relationships that he formed during his stays at prominent research laboratories in Switzerland and the United States. We last spoke with him in 2006. We sat down with him again recently to find out more about his research career and current issues, and we asked him to leave a message for young researchers.

Keywords: cryptographic theory, digital signature, structure-preserving

Engaged in overseas research activities while pursuing electronic money protocol and other projects

—Dr. Abe, please tell us about the path your research has taken to date.

Well, during my university years, I studied subjects such as radar-screen image processing and speaker recognition, which, needless to say, are unrelated to my current research. Then, in 1992, I began working at NTT Network Information Systems Laboratories in Yokosuka, and it was there that I first took up research in cryptography. That research group was researching both symmetric-key cryptography and public-key cryptography, but I became involved in the latter, and after being taught the basic concepts of public-key cryptography by NTT Fellow Tatsuaki Okamoto, who, by the way, received Japan's Medal with Purple Ribbon in 2012, I became firmly entrenched in this research field.

For the first two years, I was engaged in the design and development of cipher-and-authentication LSIs (large-scale integrated circuits) in cooperation with NTT Communication Science Laboratories. I next took up the research of cryptographic protocols, and thinking that such a protocol should not only be used to conceal a cipher but also to create something interesting, I undertook the development of electronic money. As a form of digital information, electronic money can be easily copied, and preventing its duplicate use is a major issue. In 1995 and 1996, I was in charge of protocol design for electronic money as well as its software implementation. Then, after almost completing my work on the electronic money protocol, I was given the opportunity to study abroad at the Swiss Federal Institute of Technology (ETH Zurich) as a guest researcher in 1996.

Upon returning to Japan in 1997, I entered the cryptographic theory research group and continued my work on multi-party theory that I had first taken up in Switzerland. It was during this time that I first produced results that were good enough to be accepted by a highly competitive international conference. The words “Do your work with the world in mind” spoken by my group leader soon after entering NTT kept running through my head, and I realized that I wanted to submit work that would be well received by the world at large. From then on, one of my objectives was to submit results worthy of presenting at a leading international conference. Although the risk is great in doing so, a successful paper can generate considerable response, and I have been fortunate in receiving good feedback over the years. I am still following this research style, but I sometimes feel that I’ve been neglecting involvement with the local research community in Japan.

Next, I became interested in cryptography components in applications such as electronic voting and became involved in the research of advanced digital signatures and advanced ciphers. It was during this time that I became a Distinguished Researcher, a title bestowed by the NTT Distinguished Researcher system. Then, in 2004, I travelled to North America with the idea of enriching my knowledge and working in an environment in which I could concentrate on a single research problem. I spent a year and eight months doing research at the IBM Watson Research Center, a major hub of cryptography research. I continued researching a variety of cryptography components after returning to Japan, and in recent years, I have been researching topics within a single field that I developed called structure-preserving cryptographic systems.

—What did you bring back from your two overseas experiences?

At ETH Zurich, my supervisor was Ueli Maurer, a young, up-and-coming professor at the time but a top authority in the field of cryptography today. He was a very exacting mentor. Of course, learning a lot from a wonderful teacher had a big influence on my later research activities, but so did the interaction and exchanges I had with the students around me. The people in that research group are today very active in the front lines of cryptography research. I was able to make invaluable friendships with many of them, such as Ronald Cramer of the Netherlands, a very well-known researcher in this field.

For my second overseas research trip, I thought that since I had already studied at a European university, it would be advantageous to spend time at a company in North America. Therefore, I chose the IBM Watson Research Center, which had a formidable cryptography research team. Here as well, the connections I was able to make with the people around me were of great benefit. I was able to live in direct contact with a number of prominent researchers, and from them I learned how to approach my research with a sense of urgency and also how to cope with problems. These researchers at the front line of cryptography were indeed larger-than-life people overflowing with energy. They were capable of tackling problems by harnessing their knowledge and applying various techniques in a short period of time. I came away with the impression that research is a very physical activity. The connections I made there had a beneficial effect in various ways on my later activities.

Since 2001, I have served as program committee member and chairman of many international conferences. The program committee is a forum where members discuss which papers submitted to the conference are to be included in the proceedings. Since space is limited, there are times when even good papers cannot be included, and disputes in this regard occur not infrequently. This committee is an important gathering where one can listen to the true feelings of other committee members on a variety of research results. However, unless you are well connected, you are almost never invited in, and it was even difficult for me when serving as conference chairman to get a seat. On the other hand, once you do get into a program committee, your connections widen, and I have been called upon to give invited lectures and participate in other activities as a result.

Answering the question “What is safe?” to formulate a fundamental theory of cryptography

—Can you tell us about your current research?

My research concerns basic cryptographic theory, and while this may be a bit difficult to understand, my

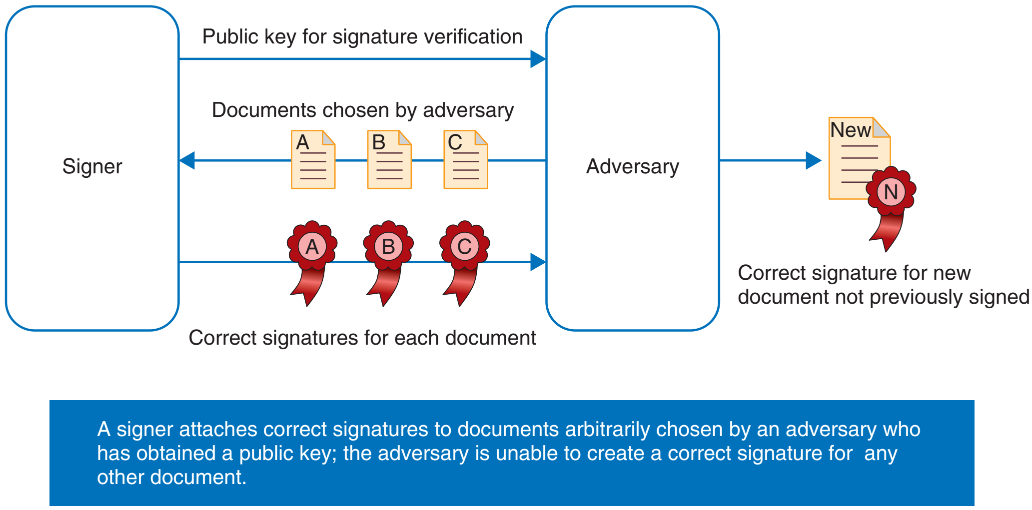

Fig. 1. Existential unforgeability against adaptive chosen message attacks.

aim is to create a foundation for safety in the provision of various types of products and services.

For example, I think about the question "What is safe?" in my research. This is what I would call cryptographic theory—defining the concept of safety from a theoretical and mathematical perspective. Let's imagine that person A sends the message "Tomorrow's plans are cancelled." to person B in encrypted form. Now, if an eavesdropper happens to view that ciphertext but cannot restore it to the original message, I wonder whether or not we can call that encryption safe. If a high degree of safety is desired, it is essential that no part of that message, such as "tomorrow's plans" or "are cancelled," be leaked. Partial information of this type such as what kind of plans were made for tomorrow or what has been cancelled could be very valuable to an eavesdropper. It is also necessary to deal with even more aggressive attacks such as those that send out ciphertexts that generate decryption errors and then analyze the type of error message returned to get hold of internal information.

This view of "safety" also holds true for digital signatures, one of my research themes. For example, if someone would like to forge an IOU with a digital signature saying "Mr. Abe borrowed 1 million yen" but there's nothing to forge such a document from, then can we say that we have a "safe" system? Moreover, if an IOU with a signature stating "Mr. Abe borrowed 100,000 yen" were to exist beforehand, and if "100,000 yen" could be rewritten as "1 million yen," we would certainly have a problem. In short, if an adversary can get hold of signatures for arbitrarily chosen messages but cannot create a signature for any other message, we can call this situation "safe". This kind of safety is referred to as "existential unforgeability against adaptive chosen message attacks," which, with the exception of physical attacks, is considered to be a standard of safety that must be satisfied by a digital signature system (**Fig. 1**). There are also schemes such as blind signatures and group signatures with more advanced functions, but the usage scenario differs for each, and as the usage environment becomes more complicated as the functions become more advanced, it becomes increasingly difficult to accurately express what is "safe" about each system.

You cannot expect to construct a safe system without clearly defining what "safe" is, and without sufficiently investigating whether that is truly a valid definition. The result of creating such a theoretical foundation is not something that is quickly manifested, but I believe that such foundations contribute to the safety of systems and methods used in society.

—Can you tell us about any specific achievements?

Well, I have published theoretical results as journal papers, but I have also developed various encryption schemes on top of those theoretical foundations. One example is the ECAO (Elliptic Curve Abe-Okamoto) signature, which is a message-recovery type of digital signature scheme in which existential unforgeability comes down to the discrete logarithm problem on an elliptic curve. This scheme has been adopted by ISO (International Organization for Standardization).

To give a more concrete example, I independently developed a mix-net anonymous communication scheme. This scheme can be used as the core component of an electronic voting system and has already been introduced to regional voting systems in Japan (**Fig. 2**). In this regard, anonymous communication software called Tor has recently appeared as one example of a mix-net application. Tor is a system that protects the privacy of users by preventing their communication paths from being traced. It can be used for whistle-blowing purposes, for example, and its use in the Arab Spring pro-democracy movement in the Middle East was recently in the news. Technology of the Tor kind has both a good and bad side to it, and while it was not a product of my own, this use of research results specifically for such activities reminded me of how socially significant my research field is, as a researcher pursuing safety in terms of privacy.

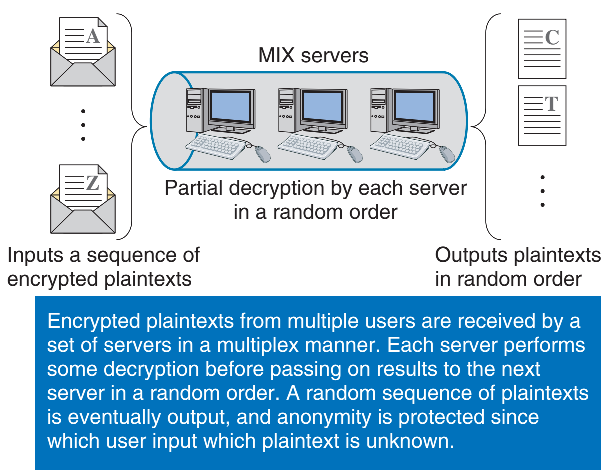

Fig. 2. Achieving transmission anonymity by mix-net.

Structure-preserving signatures that efficiently combine cryptographic components successfully developed in 2010!

—Can you tell us something about structure-preserving cryptographic systems that you are now working on?

There was a time when fears were growing about privacy infringements by companies. In 1999, there was talk that the Pentium III was equipped with a CPU (central processing unit) serial-number notification function, and that mounting that chip on a personal computer would enable that user to be identified and all user activity, for example, websites visited, to be determined. Then, in 2003, Benetton, the clothing retailer, decided to tag its products with small radio frequency identification (RFID) radio chips to improve product management. This kind of product/customer management raises fears that, in the extreme case, such chips could be scanned at some location to determine who is wearing what item and other types of personal information. Such corporate actions have given rise to boycotts and other forms of protest. Walmart in partnership with Gillette also conducted an RFID-based tag-management experiment and likewise created an uproar among consumers.

As a result of these experiences, the idea that “ignoring customer privacy issues is wrong” began to permeate corporate consciousness. For example, a cryptographic protocol was proposed that would prevent any serial number incorporated in a chip from being disseminated to the outside world and that would only make it possible to verify whether “a genuine chip is mounted.” This protocol is currently in the process of being standardized. In other words, the need was felt for a technology that could indicate that something holds true while hiding other details.

My research objective is to construct an efficient cryptographic protocol that can prove the correctness of something while preserving privacy in this manner. As part of this effort, I have been working on the micro-problem of how to combine cryptographic components to achieve “safety.” First, in 2008, I attempted to achieve an advanced type of digital signature called a “blind signature” that would combine a digital signature with a tool for convincing another party of something, which is called a non-interactive zero-knowledge proof. However, the interfaces of these two components were completely different, which created a problem. Specifically, an efficient digital signature has a mathematical structure expressed by group elements, while a non-interactive zero-knowledge proof accepts input expressed by a logic circuit to maintain maximum versatility. I therefore saw the need for middleware that could make the input and output of these two components compatible. Theoretically speaking, middleware could combine these components well, but it could also be a source of program bugs while delaying development work. With this in mind, I arrived at the idea of creating cryptographic components having compatible input/output to maintain a "group structure."

At first, I ran into problems, as I was not able to create a digital signature having structure-preserving characteristics. One aspect of cryptography is guaranteeing safety by outputting input information in a form different from its original form in such a way that the original form cannot be restored. As a result, it was very difficult to satisfy the constraint that the input and output have the same form while also achieving safety. Nevertheless, by applying a trial-and-error process and building up empirical rules much like solving a puzzle, I at long last made the first step in achieving a structure-preserving scheme in 2010 (**Fig. 3**).

Signature verification keys	$(A, B, G_z, G_r, H_z, H_u, G_i, H_i) \in \mathbb{G}_T^2 \times \mathbb{G}^{2n+4}$ $(i = 1, \cdots, n)$
Documents to be signed	$M_i \in \mathbb{G}^n$ $(i = 1, \cdots, n)$
Signatures	$(Z, R, S, T, U, V, W) \in \mathbb{G}^7$
Signature verification equations	$A = e(G_z, Z)\, e(G_r, R)\, e(S, T) \prod e(G_i, M_i)$ $B = e(Hz, Z)\, e(Hu, U)\, e(V, W) \prod e(H_i, M_i)$

By treating public keys, documents, and signatures as group elements on an elliptic curve, only group operations and pairing operations need to be performed to verify signature correctness. These characteristics make for efficient non-interactive zero-knowledge proofs.

Fig. 3. Structure-preserving signature scheme.

—What are your future ambitions?

When new worldviews or methodologies are proposed, many problems arise that need solving. There are also many things that cannot be accomplished by such methodologies that need to be pursued. At present, I am working on various new problems that seem to be arising one after another in that way. I often find myself thinking, "I want to enhance this paradigm," and that generally takes two to three years. Additionally, I would like to continue my research in efficiently creating cryptographic protocols that can protect privacy.

Playing with his children and listening to jazz piano as his great pleasures

—What do you do for rest and relaxation?

When I am engrossed in my work, I cannot get the research out of my head. However, once my concentration is broken, it's difficult to return to a zone of deep thinking. Thus, during times of concentration, it would be a shame to stop while commuting. For me, thinking is not a stressful activity. Stress for me is not getting a good reception for a paper that I have written to convey a scheme's benefits and safety. At most major international conferences related to cryptography, the paper selection rate is about 20%. I myself have lost out two times. I get especially stressed when my paper is not understood even after submitting it repeatedly. Of course, I am very pleased when a paper of mine is accepted, and I'm in a great mood for a while after that. For twenty years, I have advocated the approach of working with the world in mind, and while I have experienced some very trying times, I have colleagues that have persevered through tough times in the same way.

My greatest pleasure is taking my children to a pool in a neighborhood park and spending time with them on weekends. Since I will not be able to do this once they get older, I want to play with them as much as possible at this time.

In addition, during my stay in the United States, I wanted to do something that I could not do in Japan, so I bought a vacuum-tube audio system at an auction and listened to jazz piano to my heart's content in my room. Later, I found that I could not do without this audio system even on returning to Japan and my small apartment, and now I often listen to music using headphones. I especially like the pianist Marian McPartland.

Don't shut yourself off from the outside world—current technology may last only 10 years but personal relationships can last a lifetime

—Dr. Abe, please leave us with a message for young researchers.

When I look at young researchers, there is much to be admired and to be amazed at—they are truly industrious and serious about their work.

So I can't say that I have any advice in particular, but based on personal experience, I would like to point out that new technology comes around about every five years and that a certain type of technology may last for only five to ten years before becoming obsolete. That is a natural cycle. Personal relationships, however, can be maintained for 20 years and longer, and the benefits they provide can change with the passage of time. I would therefore encourage young researchers to create opportunities for themselves to talk with all kinds of people all the time. In other words, do not close yourself off in your research laboratory and limit your relationships to the same set of colleagues. If you talk about your ideas to ten people, some of them may become quite captivated about your work, which will more than make up for your efforts. And if you get an opportunity to do research overseas, by all means take it!

Interviewee profile

■ Career highlights

Masayuki Abe received the B.E. and M.E. degrees in electrical engineering from the Science University of Tokyo and the Ph.D. degree from the University of Tokyo in 1990, 1992, and 2002, respectively. He joined NTT Network Information Systems Laboratories in 1992 and engaged in the development of fast algorithms for cryptographic functions and their software/hardware implementation and the development of a software cryptographic library. From 1996 to 1997 he was a guest researcher at ETH Zurich, where he studied cryptography, especially multi-party computation, supervised by Professor Ueli Maurer. From 1997 to 2004 he was in NTT Information Sharing Platform Laboratories (now NTT Secure Platform Laboratories), where he worked on the design and analysis of cryptographic primitives and protocols, including electronic voting, a key escrow system, blinding signatures for digital cash systems, message recovery, and publicly variable encryption schemes. He also engaged in efficient multi-party computation based on cryptographic assumptions and zero-knowledge proofs in multi-party computation. From 2004 to 2006 he was a visiting researcher at IBM T. J. Watson Research Center, NY, USA, working with the Crypto Group, where he researched hybrid encryption, zero-knowledge proofs, and universally composable protocols. He has been a Senior Distinguished Researcher and Research Group Leader of NTT Secure Platform Laboratories since July 2013.

Software Development Technology Initiatives at NTT Laboratories

Takashi Hoshino, Kazuhito Suguri, Katsuyuki Natsukawa, and Yasuharu Yamada

Abstract

A large amount of software is used within the NTT Group of companies. Development is in progress on much of this software, but this development does not always run smoothly. Because of this, the NTT Software Innovation Center conducts research and development of software development technology in order to increase the stability and efficiency of software development. This article reports on some of the research and development underway.

Keywords: software development, software engineering, development processes

1. Introduction

A survey conducted by the Information-technology Promotion Agency (IPA) indicated that only about 15% of software projects exhibit no problems after release, and more than 10% of projects have more than ten trouble issues. The three key aspects of software development are quality, cost, and delivery (QCD); from a developer's perspective, delivery dates are met in about 85% of cases, but quality and cost targets are achieved in less than 80% of cases. From a user's perspective, cost objectives are met in approximately 80% of cases, but quality and delivery objectives are only met in approximately 70 to 75% of cases. There has been some gradual improvement when looking at changes year-to-year, but the current state is still inadequate [1].

Much software is also developed and used within the NTT Group companies. We are continually making improvements in these development projects, and efficiency is increasing, but this does not mean that all software development proceeds smoothly and steadily. In order to provide services quickly, development of the software supporting those services must proceed even more efficiently.

The NTT Software Innovation Center (SIC) is conducting research and development to create software development technologies that will bring greater stability and efficiency to all software development at the NTT Group companies.

2. Software development technology

Software engineering includes studying how to improve software development efficiency. The IEEE (Institute of Electrical and Electronics Engineers) Computer Society defines software engineering as: "(a) The application of a systematic, disciplined, quantifiable approach to the development, operation, and maintenance of software; that is, the application of engineering to software. (b) The study of approaches, as in (a)". This definition suggests an academic approach such as in establishing systematic methods. In contrast, our project is called the Software Development Technology Project and does not use the term software engineering. While the term software development technology certainly includes the systematic and quantitative initiatives of software engineering, it also implies the active pursuit of initiatives related to practical technologies commonly in use in the development workplace, which are not necessarily covered by this definition, for example, knowledge and know-how tools and other work-place aids [2].

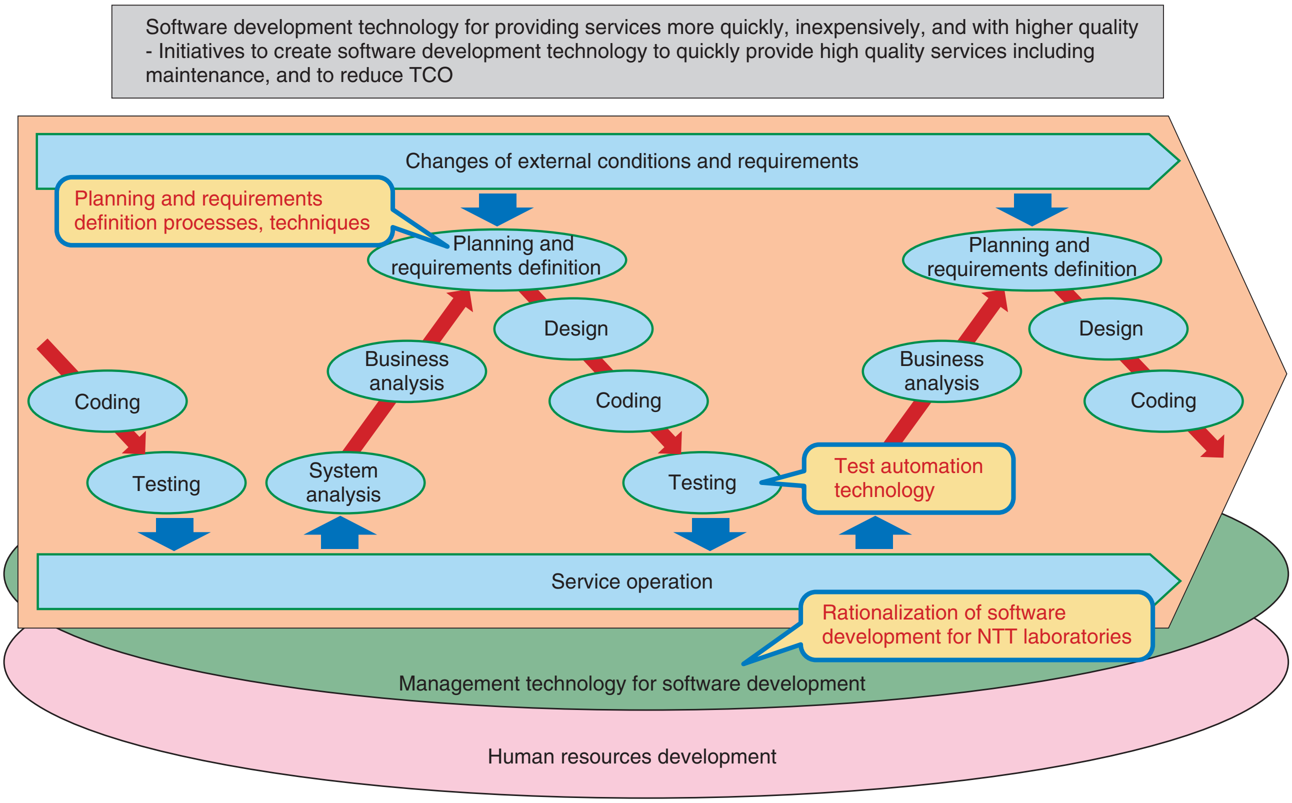

Fig. 1. Initiatives of Software Development Technology Project.

3. Research and development towards rationalized QCD

Our goal at SIC is to create software development technologies for providing services quickly, inexpensively, and with good quality. To achieve rapid service provision and to contribute to reducing the total cost of ownership (TCO), we are working on creating software development technology for application software in particular.

The typical software development process flow and activities supporting it are shown in **Fig. 1**. Before software is introduced for a service, it is developed in a series of processes, which are: *planning and requirements definition*, in which the functionality and performance required by users is decided based on objectives, return on investment, and analysis of the current system; *design*, in which the functionality and performance of the system to be provided to users is decided based on the requirements, along with how it will specifically be implemented; *coding*, in which the program is coded according to the design; and *testing*, in which the implemented program is checked to make sure it operates correctly according to the design and requirements and that it satisfies the original user requirements. When additional development is done to improve functionality or for other reasons, this process is repeated.

These processes must be performed reliably in order to achieve appropriate levels of QCD in software development. The planning and requirements definition is the most fundamental process; it is an important elemental step in which developers ask what needs to be done or what needs to be created, and it has a significant influence on later processes. If this definition is ambiguous, a lot of work may have to be repeated, which affects all aspects of QCD: cost increases (C), delayed completion (D), and lower than expected functionality or quality (Q). Thus, it is extremely important to conduct the planning and requirements definition accurately. At SIC, we are conducting research and development (R&D) on processes for performing the planning and requirements definition, and on notation practices for documenting requirements.

The testing process involves checking the operation of the software and increasing functional quality, so this work really focuses on ensuring quality (Q) and is the last measure to prevent poor quality. Testing also accounts for a large share of the software development work and cost, so improving testing efficiency can reduce the cost and shorten the development time, two factors that are directly related to costs (C) and delivery (D).

SIC is also developing technologies to support test planning and execution, with the goal of performing this test work more accurately and efficiently. The work done in all the steps of the planning and requirements definition and testing processes discussed here can have a significant effect on QCD. Further, each of the aspects of QCD is intimately related to each other. For example, pursuing a higher level of quality (Q) than required can incur more work, higher costs, and a longer time to ensure the higher quality level, which will have undesired effects on C and D. It is therefore important to proceed with an appropriate QCD balance, so it is necessary to manage QCD appropriately. SIC is conducting R&D on management of software development, with a view toward providing such QCD management. This includes issues such as establishing methods to evaluate quality and productivity, gathering development data needed for such evaluations, and establishing and operating software development standards that will formalize and enable the entire development process to proceed efficiently. Addressing the management of development quantitatively in this way will bring stability to each process and contribute to the overall stability of software development.

In these Feature Articles, we introduce some of SIC's initiatives related to important technologies and activities for increasing the stability and efficiency of software development, as discussed here. SIC has not performed this technical development from scratch on its own, but has used technologies that NTT Group companies already possess, as well as open source software and commercial technologies, with the aim of advancing open innovation and producing results quickly.

4. Linking practical needs and NTT Group companies

For software development technology, it is important to produce technologies that are immediately useful in the development workplace. In order to understand the needs of the software development workplace accurately, we are strengthening our ties with NTT Group companies.

Within the NTT Group, there are companies on both sides of software development: those that place orders requesting software development and then use the completed software, and those that take such orders and develop the software. We are striving for optimal technology development that will substantially increase development efficiency by listening to both sides, understanding, analyzing, and optimizing the real issues and needs in both workplaces, and advancing our work while increasing collaboration with companies that handle a lot of software development—even those just within the NTT Group such as NTT DATA and NTT Comware.

5. Towards the future

SIC has pursued these initiatives while maintaining a strong awareness of, and cooperating more deeply with, the development workplace. We will continue to work on creating technologies that are immediately useful in the development workplace and will select research themes suited to the needs of this workplace while striving to increase the stability and efficiency of software development within the NTT Group.

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Improving the Planning and Requirements Definition Process

Yukako Iimura, Setsuo Yamada, and Nobuyuki Kobayashi

Abstract

The first process in software development is the planning and requirements definition. In this process, the stakeholder requirements must be organized, and the requirements for implementing the software must be clarified. However, many issues arise with this process in practice, and improvement is therefore needed. In this article, we introduce our activities related to improving the planning and requirements definition process, including studying trends in research and practice.

Keywords: software development, requirements definition, planning

1. Introduction

A survey by the Information-technology Promotion Agency (IPA) [1] found that although achievement levels for quality, cost, and delivery (QCD) targets for software development projects are gradually improving, a number of problems still remain.

To solve these problems, we have been focusing on improving the planning and requirements definition process of software development projects. This is the phase in which it is determined what is to be achieved by the software and what return on investment can be obtained.

The IPA survey also investigated the causes when QCD objectives were not met. It found that, from the developer perspective, 35% or more of the projects had problems at or before requirements definition, and from the user perspective, this figure was approximately 90%. In other words, many developers and users recognized problems in the planning and requirements definition process.

Generally, problems that occur in this process are due to differences between what the users really need and what the developers think they are supposed to build. If developers develop software based on a misunderstood view of what users need, the developed software will not meet user needs. As a result, all of the work up to the point where the difference was detected must be reworked. Several researchers have pointed out that the cost of this rework increases rapidly as the time it takes to discover the error increases. A recent survey [2] reported that the cost of fixing a requirement error discovered in the system operation phase costs 68 to 110 times more than what it would cost if discovered during the planning and requirements definition process (see **Table 1**).

Table 1. Relative cost to correct a requirement defect depending on when it is discovered.

Development phase	Relative cost to correct a defect
Requirements	Base value of 1
Design	2 to 3 times higher (than base value)
Coding	5 to 10 times higher
Testing	8 to 20 times higher
Operation	68 to 110 times higher

2. Challenges of the planning and requirements definition process

Here, we discuss the various challenges that arise in the planning and requirements definition process.

(1) Diversity of stakeholders

The term *stakeholders* refers to the group of people who are involved in a software development project or are affected by the project. Generally, the stakeholders in such a project can be divided into users and developers. Users include end-users who will be using the software, and others such as the information technology department and management, for example, the chief information officer. Similarly, developers include software engineers, vendor project managers, and management, for example, the chief technology officer. The perspectives of each of these stakeholders are different, and they often have conflicting interests. Because of this, stakeholders sometimes have contradictory requirements, and these must be adjusted in order to reach agreement on what will be achieved with the software. Thus, as the number of stakeholders increases, dealing with the contradictory requirements in this way becomes more difficult.

(2) Changing requirements

In the planning and requirements definition process, requirements from stakeholders are adjusted, and agreement is reached on the function and performance of the software. However, these functions and/or performance may need to change in the requirements process due to omissions in the requirements or later changes in the environment. Handling such changes often results in scheduling delays or degraded quality. Also, adding requirements causes wide-ranging effects if they conflict with other existing requirements, as the existing requirements then need to be re-examined, and adjustments need to be made with the relevant stakeholders.

(3) Ambiguity in requirements documentation

Because the purpose of planning and requirements definition is to reach agreement among stakeholders, documentation of these requirements is extremely important. However, if requirements definition is ambiguous, multiple readers of a requirement may have a different understanding of what it means, or they may be confused as a result of interpreting a requirements statement in different ways.

If the stakeholders have differing expectations regarding the function that the software will have due to such ambiguity in the documentation, reworking will be necessary. For example, even if the developers follow the requirements definition, they may understand them in a way that is different from the users' intentions because of the ambiguous specifications, and all of the work starting from the design phase will need to be reworked.

3. Standards and guidelines related to the planning and requirements definition process

Interest in the planning and requirements definition process has increased recently, and consequently, there has been an increase in the number of related standards and guidelines being published. This section describes the Requirements Engineering Body of Knowledge (REBOK) [3][*1]—a requirements engineering knowledge system, ISO/IEC/IEEE[*2] 29148 [4]—a standard related to requirements engineering, and the Software Life Cycle Process Japan Common Frame (SLCP-JCF) [5].

3.1 REBOK

The first edition of REBOK was released by the Japan Information Technology Services Industry Association (JISA) in 2011. It provides a set of common knowledge shared and used by stakeholders consisting of both users and developers, and for both enterprise/business software systems and embedded software systems, except for domain specific knowledge. The requirements engineering process is shown in **Fig. 1**. It configures the four key knowledge areas of (1) elicitation, (2) analysis, (3) specification, and (4) verification, validation, and evaluation in an incremental and iterative way. It aims to provide appropriate knowledge to all the stakeholders involved in the requirements engineering process at appropriate levels of expertise; the stakeholders include corporate management, end-users, project managers, and software developers.

3.2 ISO/IEC/IEEE 29148: 2011

ISO/IEC/IEEE 29148: 2011 covers processes and products related to the engineering of requirements for systems and software products and services throughout their life cycle. It provides additional guidance in the application of requirements engineering and management processes for requirements-related activities in ISO/IEC 12207 and ISO/IEC 15288. It includes perspectives from areas beyond software such as the business or project that is the

*1 REBOK is a registered trademark of JISA (Registered trademark classification 9, registration no. 5458370).

*2 ISO: International Organization for Standardization; IEC: International Electrotechnical Commission; IEEE: Institute of Electrical and Electronics Engineers.

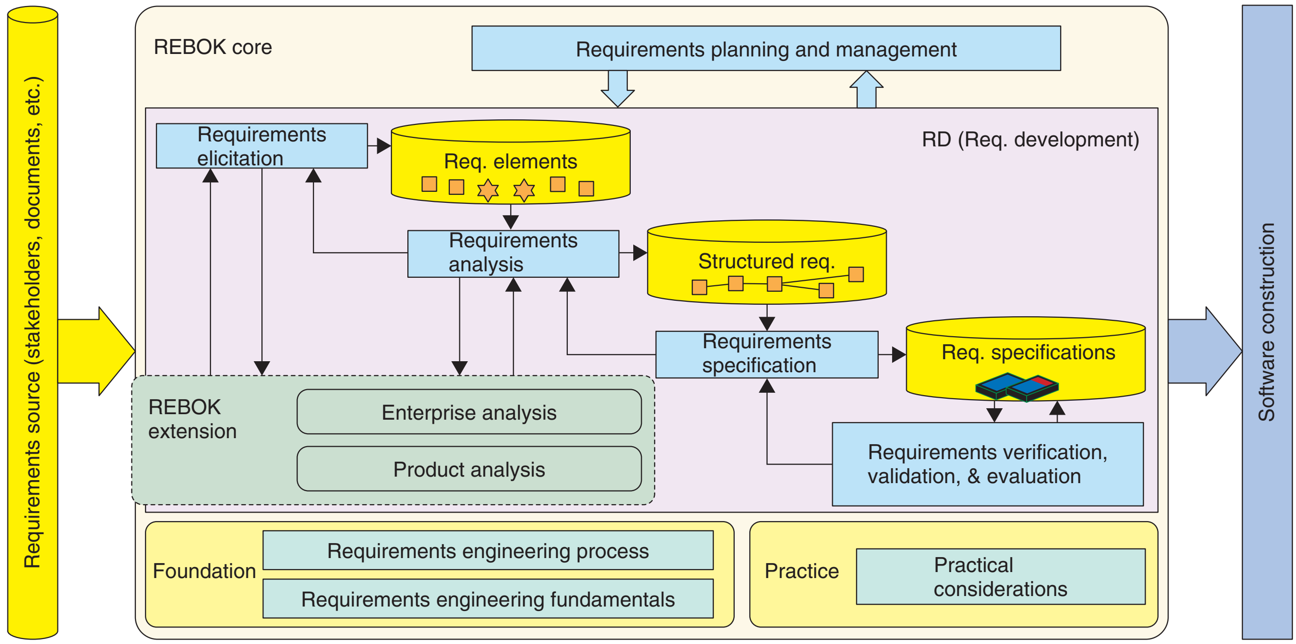

Fig. 1. REBOK process.

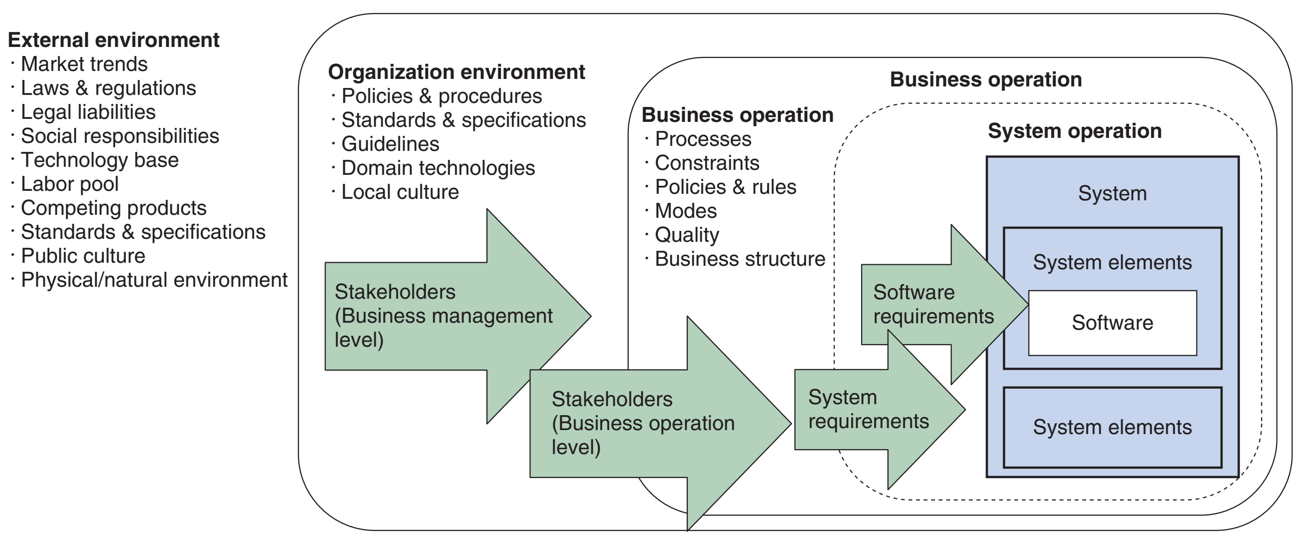

Fig. 2. Areas covered by ISO 29148.

basis for the system and the operation of the system, as shown in **Fig. 2**.

3.3 Software Life Cycle Process Japan Common Frame (SLCP-JCF)

The Software Life Cycle Process Japan Common Frame (SLCP-JCF) was created in 1994 in Japan with the goal of eliminating misunderstandings among stakeholders involved in software development. It provides comprehensive regulation of tasks and roles needed in the areas of business analysis, business design and software-related planning, requirements definition, development, operation, and maintenance as well as various other related activities. SLCP-JCF

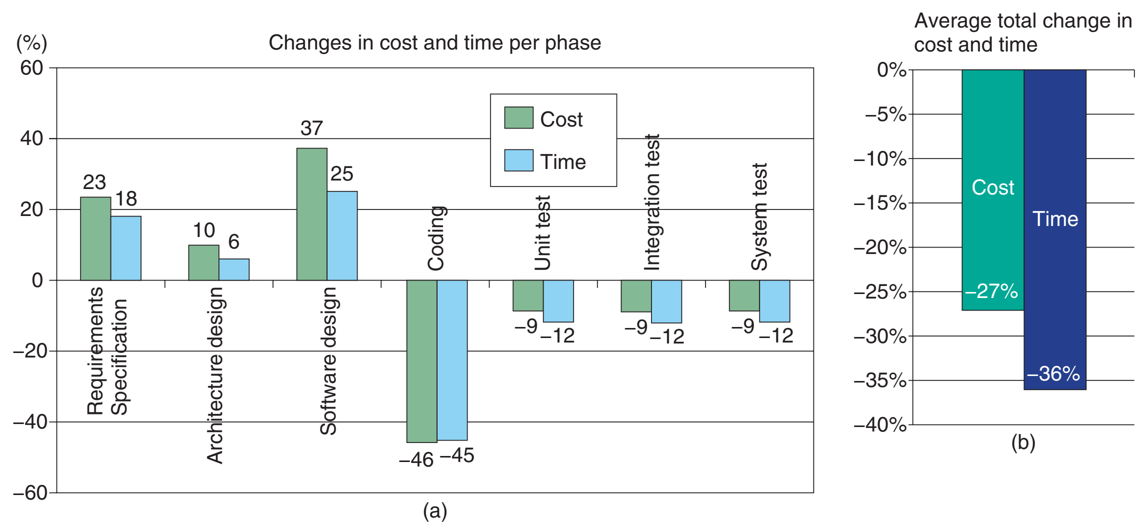

Fig. 3. Cost and time changes of software development in (a) individual development phases and (b) overall.

2007 was published in 2007 and incorporates the idea that there are fundamental issues to be addressed in the process from business and project planning through to requirements definition and enhancing the operation and user processes. SLCP-JCF 2013 was published in 2013, with improvements made to the requirements definition, operations, and service processes.

4. Initiatives related to planning and requirements definition

The NTT Software Innovation Center is studying the following areas related to planning and requirements definition.

4.1 Planning and requirements definition process

As stated previously, there are many stakeholders in the planning and requirements definition process. To achieve smooth communication among them, they must have a common understanding of what sorts of procedures need to be implemented, what steps need to be taken, what inputs and outputs are necessary, and what they each must accomplish with respect to the software development project.

Accordingly, we have been studying planning and requirements definition processes that clarify and standardize the procedures that must be implemented for planning and requirements definition, for defining the styles of deliverables, and for clarifying the division of roles.

Also, as discussed earlier, requirements change during the planning and requirements definition process due to changes in the environment or adjustments made between stakeholders. These changes in requirements also require changes in the schedule or functions to be realized, which have already been agreed upon by stakeholders. Consequently, we are also studying requirements management processes that enable effective management of any changes made to requirements and analysis of the effects of adopting the changes.

We believe that application of these processes we have been studying will help to advance software development projects by achieving mutual understanding among multiple stakeholders.

4.2 Study of methods and techniques used in the planning and requirements definition process

Although procedures and outcomes are decided during this process, the work could proceed more smoothly if certain know-how or skills were applied such as knowledge of writing requirements documents in ways that reduce ambiguity. We are therefore also creating and organizing examples of such know-how and skills.

4.3 Participation in REBOK Working Group (WG)

REBOK has been presented at international conferences related to requirements engineering [6]. The English edition of REBOK is under construction in order to meet the expectations of many people in research and industry. Initiatives to support the use of REBOK are also being undertaken. We are participating in planning for the REBOK WG and are contributing to activities that promote REBOK.

5. Study of the state of development

The improvements achieved at a German company as a result of initiatives they introduced are shown in **Fig. 3**. By performing requirements definition and other upstream processes soundly, they were successful in reducing the cost and time required for later processes, and were able to reduce the overall development cost by 27% and the development time by 36% [7].

We hope to achieve the same kinds of improvements by studying the planning and requirements definition processes and the techniques used in those processes.

In this study, it will be necessary to understand the issues involved in the early process through surveys and other means, and to incorporate input from those involved in actual development.

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Test Automation Technology to Reduce Development Costs and Maintain Software Quality

Haruto Tanno, Xiaojing Zhang, Keiichi Tabata, Morihide Oinuma, and Kazuhito Suguri

Abstract

As companies increasingly strive to reduce the cost of software while maintaining its quality, interest in technology supporting software testing is also increasing since testing is vital to maintaining quality, and it accounts for a large share of the total development cost. Currently a large part of testing is done manually, which is expensive and prone to mistakes and oversights. In this article, we introduce technologies that automatically generate comprehensive test cases and test data from software design documents, as a way to resolve these types of problems.

Keywords: software testing, integration testing, test design

1. Introduction

Software development is divided into processes, as shown in **Fig. 1**. Of these processes, testing is estimated to account for 50% of the total cost. However, most of this work is done manually, so it is an area where there is room for cost reductions. Further, faults that do not get exposed in the testing process will be released to market unresolved, so testing is really the last defense against poor quality. The fact that it is done manually, which results in errors and omissions, presents another problem in ensuring quality.

These issues could be resolved by raising the skill level of testing staff, by increasing the number of people involved, or by delaying delivery to provide additional testing time. As long as the work is done manually, though, errors and omissions cannot be entirely eliminated. In addition, these measures could lead to an increase in costs.

Given these circumstances, the NTT Software Innovation Center is working on a test automation approach that will use computers to replace work being done manually.

2. Current state of software testing support

The objectives of software testing are to verify that software has been implemented according to the design and specifications, and to reduce the number of defects. The testing process mainly consists of the five tasks shown in **Fig. 2**: test planning, test design, test execution, test reporting, and test management. In test planning, issues such as the time frame and allocation of resources for testing are decided based on the overall development plan. Test design involves clarifying the various tests that must be done and designing test cases comprehensively. In test execution, the test data are input for each of the test cases, and the software is run to check that it behaves according to design. In test management, real-time management of the state of test execution is carried out, and the test plan is revised if necessary. When all tests have been executed, the results are summarized in test reporting, completing the process.

We are working to support testing in the design and execution tasks, which are the main tasks in the testing process. Automation of these tasks can be very effective in reducing costs and ensuring quality.

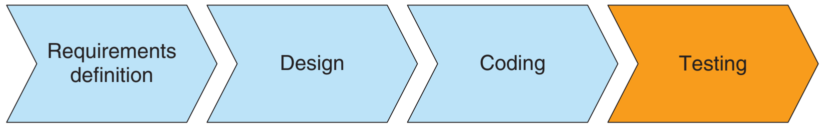

Fig. 1. Overall development process.

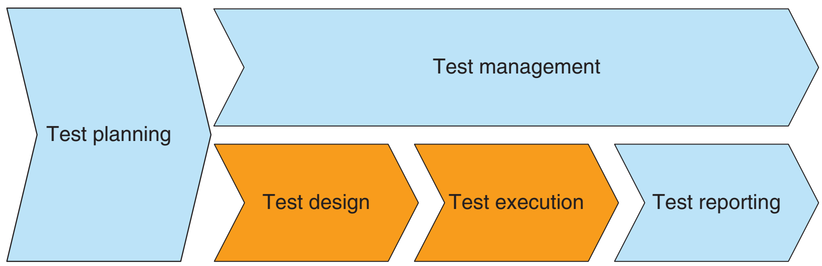

Fig. 2. Testing process.

Currently, a degree of automation has been achieved in test design and execution for unit testing of source code, with tools such as Parasoft Jtest*1 and JUnit*2. However, automation is still inadequate in integration testing, which checks the operation of software combining multiple modules, and in system testing, which tests entire systems.

Various tools are available to support the design of some functionality tests. For example, PictMaster (Microsoft) generates combinations of input values based on a combinatorial method called All-Pair, and Enterprise Architect (Sparx Systems) can generate test cases from module descriptions written in the UML (Unified Modeling Language) specification language. However, there are major barriers to introducing these tools in the development workplace. These barriers include the need for testing staff to have specialized knowledge of the tools and the testing technique which the tools use, and the need to write descriptions in an unfamiliar language.

There are also test execution tools such as Open2-Test, which automates testing of Web applications based on test scripts. However, even when using such tools, the test scripts and test data must still be prepared manually, and thus, there is still much room for further automation.

3. Research vision

Our vision is to reduce the cost and maintain software quality in the testing process by achieving automation of test design and test execution, as shown in **Fig. 3**. One feature of our approach is that it requires only the software design documents, which is the artifact of processes preceding testing, and no other new input needs to be specially created. The software design documents are input, comprehensive test cases are extracted, and test procedures, data, and scripts are generated automatically. This removes the need for testers to have specialized knowledge or to learn a new notation, so it should be possible to introduce it smoothly into the development workplace. Also, by using the test data and scripts generated during the test design, we can link tests with existing test execution tools to implement fully automated testing in one button click, from test design through to test execution.

4. Scope: Integration testing of enterprise applications

Our scope is integration testing of enterprise applications, which involves testing a system to check whether it operates correctly when a web browser, server-side processing, and database are integrated, as shown in **Fig. 4**. For example, when a search is performed using a search screen, the operations to be

*1 Parasoft Jtest: An automated testing tool from TechMatrix Corp.
*2 JUnit: A framework for automating unit testing.

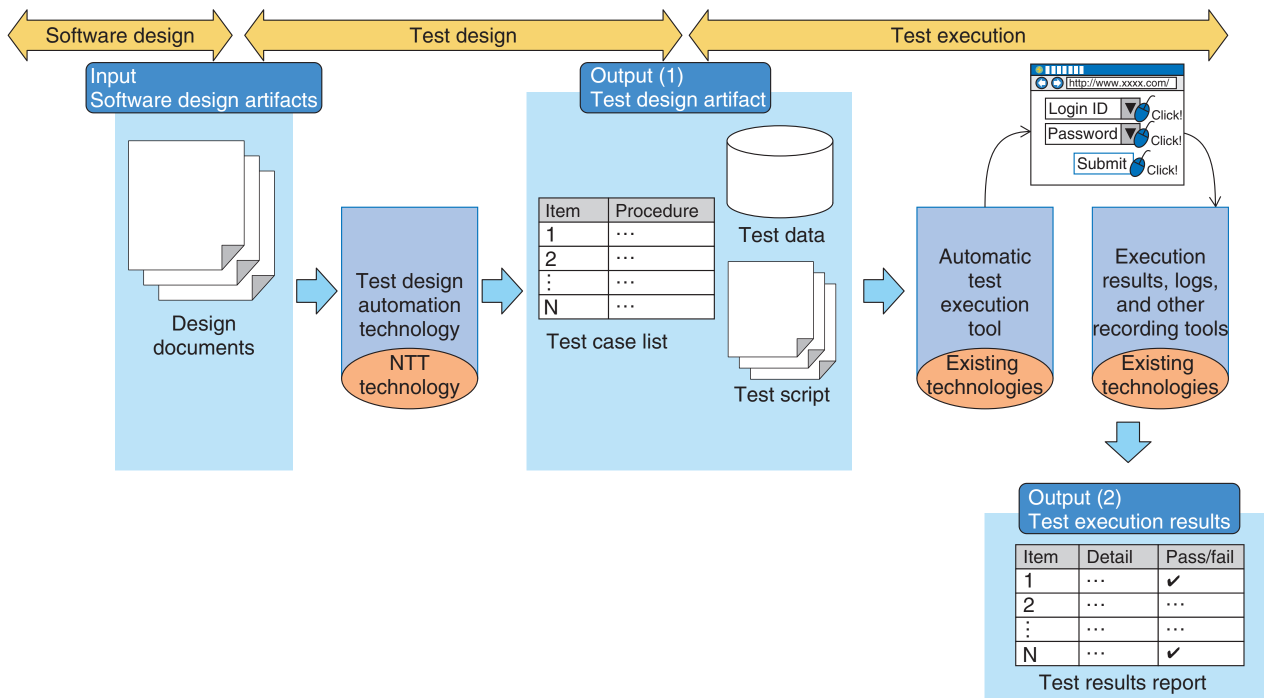

Fig. 3. Research vision.

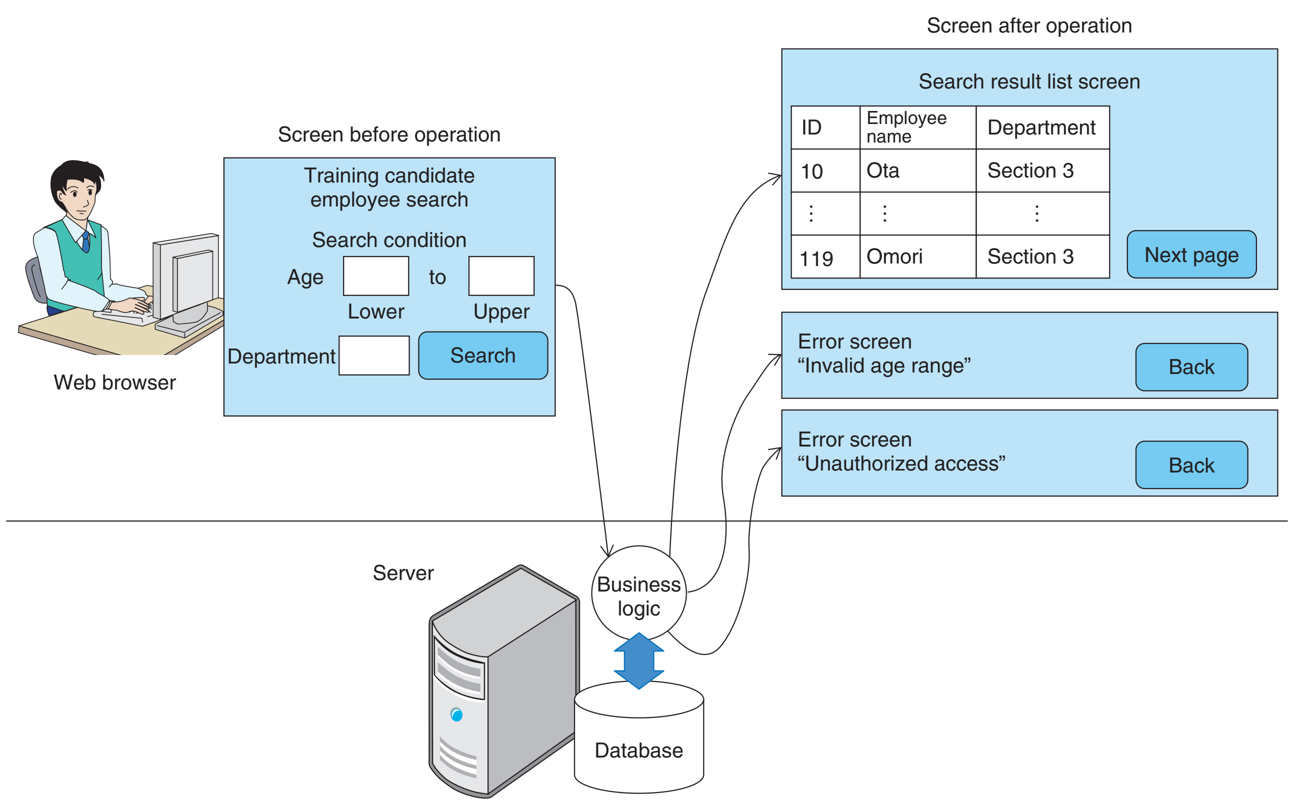

Fig. 4. Integration testing of enterprise applications.

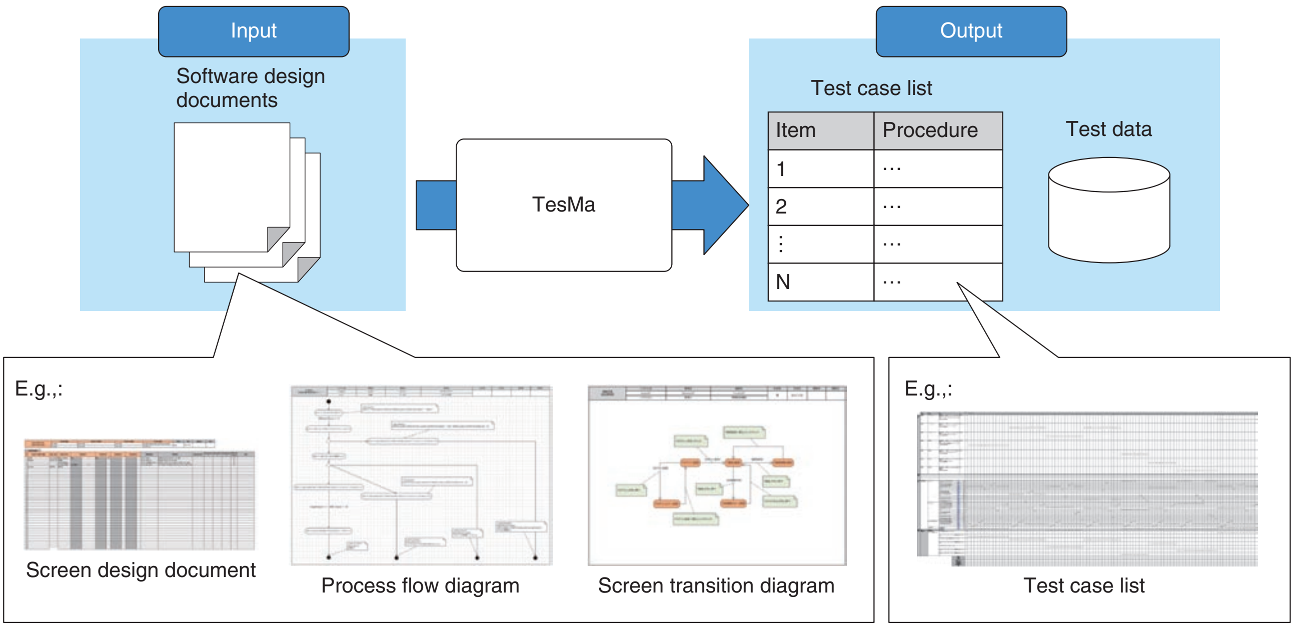

Fig. 5. Integration testing design support tool: TesMa.

checked include the search function to determine if the search occurred normally, as well as the transitions to the search results screen and to error screens. Therefore, in test design, test cases for all variations in operation and inputs, such as login IDs, must be covered without missing any test case which should be done. Test data include values to input on web browser screens and data to be inserted in the database beforehand for each test case, and these data must be created in the test design stage.

5. Integration testing design support tool: TesMa

We propose here an integration testing design support tool called TesMa, which automatically generates test cases and test data required for integration testing of enterprise applications from software design documents, as shown in **Fig. 5**. This capability can reduce the effort required for creating test cases and test data, which was previously done manually by testing staff, to the scope covered by TesMa. This tool extracts a comprehensive set of test cases, so it also avoids omissions that can occur when doing this work manually.

The tool has the following features:

- The input for the tool is a set of design documents written according to some set descriptive rules. These documents are the results of the design process, which is part of the existing development process. Thus, it has the advantage of being easy to introduce into the development workplace.
- The tool generates a comprehensive set of test cases [1] and test data [2], [3] based on processing patterns and input data variations. This helps to prevent omissions from occurring in manually generated test designs and also generates the test data required to execute each test case, so test execution is much easier.

These features enable the test tool to reduce the cost of integration testing, while maintaining software quality through a comprehensive test design.

6. Achievements and future prospects

TesMa technology is already being introduced in NTT Group companies, and its effectiveness in reducing costs while maintaining quality in comprehensive test design is becoming apparent. There are still some issues to be addressed involving the introduction of automatic test-data-generating technology into the development workplace, so some further improvements are needed. This will be a task carried out through consultation with the relevant companies. In the future, we will work on integrating our test design automation technologies with automated test execution tools, and on achieving testing that is fully automated, from test design to execution. We intend to continue to advance our research and development step-by-step toward our goal of reducing costs while maintaining quality.

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R&D Software Development Standards and their Operation

Kumi Jinzenji, Naoki Kasahara, and Takahiro Muraki

Abstract

The NTT Service Innovation Laboratories has created original software development standards for various quality levels from product incubation through to finished commercial products. These standards have been in operation for about four years and have been applied to approximately 200 software products, most of which were provided to business companies of the NTT Group. The developers and researchers in our laboratories have secured the quality and identified the risk of the products before releasing them under the responsibility of the authorized organization. This article describes our latest R&D (research and development) software development standards, including their features, operation, effects, and future developments.

Keywords: software development process, quality, risk

1. Introduction

NTT laboratories develop a variety of software products such as business applications, middleware, and information processing engines. The range of quality levels is diverse, from commercial-level high quality to low-level quality that is sufficient for product incubation. The skill levels of developers are also diverse. Moreover, these products are used in various departments of the business companies, which have different requirements and demands for software quality depending on their business objectives. These differences in our products and how they are used have sometimes resulted in problems after their release to business companies. Defects have been found when products were used in ways not anticipated by the developers, and delays have occurred in dealing with such defects. To solve these issues, it was necessary to establish rules for the organizations developing the software so that they could secure the software quality and identify the associated risk of the products and could take responsibility for implementing the rules. Accordingly, in July 2009, the NTT Software Innovation Center started addressing these issues by creating standards for software development and clarifying the rules for operation of these standards. Generally, software development standards define processes and activities necessary to continually improve product quality or productivity. Our software development standards have additional features over typical standards, with added processes that enable the software product developing organization to take responsibility for product quality and risk. The standards have undergone a few revisions in recent years, but NTT Service Innovation Laboratories settled on the new *R&D* (*Research and Development*) *Software Development Standards* in April 2013.

2. Features of the R&D software development standards

The document describing the R&D software development standards has four parts: the main text of the standards, the forms and samples section, operational guidelines, and additional documents that help readers understand the development standards. All of the processes and activities described in the main text do not necessarily always have to be performed. The processes and activities that are particularly important are marked and selected as a *mandatory* process checklist. Achieving these mandatory processes can

Table 1. Definitions of software quality classes.

Quality class	Definition with respect to suitability for introduction in a business	Example of use	Main expected users
A	Companies can introduce the software product to their businesses largely as-is, and it will be used under a very strict SLA, as with infrastructure or network services for which the service must not stop.	Infrastructure or network service in a company.	Individual consumer and cooperate customer
B	Companies can introduce the product to their businesses as-is, but it will be used in conditions where the application can be restarted to some extent, as with a software package or solution.	Package or solution in a company, disclosure of technology to a related company.	Individual consumer and cooperate customer
C	The product is used in a somewhat limited manner, as with a trial, and is introduced to companies with conditions on its functionality. Some of the architecture will require further improvement or additional testing.	Service trial conducted by company or laboratory.	Individual consumer, cooperate customer and company employees
D	Usage is extremely limited, as with a demonstration of functionality; for installation, there are conditions on functionality and architecture, and testing may require drastic revision.	Demonstration at a company	Company employees
E	No quality evaluation has been done, so it cannot be introduced in a business.	Research use	Researchers

be considered to be conforming to the development standards. The main text of the standards is used as a reference for these mandatory processes. These standards were written based on the assumption that a waterfall development[*1] process is used, but by redefining several mandatory processes, these standards can be applied to agile development[*2] processes as well.

Further, these development standards have four original features not generally seen in existing standards. The first three features were introduced in the predecessor to this research, *Essentials of Software Development for Incubation* [1], and this revision strengthens and improves the original features. The four features are described in detail in the subsections below.

2.1 Introduction of software quality classes

The quality classes defined in the R&D software development standards are listed in **Table 1**. There are five quality classes, A to E. These five quality classes can be broadly divided into three categories. First of all, Classes A and B consist of software that companies can use as-is (that is, the software can be directly introduced into a company's package or service). Further, Class A software has a strict service level agreement (SLA) to ensure the system the software is used in never stops, while Class B software permits restarts of the certain degree.

Second, in Classes C and D the software cannot be used as-is and/or needs further improvement. Class C software requires some quality issues to be improved before it can be released for business use, and Class D software needs to be totally improved or refactored.

Finally, Class E includes products of unknown quality, so this software cannot be introduced in a business in operation.

These quality classes were decided by developers, who considered how the software would be used after being released to business companies.

2.2 Quality requirement to build in and verify with a quality checklist

The R&D software development standards establish 105 items to be checked in a quality class checklist based on quality characteristics and sub-characteristics of ISO/IEC (International Organization for Standardization/International Electrotechnical Commission) 9126, the international standard for the evaluation of software quality. This makes it possible to gain a concrete understanding of work required to build in and verify quality (**Table 2**). The quality checklist provides recommended criteria for each quality class, which is based on building in and verifying quality with business applications. The recommended criteria are general information for the developers but are not mandatory because the product

*1 Waterfall development: A development method in which all functions sequentially pass through several processes to completion. In principle, the previous process is completed before proceeding to the next.

*2 Agile development: A development method in which the item being developed is divided into many small functions, which are iteratively implemented one after another, minimizing the risk due to changes in requirements.

Table 2. Quality characteristics and recommended criteria.

No.	Quality characteristics		Recommended criteria				
			Quality class				
	Quality characteristics	Sub-characteristics	A	B	C	D	E
1	Functionality	Suitability	☆	☆	☆	☆	-
2		Accuracy	☆	☆	☆	☆	-
3		Interoperability	☆	☆	☆	-	-
4		Security	☆	☆	☆	-	-
5		Functionality compliance	☆	☆	☆	-	-
6	Reliability	Maturity (validity)	☆	☆	☆	-	-
7		Maturity (fault convergence)	☆	☆	☆	-	-
8		Fault tolerance	☆	☆	☆	-	-
9		Recoverability	☆	☆	☆	-	-
10		Reliability compliance	☆	-	-	-	-
11	Usability	Understandability	☆	☆	-	-	-
12		Learnability	☆	☆	☆	-	-
13		Operability	☆	☆	☆	-	-
14		Attractiveness	-	-	-	-	-
15		Usability compliance	☆	-	-	-	-
16	Efficiency	Time behaviour	☆	☆	☆	☆	-
17		Resource utilization	☆	☆	☆	☆	-
18		Efficiency compliance	☆	-	-	-	-
19	Maintainability	Analyzability	☆	☆	☆	-	-
20		Changeability	☆	☆	-	-	-
21		Stability	☆	☆	-	-	-
22		Testability	☆	-	-	-	-
23		Maintainability compliance	-	-	-	-	-
24	Portability	Adaptability	☆	☆	☆	-	-
25		Installability	☆	☆	-	-	-
26		Co-existence	☆	☆	-	-	-
27		Replaceability	☆	☆	-	-	-
28		Portability compliance	-	-	-	-	-

Examples of conformance points for recoverability

(1) After a fault occurs, the software is able to return to the initial statebefore processing started, and perform the processing over again.

(2) Data can be recovered accurately using checkpoints or another mechanism after a fault occurs, and processing can resume within the required recovery time.

(3) The affected processes can be isolated when a fault occurs, and other processes can continue to operate.

(4) Traces, logging, dumps, or other records for analyzing the fault can be used when a fault occurs.

quality requirement depends on the characteristics of each software product and on the developers' customers. It is important that all developers share the checked result and recognize which quality characteristics are included in the development requirements.

2.3 Documentation according to quality class

The skill levels of developers at NTT laboratories are quite diverse, so the development standards provide sample documents with levels of descriptions corresponding to high-quality products of Class B and above, including a basic design document, a project planning document, and a release readiness document (the three principal documents). Some examples of items included in a project planning document are listed in **Table 3**. General-development-standard documents typically only describe items in simple, general, and broad terms, so it is difficult to create concrete and usable documents for a high-quality-class product without adequate development experience, knowledge, and skills. Thus, for the R&D software development standards, we make it possible to achieve the desired quality class regardless of the skill set available by including many possible activities, metrics, and evaluation methods. When a product with a lower quality class is developed, only items in the samples up to the target quality level need to be followed, and the rest of the items can be deleted. When we evaluated the description levels in documents within NTT laboratories, we found that the level of description seemed to correspond to the quality level better when using the Class B samples than when using the Class C samples.

2.4 Mandatory processes based on quality class

These development standards define mandatory processes according to the target quality class (**Table 4**). Mandatory processes can be broadly divided into three categories: two project reviews, creation of the three principal documents, and development management. We have made it possible to select three levels of process sets for each of these categories according to the target quality level.

Table 3. Example descriptions of verification methods and metrics in a project planning document.

Process	Functional design	Detailed design	Coding	Unit testing	Integration testing	System testing	Field testing
Verification method	Software review			Software testing			
	Review	Review	Code review	- White box test - Black box test	- Black box test - Regression test - Recovery test	- Black box test - Regression test - Time and resource efficiency test - Recovery test - Load test - Stability test - Multi-hardware test - Manual test	- Black box test - Regression test - Operational test - Non-functional tests
Metrics	- Review frequency and time - Number of errors - Number of comments	- Review frequency and time - Number of errors - Number of comments	- Review frequency and time - Number of errors - Number of comments	- Coverage - Number of test cases - Test density - Number of bugs - Bug density	- Number of test cases - Test density - Number of bugs - Bug density	- Number of test cases - Test density - Number of bugs - Bug density - Fault convergence	- Number of test cases - Test density - Number of bugs - Bug density - Fault convergence

Table 4. Mandatory processes.

Mandatory processes		Class A	Class B	Classes C and D
1	Project review	Mandatory		
2	Create three principal documents	Mandatory (level of description according to quality class)		
3	Development management	Mandatory	Partially mandatory	Not mandatory

Mandatory processes concerned with two project reviews are common to all quality classes in order to allow the software development organization to take responsibility for their project risk as well as their product risk and product quality. In addition, the first project review is done by an organization manager to confirm project baselines and decide whether or not to continue the project. The second project review is also done by an organization manager to verify the product quality and decide whether the product is ready for release. Creation of the three principal documents is also common to all quality classes, but the description details depend on each project. Furthermore, parts of the development management process can be omitted, depending on the quality class. We also define mandatory processes for existing products, which refers to software products developed before our R&D software development standards were in operation. Specifically, for *existing* products, most of the mandatory processes are activities centered on the second project review (release decision).

3. Operation of the R&D Software Development Standards

In order to avoid ending up with standards that are only a mere façade and the possibility that they will become obsolete, the R&D software development standards are operated using a Plan-Do-Check-Act (PDCA) cycle (**Fig. 1**). The core activities of this PDCA cycle are described below.

3.1 Operational rule provisions

The following two operational rules were authorized in NTT Service Innovation Laboratories when establishing the R&D software development standards.

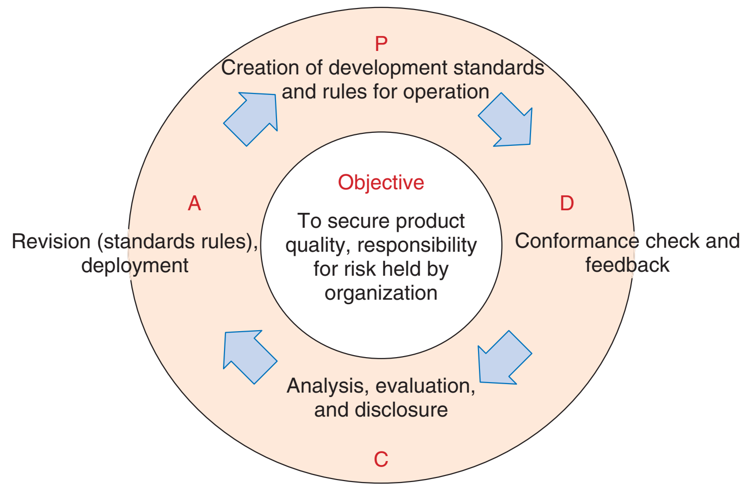

Fig. 1. PDCA cycle.

(1) The R&D software development standards shall be applied to products intended for use in the business companies and products intended for use in service trials for NTT customers, and they shall achieve one of the four quality classes from A to D.

(2) The top managers of the software developing organization shall conduct two project reviews on cases where the R&D software development standards are being applied.

Rule (1) clarifies what is subject to the development standards and the target quality class, and Rule (2) ensures that the organization is taking responsibility for the quality and risk associated with products.

In the first project review, the managers holding responsibility in the organization check the project scope, QCD (quality/cost/delivery) baseline, as well as the risk. In the second project review, they make a decision on release after checking the product quality, provision conditions, and risk.

3.2 Standards compliance check and feedback

The standards compliance check involves comparing checklists submitted by developers with evidence to see whether the mandatory processes are being achieved. Currently, this procedure is being done by the development standards operation group. The standards compliance check is done immediately after the two project reviews. The results of the check are brought back to developers by the development standards operation group in a meeting, which is used as a setting for communication between the software developer and the operation side that is also creating the development standards. These activities ensure that all projects can be monitored in the laboratories and thus avoid having standards that are mere façades.

3.3 Analysis and evaluation of the state of operation

Approximately once every six months, overall trends in the state of operation are analyzed, evaluated, and disclosed. These results are brought back so they can be used in subsequent actions of each software development project.

3.4 Revision and deployment

The development standards need to be updated when issues arise. To maintain the quality of standards documents during the updating process, reviewers selected within each organization apply the development standards. Trials are sometimes conducted to examine the effects of new policies on R&D activity. Reviews and trials have also been conducted when updating the R&D software development standards in order to check whether there are any issues with their operation or effects. Then a formal meeting is held to authorize the development standards, and they are deployed through presentations and by publishing the standards documents on a dedicated website.

4. Application results, effects, and future issues

The R&D software development standards have been in operation since April 2013, and as of the end of July 2013, they have been applied to approximately 30 cases. When the preceding development standards are included, the number of cases they have been applied to exceeds 200. We now have an understanding of the quality of software products that have been introduced into the business companies, so the objectives of this initiative have been achieved. A task for the future is to quantitatively evaluate the efficiency of operation and the validity of our strategies towards securing software quality and recognizing risk.

It is important how both the creation of software development standards and their operation are considered. We will expand the implementation of our R&D software development standards and our operational know-how to organizations within the NTT Group.

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Optical Node and Switch Technologies for Flexible and Economical Networks

Mitsunori Fukutoku, Yasuhiro Sato, and Senichi Suzuki

Abstract

Network traffic is increasing rapidly, and high-performance optical nodes are needed to build networks that can handle it with flexibility and efficiency. This article introduces the latest technical trends in this area, including reconfigurable optical add/drop multiplexer (ROADM) technology, which is used to implement advanced optical nodes, and optical switching technology, which is the basis for the primary devices used for ROADM.

Keywords: ROADM, optical switch, optical node

1. Introduction

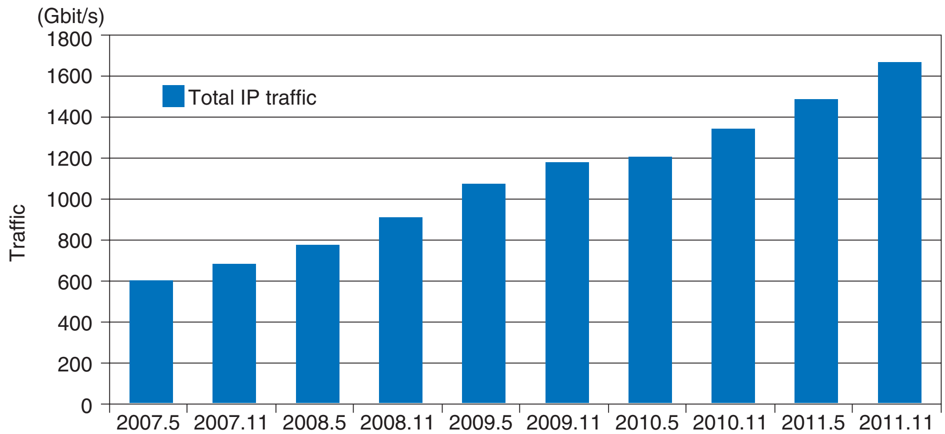
The Internet and various other network services were developed based on their use via personal computers (PCs). However, with the spread of smartphones and tablet PCs, such services have become even more common and have permeated broadly into our lives. NTT's research laboratories have continuously engaged in research and development (R&D) of optical networks as a base technology for providing network services. Domestic and international Internet traffic figures are shown in **Figs. 1** and **2** [1], [2]. As network services have expanded, traffic has increased by a factor of approximately 1.4 each year. In the future, the use of smartphones and tablet PCs will continue to spread, but various other items in our daily lives will also become *networked* devices, or in other words, devices that are always connected to the network and that generate data without human intervention, and communicate machine-to-machine (M2M). When such an environment is realized, the data traffic passing through optical networks will surely increase further still. It has been estimated that global traffic on the Internet will triple over the five-year period from 2012 to 2017 [2]. Such rapid increases in network traffic will require optical network systems, especially long-haul and metropolitan area systems that concentrate data traffic, to accommodate the yearly increases with flexibility, efficiency, and economy.

The latest optical transport technologies achieve ultrahigh-speed communication at 100 Gbit/s on a single channel using digital coherent technology by combining coherent transmission, which uses wave properties widely used in wireless networking, and digital signal processing (DSP) technology [3]. In addition to conventional high-density optical wavelength division multiplexing (WDM), which uses fixed frequency intervals, research has begun on the use of optical frequencies with higher information density for high-capacity, ultrahigh-speed optical network systems [4].

2. Advanced optical node technology for optical networks

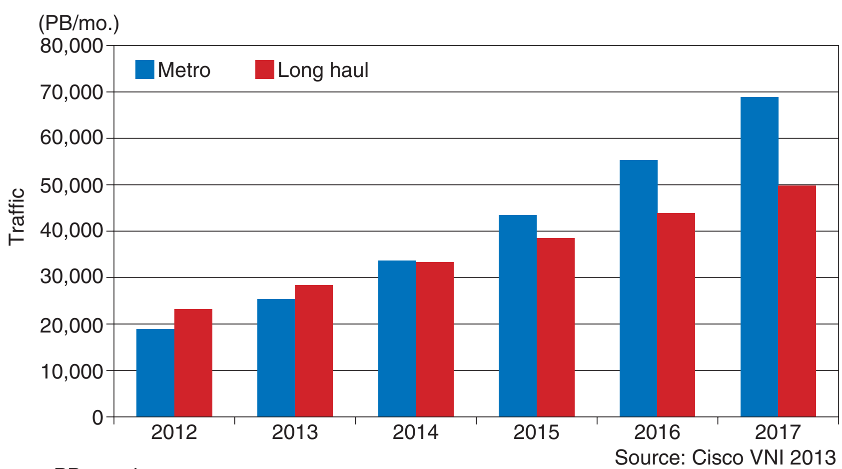
2.1 WDM technology

Similarly, optical cross-connect technology uses high-density WDM technology to achieve flexible and economical optical networking systems. The changes in optical network system architectures over the years are shown in **Fig. 3**. These networks began with point-to-point connections, which realized high capacity through optical signal WDM, and progressed



FY: fiscal year
IP: Internet protocol
MIC: Ministry of Internal Affairs and Communications

Fig. 1. Internet traffic in Japan.



PB: petabytes
VNI: Visual Networking Index

Fig. 2. Global Internet traffic.

through single-ring configurations using reconfigurable optical add/drop multiplexers (ROADM) able to add and drop individual optical signals, to the current economical optical network systems in multi-ring configurations using multi-degree ROADM.

An illustration of ROADM is shown in **Fig. 4**. Input optical signals can be dropped or added, and paths can be selected without converting optical signals to electrical signals. This allows ring network systems to be constructed economically. An example of a basic two-path ROADM configuration is shown in Fig. 4(a). Optical multiplexers and demultiplexers separate multiple wavelengths, and an optical switch adds or drops signals according to the wavelength. Signals can be added and dropped without converting them from optical to electrical, enabling high-capacity optical paths to be provided economically. The optical switches used for ROADM use quartz planar lightwave circuit (PLC) technology, which was first used in components such as optical multiplexers, demultiplexers, and splitters, and is very reliable since there are no moving mechanical parts [5].

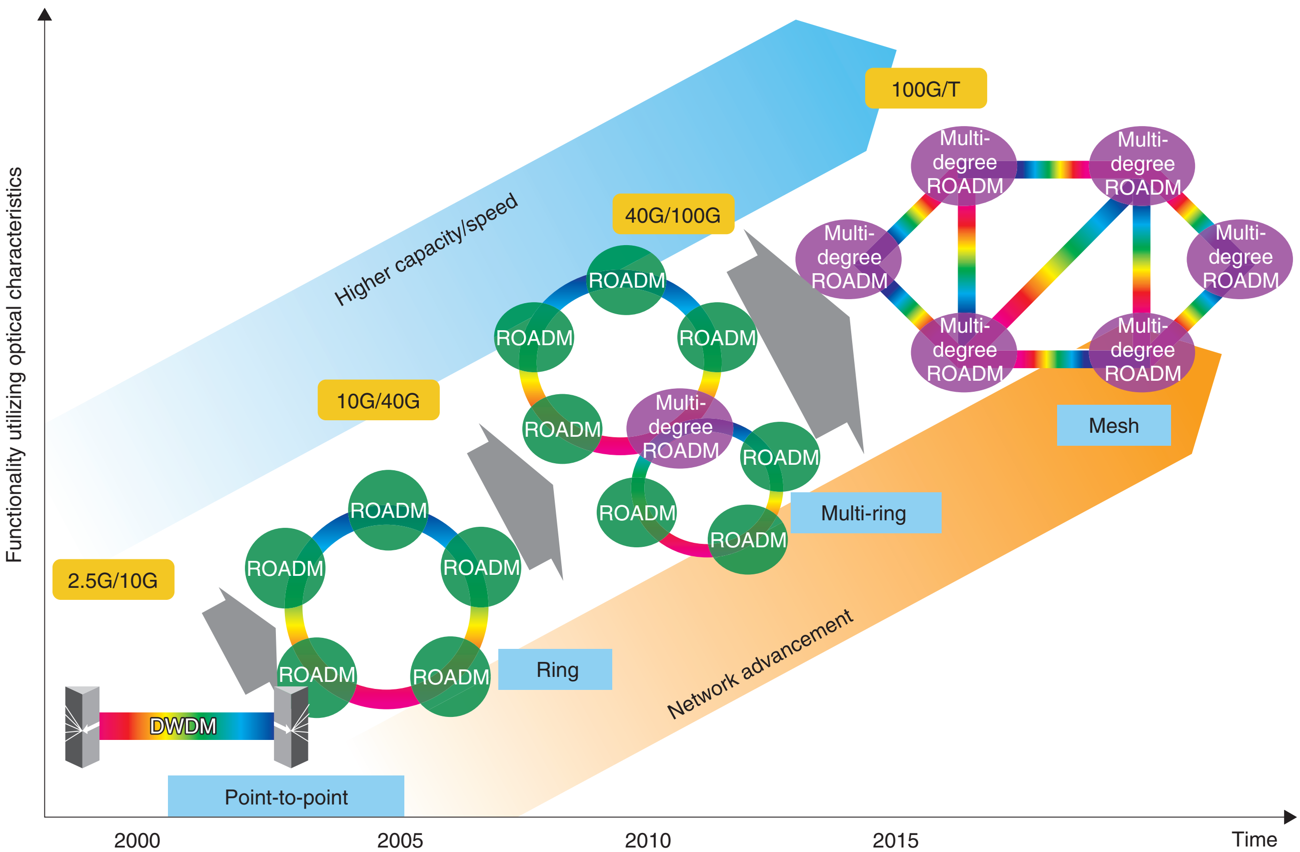


Fig. 3. Optical Network Development.

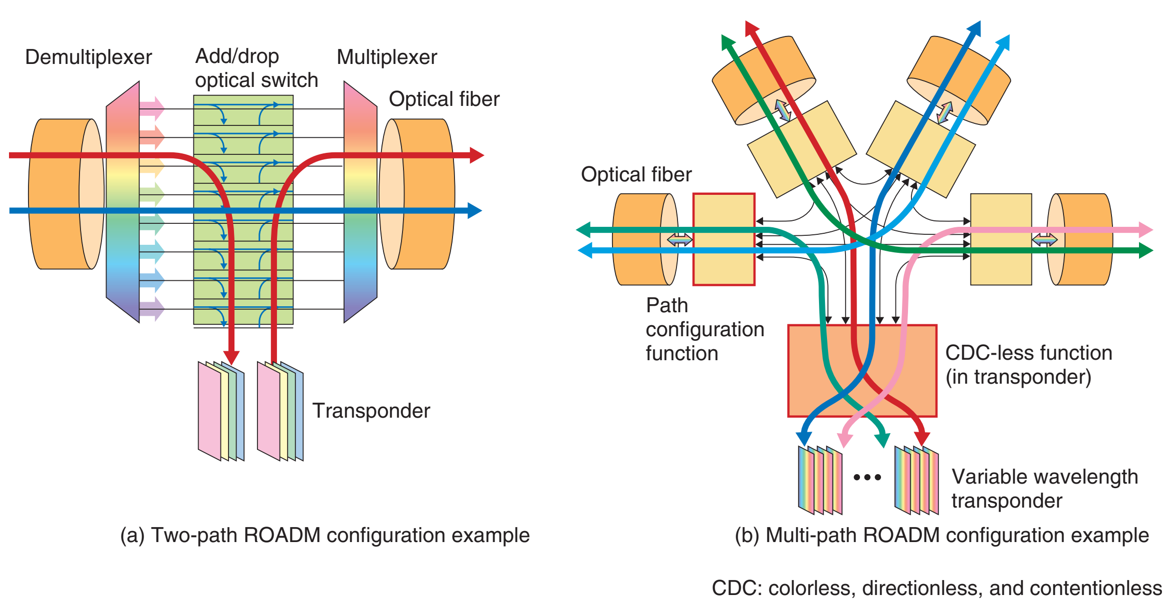


Fig. 4. ROADM configuration examples.

2.2 CDC technology

An example of a multi-port ROADM configuration implementing a multi-ring mesh network is illustrated in Fig. 4(b). As shown in the figure, with multi-port ROADM, signals carried by multi-path fibers are not converted to electrical signals, and paths can be changed, dropped, or added (optical cross-connect operations) according to wavelength. Currently, in addition to path changes, drops, and adds, even more advanced optical cross-connect operations using ROADM are being studied. With ROADM thus far, the wavelength or path has been fixed for each transponder (the optical transmit/receive interface). Colorless, directionless, and contentionless (CDC) functions are being studied that will enable implementation of flexible and economical network systems in which wavelengths and paths can be configured freely, faults can be switched out by wavelength, and optical paths can be configured remotely. ROADM using CDC functions is called CDC-ROADM. Here, *colorless* refers to functionality that allows input and output wavelengths on ports to be allocated freely through the addition of a variable wavelength function to the demultiplexing and multiplexing filters. The transponder wavelengths can be changed without having to physically switch connections. *Directionless* refers to functionality whereby the directions of input and output paths can be configured freely rather than being fixed by creating switches comprised of transponders. *Contentionless* refers to functionality in optical nodes implementing the previous two functions whereby any wavelength can be allocated to other paths with no restrictions on wavelength configuration. These functions enable signals to be configured freely. CDC-ROADM is described in detail with configuration examples implementing this functionality in the Feature Article entitled, "Next-generation Optical Switch Technologies for Realizing ROADM with More Flexible Functions [6]."

2.3 WSS technology

Currently, the main device used in multi-degree ROADM as a path-configurable switch is the wavelength selective switch (WSS) utilizing spatial optics technology. Wavelength-multiplexed input signals are demultiplexed using a diffraction grating, and add, drop, and path selection operations are implemented without converting signals from optical to electrical. This is done using spatial light modulators such as microelectromechanical systems (MEMS) mirrors or liquid crystal on silicon (LCOS) devices to configure paths by wavelength. It is now possible to implement multi-path path selection using MEMS mirrors or LCOS, and multi-ring optical networks have been implemented with the development of this optical switching technology. Details of WSS are introduced in the Feature Article entitled, "WSS Module Technology for Advanced ROADM [7]."

Several methods for implementing CDC functionality have been studied. One such method uses multicast switches using PLCs; these switches have a simple structure that can be implemented in compact form. The Feature Article entitled, "Multicast Switch Technology that Enhances ROADM Operability [8]," introduces the functions enabled in transponders.

3. Topics covered in Feature Articles

As discussed above, advances in ROADM are necessary in order to implement networks that are able to deal with the increasing traffic flexibly and economically. Currently, NTT Network Innovation Laboratories, NTT Microsystem Integration Laboratories, and NTT Photonics Laboratories are collaborating on optical-switch R&D in order to realize highly advanced ROADM. These Feature Articles introduce the initiatives underway at these three laboratories. First, CDC-ROADM, which is necessary for highly operable and reliable optical networks, is described using practical examples. Then, WSS, which realizes the per-wavelength path configuration function of ROADM, is introduced. MEMS WSS is taken as an example of WSS, and technologies required to implement it are explained, including optical design, implementation design, and control function technologies. Finally, we describe a multicast switch technology that uses PLC technology to implement CDC functions.

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Next-generation Optical Switch Technologies for Realizing ROADM with More Flexible Functions

Yohei Sakamaki, Takeshi Kawai, and Mitsunori Fukutoku

Abstract

Colorless, directionless, and contentionless reconfigurable optical add/drop multiplexing (CDC-ROADM) has been attracting considerable attention recently for its potential use in constructing cost-effective photonics transport networks in long-haul and metro area transmission systems and improving their operational flexibility. This article describes the latest trends in the research and development of optical switch technologies for realizing CDC-ROADM.

Keywords: ROADM, optical switch, WSS

1. Overview of multi-degree ROADM

Reconfigurable optical add/drop multiplexing (ROADM) has brought new flexibility and scalability to conventional static photonic transport networks. Multi-degree ROADM was developed after the introduction of basic 2-degree ROADM in order to realize mesh-based network topologies [1].

We first describe here the multi-degree ROADM node configuration. A 4-degree ROADM node configuration connecting two ring networks is shown in **Fig. 1** as an example. The incoming wavelength-division-multiplexing (WDM) signals from the degree-1 input fiber are delivered to the drop-side optical switch. If these signals are to be transferred to other ROADM nodes, the optical switch selects the optical path to degree 2 (red line), degree 3 (orange line), or degree 4 (green line) for each wavelength signal. When the transponders at this node receive these signals, the optical switch selects the drop path (purple line) to deliver the signals to another optical switch, namely a transponder aggregator (TPA). Then, the TPA allocates the input signals to each desired transponder for each wavelength channel. On the add side, the output signal from the transponder is routed to an add-side optical switch by way of an add-side TPA. The add-side optical switch collects add signals and signals that pass through this node and then launches them into the output fiber.

Today, in addition to the multi-degree function, colorless, directionless, and contentionless (CDC) functions are expected to play important roles in achieving more flexibility in terms of wavelength routing and wavelength assignment [2].

2. Optical switch technologies for realizing CDC-ROADM

Next, we describe in detail the optical switch technologies required for constructing a CDC-ROADM node.

2.1 Colorless function

The freedom provided by the colorless function is that the optical signal wavelength is not fixed by the physical input/output port of the TPA and can be set using software control. The colorless function is shown in **Fig. 2** in more detail. Note that the figure shows the optical switches of degrees 1 and 3 extracted from Fig. 1(b).

The switch structure of the TPA without the colorless function is shown in Fig. 2(a). To connect the optical paths of the WDM signals between the input/output fibers of each degree and the transponders at

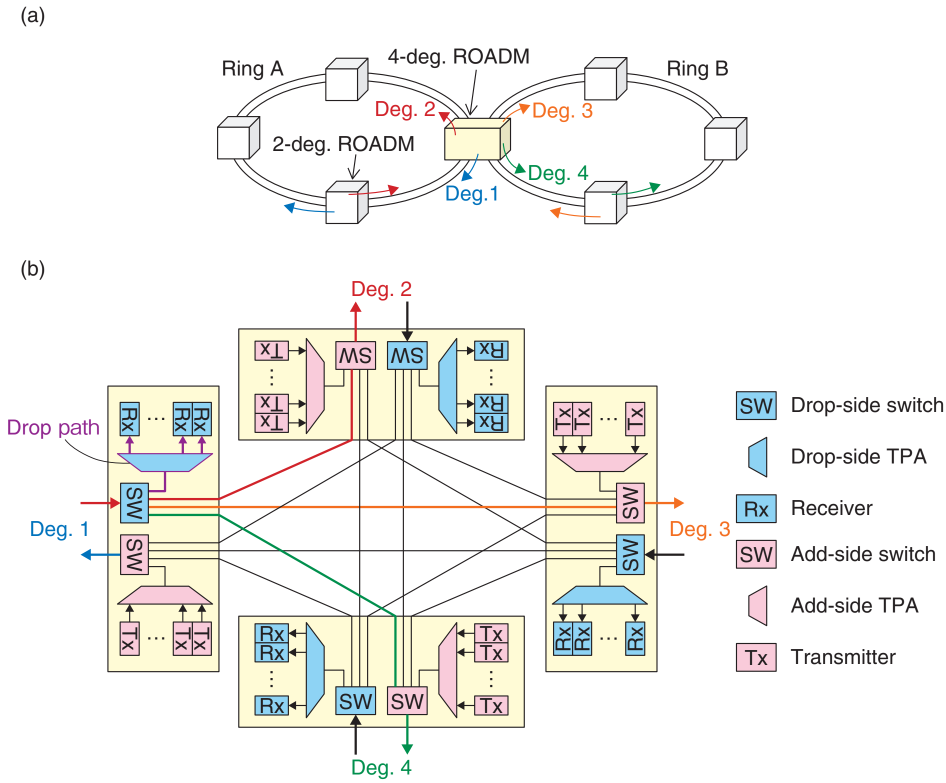

Fig. 1. (a) Example of multi-ring network and (b) 4-degree node configuration.

the ROADM nodes, the TPA must select the signal path to the desired transponder for each wavelength channel. Since a conventional TPA consists of an arrayed-waveguide grating (AWG) where the output port assignment is determined by the wavelength of the optical signal, the signal wavelength of the transponder is also determined by the port connected to the TPA. This switch structure causes certain problems with respect to operation. For example, if the signal wavelength of the transponder needs to be changed from λ1 to λ2 to deal with a traffic change, the connection port of the TPA must also be changed. This connection port change involves tasks that must be performed manually in the field at the site where the node equipment is located, and this reduces the flexibility of the network operation.

This restriction can be lifted by using a wavelength-selective switch (WSS) instead of an AWG at the TPA. The switch structure of the colorless TPA is shown in Fig. 2(b). The WSS can deliver the input WDM signals to any output port for each wavelength channel. Moreover, these output port assignments can be changed under software control. Therefore, by

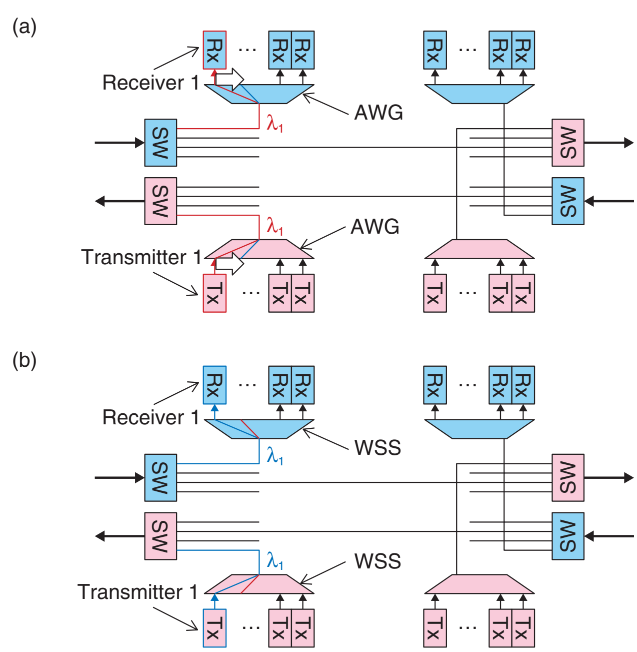

Fig. 2. (a) Colored TPA and (b) colorless TPA.

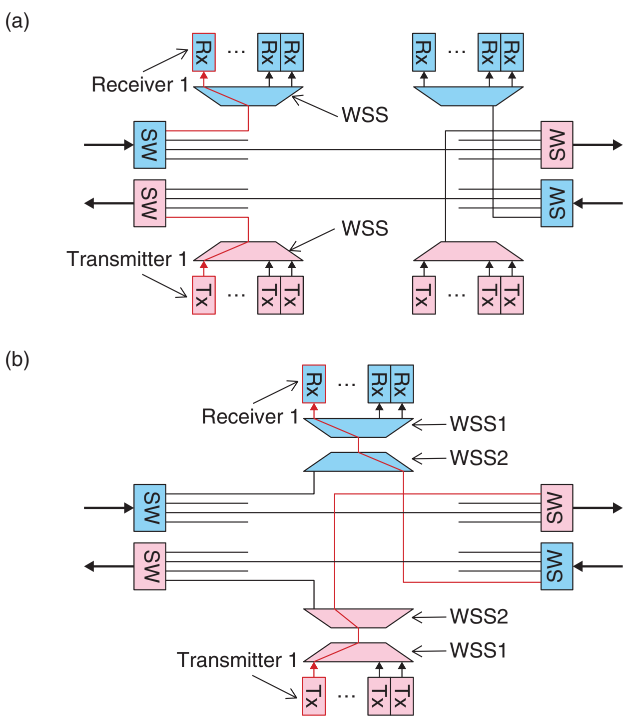

Fig. 3. (a) Directed TPA and (b) directionless TPA.

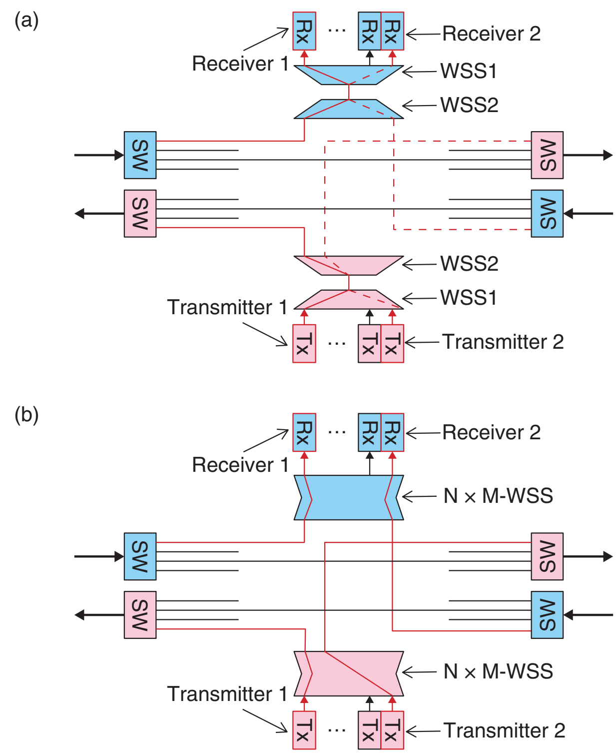

Fig. 4. (a) Contention TPA and (b) contentionless TPA.

using the WSS, we can change the wavelength path setting without having to do any work in the field. This added function is called colorless because the path between the transponders and the input/output fiber is not fixed by the wavelength (= color) of the optical signal.

2.2 Directionless function

A directionless function provides the freedom to connect the signal path from the transponder to any input/output fiber by connecting the TPA to every degree of the ROADM node. The switch structure of the directed TPA is shown in **Fig. 3(a)**. Since commercially available WSSs have a 1 × N switch structure, the signal path from the transponder can be connected to only one input/output degree. This restriction presents no problem for a conventional 2-degree ROADM, but it imposes an operational limitation on a multi-degree ROADM.

As shown in **Fig. 3(b)**, the opposite WSSs provide a way to overcome this restriction. WSS1 aggregates the signals from the transmitters (or to the receivers), and then WSS2 connects them to the desired input/output fiber for each wavelength channel. This added function is referred to as directionless. The directionless function provides numerous benefits. For example, a colorless and directionless ROADM allows spare transponders to be shared among all the wavelength channels and degrees in the node.

2.3 Contentionless function

A contentionless function removes the wavelength restriction from the TPA. This function allows multiple wavelength channels of the same wavelength at a single TPA. Thus, a transponder can be assigned to any wavelength as long as the number of wavelength channels with the same wavelength does not exceed the number of degrees.

The switch structure of a TPA with colorless and directionless functions and CDC functions are shown in **Figs. 4(a)** and **(b)**, respectively. In Fig. 4(a), multiple wavelength channels with the same wavelength cannot be input because a single fiber connects two WSSs (WSS1 and WSS2). This TPA structure imposes a restriction; that is, when the path of an optical signal with a wavelength of λ1 is connected between transponder 1 and the input/output 1-degree fiber, the path of the signal with a wavelength of λ1 cannot be connected between transponder 2 and any input/output fibers, even those other than the 1-degree fiber.

The contentionless function removes this wavelength restriction from the TPA. A TPA with the contentionless function is shown in Fig. 4(b). To realize this function, we expect to see the development of an M × N WSS, where one of the M input ports can be connected to any of the N output ports. However, M × N WSSs are not yet commercially available because of the high level of difficulty involved in achieving them. Thus, multi-cast switches have been attracting considerable attention as an alternative.

3. Recent trends in WSS development

Next, we provide a brief introduction to recent R&D activities related to the development of the WSS, which is essential if we are to realize CDC-ROADM.

(1) High port count: We must increase the number of output ports of the WSS if we are to increase the number of degrees and transponders in the ROADM node. The 1 × 2 and 1 × 4 WSSs were developed at an early stage, and the 1 × 9 WSS is now commercially available. To realize a large-scale node such as that required for 8-degree ROADM, a target of 20 or more output ports is expected.

(2) Downsizing: The equipment size increases as the number of optical switches in the ROADM nodes increases. Thus, downsizing the WSS module is an important issue in terms of realizing more functional nodes within a limited equipment size. Now, the realization of a two-in-one concept whereby a single module has the same functionality as two separate WSSs has become the development goal.

(3) Performance improvement (wider bandwidth and lower insertion loss): Successive optical filtering as a result of cascading ROADM nodes with the WSS has led to a reduction in the available bandwidth and an increase in optical signal loss. This performance degradation becomes more significant with increases in the number of WSSs that an optical signal passes through. Therefore, to suppress the degradation effect caused by introducing CDC functions into ROADM nodes, it is important to improve such optical characteristics as the bandwidth and the insertion loss of a single WSS. For example, we must achieve a wider bandwidth so that the performance degradation caused by filtering can be almost halved compared with that of a conventional WSS.

(4) Flex grid: The elastic optical network has been attracting considerable attention regarding the construction of next-generation optical communication systems with higher spectral efficiencies [3], and there has been extensive research and development activity with a view to achieving this concept. In such networks, it is essential to realize a flex grid where the frequency bandwidth occupied by a single wavelength channel can be flexibly adjusted. Thus, it is also necessary for the WSS to be able to adjust the channel bandwidth during operation.

4. Activities of NTT laboratories

Finally, we describe the recent activities of NTT laboratories in relation to CDC-ROADM. We proposed a CDC-ROADM node configuration composed of a 1 × 43 WSS and an 8 × 12 MCS based on silica-based planar lightwave circuit (PLC) technology. These optical switches were first developed in our laboratories. Our proposed approach will contribute to a substantial reduction in the size and cost of the CDC-ROADM node equipment. In addition, we reported the results of a transmission experiment showing that the introduction of these optical switches imposed no significant penalty on 100G PDM-QPSK (polarization-division-multiplexing quadrature phase-shift keying) signal transmission systems [4].

5. Future development

The traffic generated by the expanding use of various new services continues to increase. To deal with the larger amounts of traffic while maintaining or lowering network costs, we need to ensure that ROADM nodes to achieve greater flexibility, for example, by providing a CDC function. Meanwhile, to satisfy the various demands caused by the extension of the ROADM application range, it is important to achieve the optimal balance between node scale and cost. Thus, optical switches with more input/output ports and flexible connections will play important roles in achieving such optical nodes. In the future, we believe that the sophistication and miniaturization realized by integrating additional functions such as optical channel monitoring into optical switches will steadily progress once a WSS with a higher port count or an M × N WSS becomes commercially available.

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WSS Module Technology for Advanced ROADM

Yuzo Ishii, Naoki Ooba, Akio Sahara, and Koichi Hadama

Abstract

Wavelength selective switches (WSSs) are the key to implementing advanced reconfigurable optical add/drop multiplexing (ROADM) with colorless- directionless-contentionless (CDC) functionality, but a complex module (subsystem) requires a skillful balance combining optical, mechanical, and control design technologies. This article discusses technical issues in implementing WSS from optical, mechanical, and control perspectives.

Keywords: WSS, MEMS, LCOS

1. Introduction

Wavelength selective switches (WSSs) are components used in wavelength division multiplexing (WDM) optical networks to route signals between optical fibers according to wavelength. The basic functions of WSSs are shown in **Fig. 1**. The main functions are switching by port switches, which are connected to output ports for each wavelength in the input WDM signal, and attenuation, in which the power level of transmitted light is adjusted for each wavelength. The hardware is divided into an optics module and a control module. A WSS has many input and output ports, so a bulk diffraction grating is used, which is able to multiplex and demultiplex signals at the same time in a single port. Active elements include a spatial light modulator device, for example, a microelectromechanical systems (MEMS) mirror [1], or a liquid crystal on silicon (LCOS) device, which can change the reflected direction of the input light beam. Beam pathways are different for each combination of wavelength and port, so beams cross each other within the WSS optical module. All of these pathways must be stable and have low losses, so the design of beam paths and spatial light modulator drivers and controls is very important in implementing appropriate attenuation. In addition to driving and controlling the switching element (spatial light modulator), the control module must detect module faults and errors, perform monitoring and control for coordination with higher-level systems, and provide a user interface.

Technical issues in implementing WSSs are discussed below from the perspectives of optical, mechanical, and control (electronic monitoring and control) design.

2. WSS technical issues

2.1 Optical design

The optical system for a WSS can be broadly divided into two sections: the wavelength section, which separates the input wavelengths using a diffraction grating, and the switch section, with its array of ports. The wavelength section design is basically a confocal optical system with the beam waists of the fiber end and MEMS mirror (or LCOS device) end. Wavelengths are separated spatially, so the configuration is similar to a high-resolution spectrometer. To achieve a wide transmission bandwidth, the beam diameter must be small at the MEMS mirror. However, this also reduces the depth of focus, so a meniscus lens or prism can be added for image correction.

The switch section design differs depending on the type of switch element used. A comparison between MEMS mirrors and an LCOS device is shown in

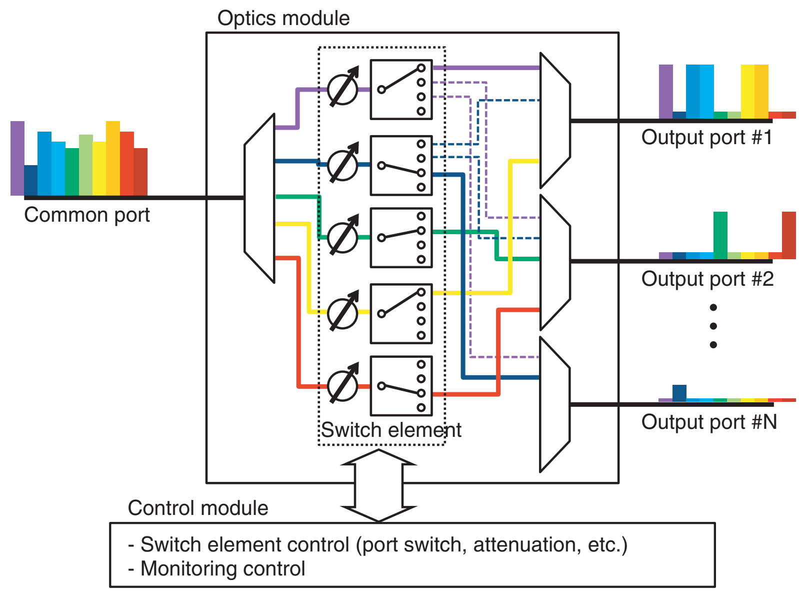

Fig. 1. Basic functionality of WSS.

Fig. 2. With MEMS mirrors, it is more difficult to increase the size of the MEMS mirrors than to achieve a larger rotation angle, so the optical system for the switch section is divided into a front end and a back end. The front end generates a beam diameter that suits the size of the MEMS mirror. A confocal optical system, symmetric on either side of the diffraction grating, is generally used for the back end. For attenuation, optical axes are intentionally offset by rotating the MEMS mirror perpendicular to the switch face (wavelength face).

By contrast, with an LCOS device, instead of the advantage of providing a large reflection surface on the order of millimeters, the device generates diffraction losses (excessive losses) using a large diffraction angle. Thus, when an LCOS device is used, the switch section can be implemented with just a 2-f optical system* for the front end. This configuration may seem simple, but it is inseparable from the wavelength section, so there are many design constraints. LCOS devices are also polarization dependent, which presents other difficulties such as the need for a polarization diversity configuration.

With these forms used as a base, an optimal design must satisfy WSS performance specifications (number of ports, bandwidth, losses, cross-talk, size, etc.), while considering switch element characteristics (rotation angle, size, losses, etc.). Lens and optical system aberrations are related to the dependence of losses and bandwidth on wavelength and port, and residual stray light causes degradation due to transmission ripple and cross-talk. Aberration and stray light are therefore significant problems. When the number of ports is increased in the future, there will be room to work with the arrangement of the ports, and configurations such as 2D port arrangements have been proposed. There are also other devices besides the MEMS mirrors and LCOS devices discussed above that can be used as switch elements, for example, digital micro-mirror devices and transmission-type LCDs (liquid crystal displays). LCOS and DMD devices are composed of small pixel elements, so they are suitable for FlexGrid applications.

2.2 Optical module design

The optical module is composed of optical components such as lenses and switch elements, as well as mechanical components for maintaining highly accurate positioning of the optical components.

The shape and position of the optical components were determined through simulation in order to achieve the desired optical design characteristics. To implement these characteristics at the module level,

* 2-f optical system: An optical system with the front focal point of the lens at the object, and the back focal point at the image plane. If the fiber array is aligned parallel to the optical axis on the object plane so it intersects the image plane, then it is also an optical system that converts between position and angle.

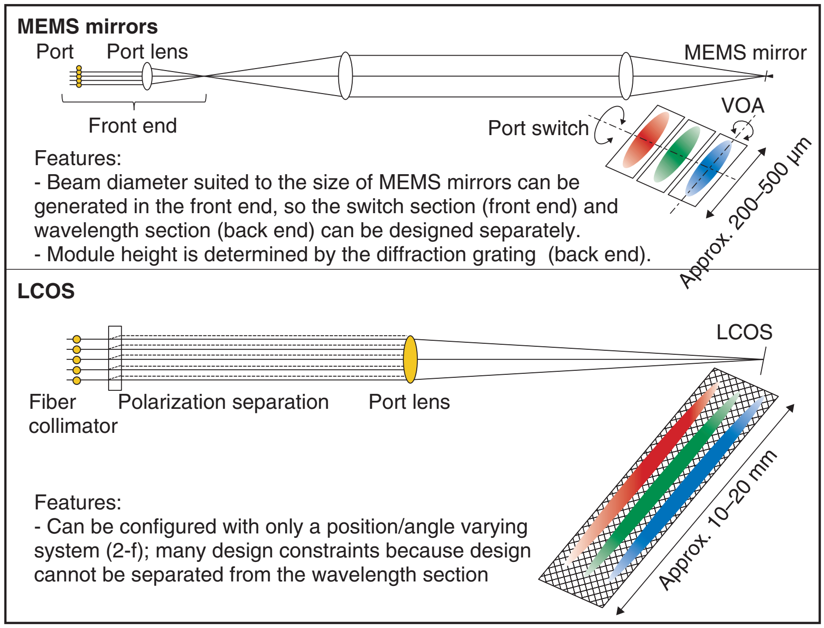

Fig. 2. Comparison of optical systems used for switch section.

the production variances and accuracy of alignment in assembly are verified and are taken into consideration while designing the configuration and assembly procedures. Also, in order to achieve the high wavelength accuracy and stable transmission characteristics needed for the WSS, a final process had to be planned. This process involved aligning the element positions and checking the characteristics while actually passing light through the system, and then fixing the positions.

In theory, a WSS is a three-dimensional (3D) optical system that must be of sufficient size and that has light paths expanding in both the wavelength and switch axis directions. However, in actual devices, reflective mirrors are used to fold up the light paths and achieve a compact design configuration. Reducing the size of the optical system not only reduces the size and weight of the module, it is also important for increasing the mechanical strength, reducing dependencies on environmental factors, and maintaining stable optical characteristics. A schematic diagram of the 1 × 9 WSS optical module developed by NTT is shown in **Fig. 3**. A compact and stable module is implemented by arranging each optical element in 3D on an alloy block with a low thermal-expansion coefficient.

The WSS module is built as a hermetically sealed structure for two reasons. The first is that the refractive index of air is dependent on environmental factors such as air temperature and pressure, and this can cause fluctuations in the diffraction angles of the diffraction grating, and thus, in the WSS channel wavelengths. Creating a hermetically sealed structure fixes the air density and controls the channel wavelength fluctuation within the level needed for current high-density WDM systems. The second reason is that changes in internal humidity can reduce the reliability of MEMS mirrors or LCOS switch elements. By maintaining low internal humidity in the structure, the high stability and reliability required of a telecommunication device can be maintained, even when used in high-temperature environments.

Also, when MEMS mirrors are used, the characteristics can fluctuate due to its structural resonances, and anti-vibration structures such as rubber dampers must be used to prevent damage. For the 1 × 9 WSS using MEMS mirrors, hermetically sealed conditions for the optical module were achieved by fixing it in a hermetic case with a rubber damper, fixing the cover to the hermetic case using welding techniques, and passing input/output fibers and MEMS driver electrical terminals through a solder seal.

2.3 Electrical monitoring and control

Electrical monitoring and control drives and controls the active elements of the optical module

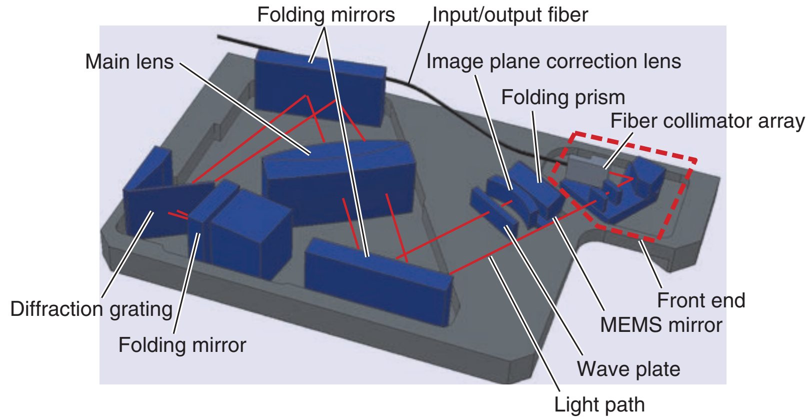

Fig. 3. Internal structure of WSS optical module.

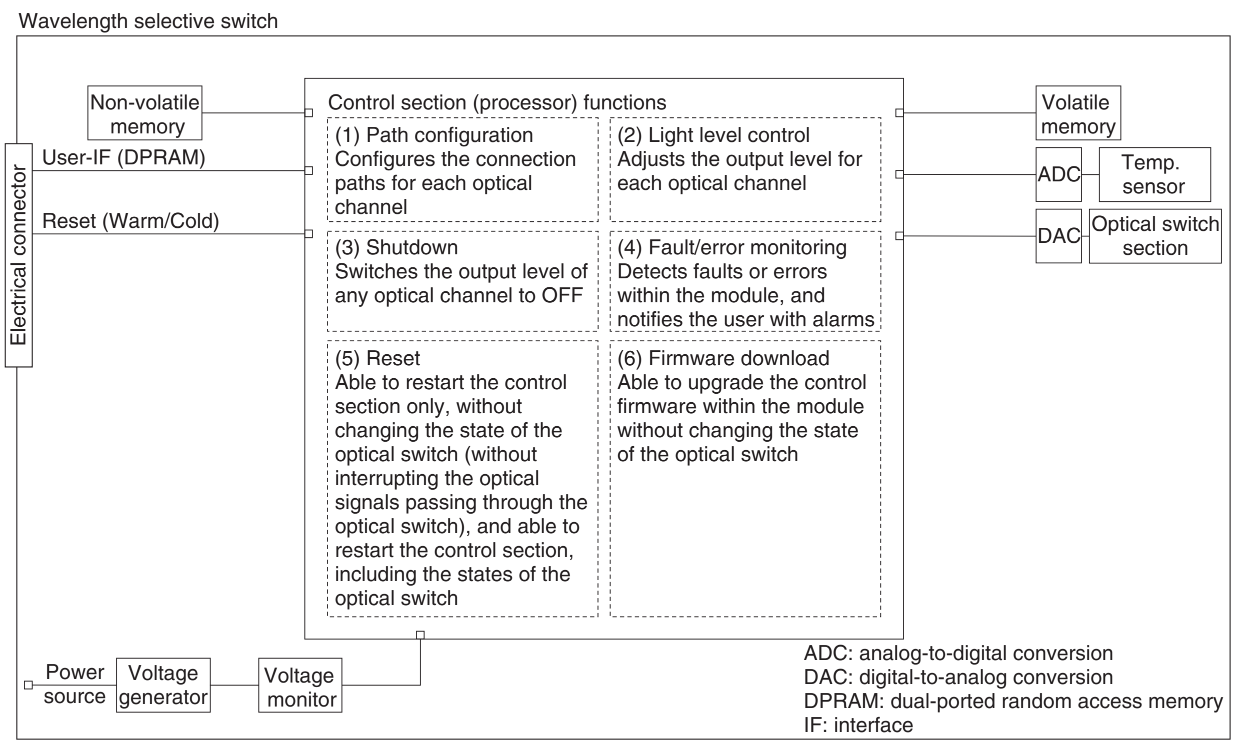

Fig. 4. WSS module control structure.

(the spatial light modulator), and also detects any faults or errors in the module, provides the monitoring and control required for linking with higher-level systems, and controls the user interface.

The overall control structure of the WSS module is shown in **Fig. 4**. This module is composed of a control process, a voltage generator/monitor section, volatile and nonvolatile memory, temperature sensors, and other components, which are used to control the optical module described above (*optical switch* in the diagram). The control processor performs control processing for the switch device in the optical module (MEMS mirror or LCOS device) and also processes control signals such as resets or commands sent by the user, monitors for faults or errors in the WSS module, and notifies the user if any such fault or error

Table 1. WSS module fault/error monitoring items.

(i) Command error	Monitors whether or not commands sent by the user can be processed correctly by the module
(ii) Temperature anomalies	Monitors whether the temperature has exceeded the range in which the module can operate correctly, whether due to external or internal causes
(iii) Firmware error	Monitors whether any errors occur when new control firmware is downloaded
(iv) Hardware fault	Monitors for faults in components within the module (memory, control components, sensors, power circuits, ADC, etc.)
(v) Data error	Monitors whether data values used in control section have changed from their original values due to hardware fault, software error, or other cause

Table 2. Severity for user when faults/errors occur.

(1) Requires module to be changed	When a hardware fault or other issue cannot be resolved while the user is using the module
(2) Resolvable with operations by the user	When the issue can be resolved by having the user send commands, such as when a command error occurs
(3) No user operations required	When the software is able to resolve the error within the module itself, as when there is a data abnormality due to a software error

occurs in the module. Communication with the user (commands, reset, alarms, etc.) occurs through the electrical connectors.

Control in the WSS module is divided into six functions: (1) Path configuration, (2) Light level control, (3) Shutdown, (4) Fault/error detection, (5) Reset, and (6) Firmware download (Fig. 4).

Implementing monitoring functions as a subsystem of the WSS module is important, and the fault/error monitoring functions are described in detail below.

The WSS control module monitors fault/error items including: command errors, temperature anomalies, firmware errors, hardware faults, and data errors (**Table 1**).

If a fault or error occurs while the WSS module is operating, the effects on the user are categorized into one of three levels (**Table 2**).

- The module must be changed
- The issue can be resolved through user operations
- The issue does not require user intervention

Thus, when a fault or error occurs, it is important to consider the effect of the problem on the user as described here when determining what sort of alarm or notification will be sent to the user.

3. Future prospects

As discussed above, the WSS module was implemented by combining a wide range of technologies. For example, even for the thermal characteristics alone, it was necessary to coordinate a wide range of design techniques. These included optical design to consider how the refractive index of glass depends on temperature, mechanical design to consider the thermal deformation of parts and the effects of environmental changes, and control design to compensate for temperature issues.

In the future, it will be necessary to further increase the bandwidth and number of ports for the WSS, and a much greater level of coordination will be necessary. Regarding the FlexGrid, a WSS using an LCOS device has been progressing, but while it is possible to control an LCOS device at the pixel level, driver control at that level is very complex. Manufacturing that is able to skillfully coordinate optical, mechanical, and control design techniques is expected to drive the development of ROADM with CDC functionality.

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Multicast Switch Technology that Enhances ROADM Operability

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Abstract

A multicast switch is a compact and cost-effective optical switch that realizes a colorless, directionless, and contentionless function and enhances the operability of a multi-degree reconfigurable optical add/drop multiplexer. This article describes the circuit configuration and characteristics of the multicast switch, which employs a silica-based planar lightwave circuit.

Keywords: ROADM, optical switch, PLC

1. Overview of CDC function

A colorless, directionless, and contentionless (CDC) function enables us to connect optical add/drop signals at any wavelength and from/to any direction in a multi-degree reconfigurable optical add/drop multiplexer (ROADM) to local transponders without any signal contention. ROADM systems are advantageous in that wavelength division multiplexing (WDM) optical signals can be routed individually without optical-electrical conversion, and they have been evolving from ring to multi-degree ROADM systems. A multi-degree ROADM can select wavelength-by-wavelength whether an incoming WDM signal from any direction will pass through the node and continue in any direction or will be added/dropped at the local node. However, in a conventional ROADM, the wavelength and direction of the optical add/drop signals are assigned in terms of the port to which they are connected, and this makes it necessary to reconnect optical fibers to transponders manually. A multi-degree ROADM with a CDC function that makes it possible to connect optical signals with any wavelength in any direction to any transponder enhances system operability and enables us to construct more flexible and reliable networks.

2. TPA using multicast switch

To realize the CDC function, an optical switch that can assign any wavelength and any direction to each transponder must be employed between the add/drop ports and the transponders. This switch is called a transponder aggregator (TPA). An $N \times M$ TPA is required on both the drop and add sides; here, N is the number of input/output routes, and M is the number of transponders. In the TPA, WDM signals are incoming from or outgoing to the ROADM, while a single wavelength is received from or sent to the transponders. On the drop side, the capability to connect different wavelength signals from the same direction to different transponders is required, while on the add side, the capability to launch different wavelength signals from different transponders in the same direction is required.

Among TPA configurations, the multicast switch offers a compact and cost-effective TPA. The TPA architecture that employs a multicast switch is shown in **Fig. 1**. In a multicast switch on the drop side, WDM signals from each direction are broadcast by a $1 \times M$ splitter, and the signals from the desired incoming fiber are selected by an $N \times 1$ optical switch. A WDM signal at the desired wavelength is extracted by a tunable filter, and then the selected signal is received by the transponder. This architecture enables us to select an optical signal at any wavelength from any direction. The same wavelength signals from other input directions are rejected by the optical switch, which eliminates any signal contention in the TPA.

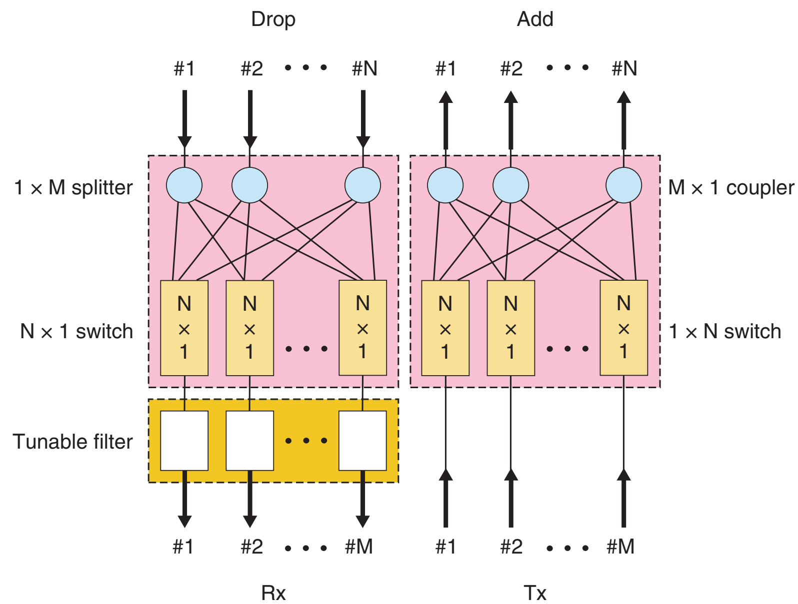

Fig. 1. TPA architecture employing multicast switch.

On the add side, the output signals from the transponders are routed to a desired outgoing fiber by a 1 × N switch array, combined with different wavelengths by an M × 1 coupler, and then launched into the add ports of the ROADM. This architecture enables us to send an optical signal at any wavelength in any output direction.

The advantage of a TPA using a multicast switch is that it is composed of compact optical components including optical splitters and switches. This is unlike a TPA, which uses a wavelength selective switch (WSS) or a large matrix switch. Although a multicast switch has an intrinsic splitting loss because it includes an optical splitter, we can compensate for this loss with an optical amplifier. A multicast switch based TPA also has the advantage that its switch scale can be expanded by cascading optical splitters when the number of transponders increases. Thus, it is suitable for multi-degree ROADMs that have a small number of add/drop signals.

3. Multicast switch using PLC

3.1 Circuit configuration

An optical switch using a silica-based planar lightwave circuit (PLC) is operated by the thermo-optic effect of silica-on-silicon waveguides. It offers good reliability and mass producibility because it has no moving parts, and many chips can be fabricated simultaneously in wafer processing [1]. Another advantage is that many functional elements can be integrated, thus making it suitable for constructing a multicast switch.

As shown in Fig. 1, the TPAs on both the drop and add sides comprise N units of 1 × M splitters (or M × 1 couplers) and M units of 1 × N switches that are interconnected, and they are identical except for the tunable filters on the drop side. This architecture is the same as that of an optical switch used for photonic transport systems [2], and an 8 × 8 switch was fabricated using a PLC. However, the conventional switch comprises 8-arrayed 1 × 8 switches and 8-arrayed 8 × 1 couplers, and those chips are separated and connected via a 64-fiber circuit sheet as shown in **Fig. 2(a)** to avoid having too many waveguide crossings on a PLC chip. They were packaged into a 240 mm × 95 mm × 12.5 mm module [3]. We recently developed a new circuit configuration that integrates the splitter and switch [4], as shown in **Fig. 2(b)**. The 8-arrayed 1 × 8 switch comprises eight 1 × 2 switch elements cascaded serially, with a gate switch placed after each 1 × 2 switch element. We divided the 8 × 1 coupler into 2 × 1 elements, and placed them between the stages of the switch elements. This new circuit configuration reduces the maximum number of waveguide crossings by three fourths, and establishes an even number of them between the paths. This allows single chip integration of the 8 × 8 multicast switch

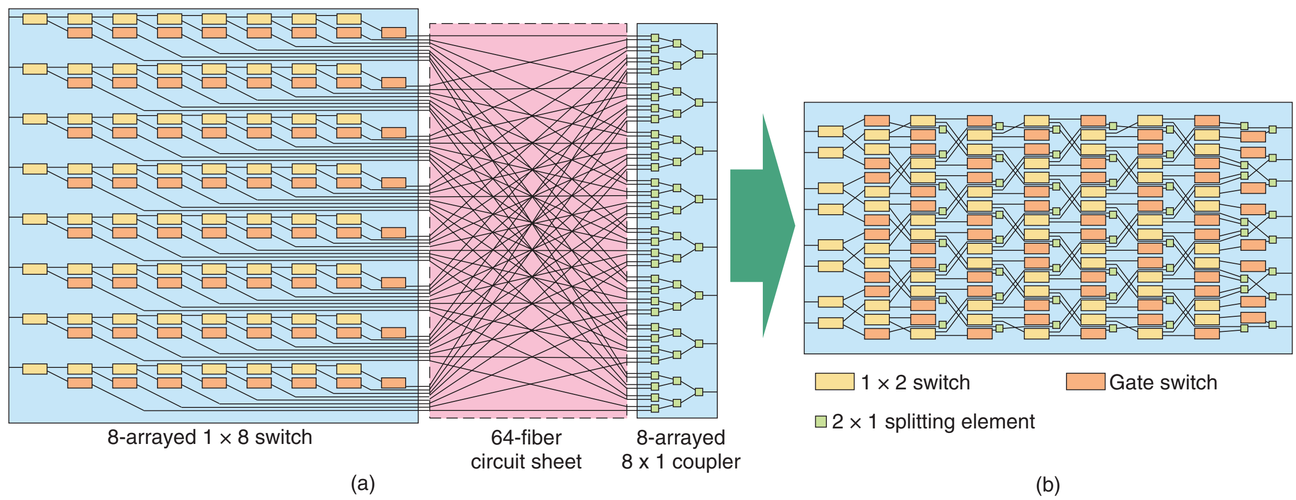

Fig. 2. (a) Conventional and (b) new circuit configuration of PLC-based multicast switch.

and makes it possible to eliminate the fiber circuit sheet, which reduces the size of the optical switch module as described below.

3.2 Fabricated PLC

We fabricated an 8 × 8 multicast switch using a PLC based on the architecture shown in Fig. 2(b). The 1 × 2 and gate switch elements are based on a Mach-Zehnder interferometer with a path difference of half a wavelength between its arms. When we activate a thermo-optic phase shifter, optical outputs between the two ports are switched in 2 ms [1]. The fabricated chip and module are shown in **Fig. 3**. The chip is 110 mm × 15 mm, and the fiber pig-tailed module is 150 mm × 45 mm × 13 mm, which is one third the size of the conventional module.

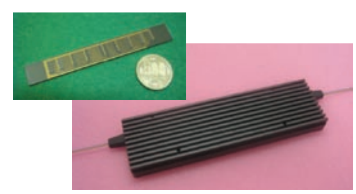

Fig. 3. Fabricated chip and module.

3.3 Optical performance

The measured performance of the multicast switch is shown in **Fig. 4**. The average insertion loss of the switch was 11.9 dB with a maximum value of 12.0 dB. This is the same as that of a conventional switch using a fiber circuit sheet. The loss includes an intrinsic splitting loss of 9 dB and an excess loss of 3 dB. The waveguide crossing induced loss was estimated to be 1 dB. The average and maximum polarization dependent losses (PDL) were 0.13 and 0.22 dB, respectively. The average wavelength dependent loss (WDL) between 1530 and 1570 nm was 0.66 dB, and the maximum value was 1.10 dB. The average and minimum off-state losses were 62.6 and 42.4 dB, respectively. We employed heat-insulating grooves to reduce power consumption. The average electrical switching power was 0.2 W per path, and the total power consumption was 1.6 W. This performance is satisfactory for practical applications.

We also fabricated an 8 × 12 multicast switch based on the circuit configuration [5]. The average and maximum insertion losses of the 8 × 12 multicast switches were 14.1 and 14.5 dB, respectively, including an intrinsic splitting loss of 10.8 dB. The PDL was less than 0.2 dB. The average WDL between 1530 and 1570 nm was only 0.1 dB, and the maximum value was 0.3 dB. The average extinction ratio between the on and off states was 59.2 dB, and the minimum value was 45.4 dB. These results indicate the good scalability of the PLC-based multicast switch.

4. Conclusion

We described the circuit configuration and the performance of an N × M multicast switch that integrates 1 × M splitters and 1 × N switches into a single PLC

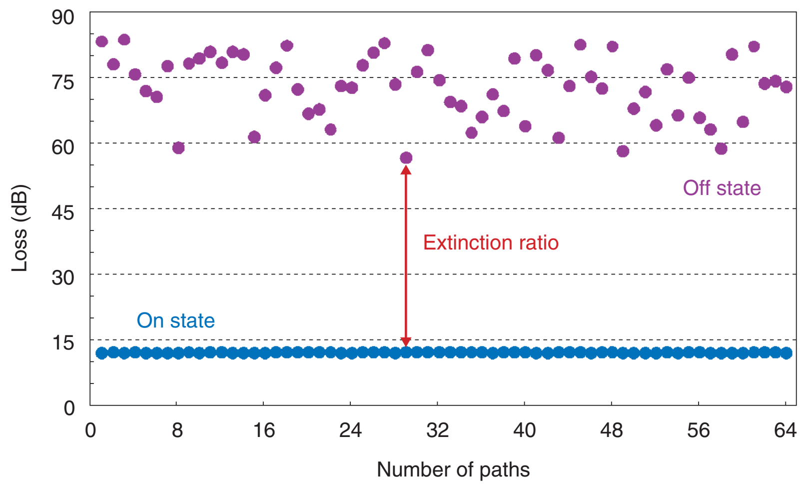

Fig. 4. Measured performance of multicast switch.

chip. This PLC-based multicast switch enables us to realize a multi-degree ROADM with a CDC function cost effectively and with a small footprint. We plan to reduce the power consumption further and enhance the optical performance of the PLC-based multicast switch.

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Statistical Grammar Induction for Natural Language Parsing

Hiroyuki Shindo

Abstract

Parsing, or syntactic analysis, is a fundamental problem in natural language processing. A natural language parser begins with words of input and builds up a syntactic tree, applying grammar rules acquired from language corpora beforehand. This article focuses primarily on the acquisition of grammar rules from language corpora, which is called grammar induction, and describes recent advances in statistical grammar induction for statistical parsing.

Keywords: natural language processing, parsing, grammar induction

1. Introduction

Parsing, or syntactic analysis, is a fundamental problem in the field of natural language processing (NLP). The resulting analyses are useful for developing high-quality NLP applications such as machine translation, automatic summarization, and information extraction. Consider the English-Japanese translation as an example. English follows the S-V-O word order; that is, the subject comes first, the verb second, and the object third. By contrast, Japanese follows the S-O-V word order. Thus, when translating from one language to another, syntactic information such as subject, verb, and object is necessary for correct word reordering.

It is known that the syntactic information of a sentence can be encoded in tree-structured forms such as phrase structure trees and dependency structure trees. Many human-annotated corpora of syntax trees such as Penn Treebank [1] have been developed. An example of a syntax tree is shown in **Fig. 1**. The tree contains the syntactic categories PRP, NP, VBP, VP, and S, which respectively indicate pronoun, noun phrase, verb, verb phrase, and sentence. A natural language parser begins with words of input, for example, *She loves me*, and builds up the syntactic tree as shown in Fig. 1, applying grammar rules such as S → NP, VP and VP → VBP, NP.

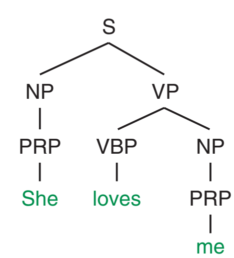

Fig. 1. Example of syntax tree.

Statistical parsing essentially involves three steps: modeling, learning, and decoding. An illustration of these steps used in building a statistical parser is shown in **Fig. 2**. Modeling syntax trees is formalized as a probabilistic grammar. Probabilistic grammars consist of a set of structural rules (tree fragments) that govern the composition of sentences, clauses, phrases, and words. Each rule, called an elementary tree, is assigned a probability.

With a probabilistic grammar and a collection of syntax trees, the learning process finds the optimal parameters that fit the training data based on some criteria such as maximum-likelihood estimation. For decoding, the statistical parser searches over a space of all candidate syntactic analyses according to the grammar rules. It then computes each candidate's probability and determines the most probable parse

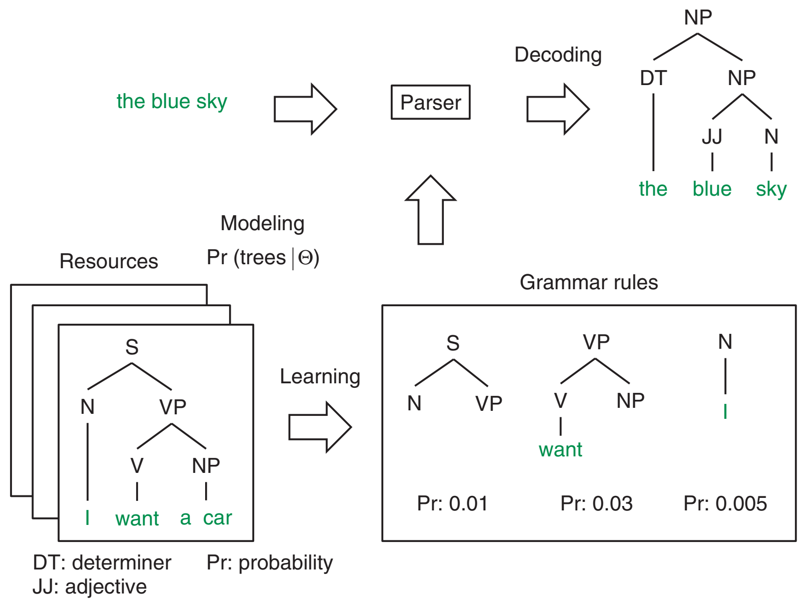

Fig. 2. Illustration of modeling, learning, and decoding for natural language parsing.

tree.

Some well-known probabilistic grammars for modeling syntax trees, which underlie the state-of-the-art statistical parsers, are reviewed in this article. Additionally, grammar induction algorithms for learning grammar rules based on the probabilistic grammars are introduced.

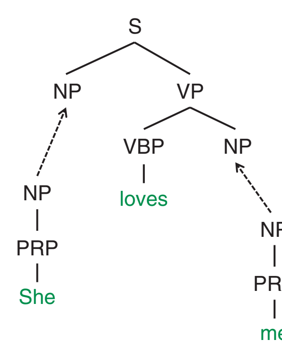

Fig. 3. Example of TSG derivation.

2. Probabilistic grammars

This section briefly reviews probabilistic tree substitution grammars (TSGs) and probabilistic symbol-refined tree substitution grammars (SR-TSGs) for statistical modeling of syntax trees.

2.1 TSGs

Formally, a TSG is defined by a 4-tuple: G = (T, N, S, R) where

- N is a finite set of nonterminal symbols,
- T is a finite set of terminal symbols,
- $S \in N$ is the distinguished start symbol, and
- R is a finite set of productions (a.k.a. (also known as) rules).

The productions take the form of elementary trees, that is, tree fragments of height ≥ 1. The root and internal nodes of the elementary trees are labeled with nonterminal symbols, and leaf nodes are labeled with either terminal or nonterminal symbols. Nonterminal leaves are referred to as frontier nonterminals and form the substitution sites to be combined with other elementary trees.

A *derivation* is a process of forming a parse tree. It starts with a root symbol and rewrites (substitutes) nonterminal symbols with elementary trees until there are no remaining frontier nonterminals. An example of TSG derivation is shown in **Fig. 3**. Different derivations may produce the same parse tree. Therefore, recent studies on TSG induction [2], [3] have employed a probabilistic model of TSG and have predicted derivations from observed parse trees in an unsupervised way.

A probabilistic TSG assigns a probability to each rule in the grammar. The probability of a derivation is simply defined as the product of the probabilities of its component elementary trees as follows:

$$p(\{e\}) = \prod_{X \to e \in \{e\}} p(e|X)$$

where $\{e\} = (e_1, e_2, \cdots)$ is a sequence of elementary trees used for the derivation, $X = \mathrm{root}(e)$ is the root symbol of e, and $p(e|X)$ is the probability of generating e given its root symbol X. It should be noted that probabilistic TSG assumes a sort of *context-free* grammars, which means that e is generated conditionally independent of all others given X. Since the derivation of a syntax tree is usually unobserved, our grammar induction task turns out to be inferring the most probable TSG derivation for each syntax tree in an unsupervised fashion. The extracted TSG rules and their probabilities are used to parse raw sentences.

2.2 SR-TSGs

The symbol-refined tree substitution grammar (SR-TSG) proposed previously [4] is an extension of the TSG model where every symbol of the elementary trees can be refined (subcategorized) to fit the training data. An example of SR-TSG derivation is shown in **Fig. 4**. In the figure, syntactic categories such as S-1 and NP-0 are refined in order to model syntax trees more accurately. For example, grammar rules are likely to generate pronouns such as *I* and *you* as subject noun phrases, while generating other objects such as *pen* and *box* as object noun phrases. We expect symbol refinement to automatically cluster subject noun phrases as NP-0 and object noun phrases as NP-1. For SR-TSG, it is necessary to infer both TSG derivation and symbol subcategories of every node from a training corpus of syntax trees. In the standard TSG, the extracted SR-TSG rules and their probabilities are used to parse raw sentences.

One major issue regarding modeling an SR-TSG is that the space of the grammar rules will be very sparse since SR-TSG allows for arbitrarily large tree fragments and also an arbitrarily large set of symbol subcategories. The authors of the previous study [4] addressed this data sparseness problem by employing a three-level hierarchy to encode a backoff scheme from a set of complex SR-TSG rules to a set of simpler grammar rules. An illustration of a three-level hierarchy for the SR-TSG model is shown in **Fig. 5**. In the figure, the first level allows every SR-TSG rule. However, the second level only allows tree fragments of height = 1, and the third level only allows tree fragments of height = 1 and unrefined child nodes. To address the data sparseness problem, the probability of the SR-TSG rule (the first level) is interpolated by the probability of simpler tree fragments (second and third levels).

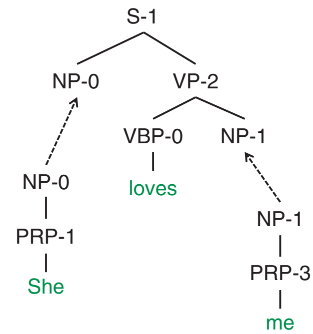

Fig. 4. Example of SR-TSG derivation.

Specifically, the probability distribution of SR-TSG is defined as follows:

$$p(e_i|\{e\}_{-i}, X, d_X, \theta_X) = \alpha_{e_i,X} + \beta_X \times P_0(e_i|X)$$

where $\alpha_{e_i,X} = \dfrac{n_{e_i,X} - d_X \cdot t_{e_i,X}}{\theta_X + \Sigma_e n_{e_i,X}}$ and $\beta_{e_i,X} = \dfrac{\theta_X + d_X \cdot \Sigma_e t_{e,X}}{\theta_X + \Sigma_e n_{e_i,X}}$.

$\{e\}_{-i} = e_1, e_2, \cdots e_{i-1}$ are previously generated trees, and $n_{e_i,X}$ is the number of times e_i has been generated in $\{e\}_{-i}$. Here, $t_{e_i,X}$ is the value of an internal variable called *table*, P_0 is called a base distribution over e, and d_X and θ_X are parameters of the model. This probability model is based on the Pitman-Yor process [5]. (See [4] for details.)

Roughly speaking, the first term $\alpha_{e_i,X}$ is the probability of e based on the number of times the tree fragment has been generated so far. The second term $\beta_X \times P_0$ is the smoothing probability of e, which is computed using the simpler grammar rules as shown in Fig. 5. Even if some grammar rule e does not appear in the training corpus, that is, $\alpha_{e_i,X} = 0$ the probability of e becomes higher than zero due to the smoothing probability $\beta \times P_0(e|X)$.

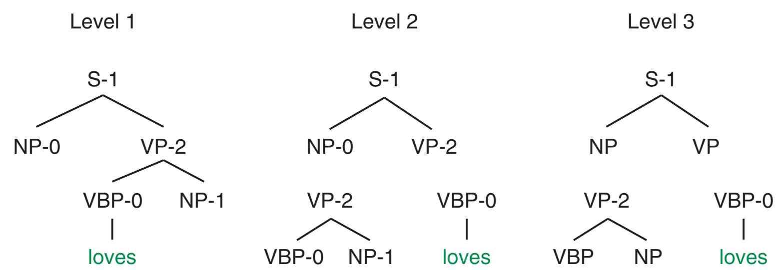

Fig. 5. Three-level hierarchy for SR-TSG model.

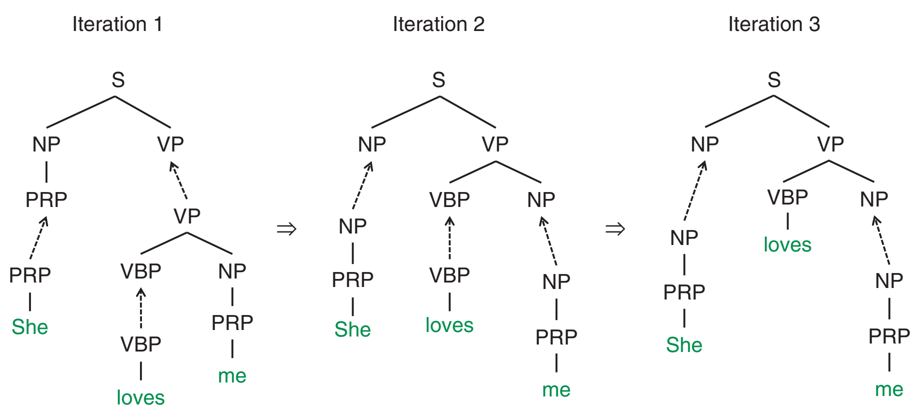

Fig. 6. Gibbs sampling for TSG induction.

3. Inference

Once we define the probabilistic grammar model such as TSG or SR-TSG, we can infer the most probable grammar rules (derivation) from a training corpus of syntax trees. For the inference of grammar rules, Gibbs sampling [6] is one of the most common techniques applied to obtain derivation samples from the posterior distribution.

The basic procedure of Gibbs sampling for inferring TSG rules is explained here as an example. The inference of TSG derivation corresponds to inducing substitution nodes. A substitution node is a node of a parse tree that forms the root node of some elementary tree. For example, in Fig. 3, two NP nodes are substitution nodes, while all the other nodes are non-substitution nodes.

An illustration of Gibbs sampling for TSG induction is shown in **Fig. 6**. For each iteration, the Gibbs sampling algorithm works by sampling the value of each binary variable (1 for substitution node and 0 for non-substitution node) according to the posterior distribution in random order. When it reaches convergence, we can obtain the most probable derivation according to the posterior distribution over grammar rules. For the inference of the SR-TSG model, it is necessary to induce substitution nodes plus latent subcategories for every node.

4. Experiment

4.1 Setting

Some experimental results of statistical parsing using TSG and SR-TSG are introduced in this section. The standard data set for evaluating parsing performance is the Wall Street Journal (WSJ) portion of the English Penn Treebank [1]. The Penn Treebank data set consists of 24 sections; we used sections 2–21 for the training corpus and 23 for testing.

For training, the grammar rules are extracted by Gibbs sampling from a collection of syntax trees in the training data. For testing, the algorithm begins with words of input, rather than a syntax tree, and then predicts the syntax tree. The parsing results are obtained with the MAX-RULE-PRODUCT algorithm [7] by using the extracted grammar rules. The accuracy of the predicted syntax trees is evaluated by bracketing the parsing accuracy (F1 score) of the predicted parse trees.

4.2 Results and discussion

The F1 scores of context-free grammar (CFG), TSG, and SR-TSG models [4] are listed in **Table 1**. The parsing accuracy of the SR-TSG model with three backoff hierarchy settings is also listed in the Table in order to show the effects of backoff smoothing on parsing accuracy. In Table 1, F1 (small) indicates that we used only section 2 (small training data) for training, whereas F1 (full) indicates that we used sections 2–21 (full training data) for training. Moreover, SR-TSG (level 1) denotes that we used only the topmost level of the hierarchy. Similarly, SR-TSG (level 1 + 2) denotes that we used only levels 1 and 2 for backoff smoothing.

Table. 1. Comparison of parsing accuracy.

Model	F1 (small)	F1 (full)
CFG	61.9	63.6
TSG	77.1	85.0
SR-TSG (level 1)	73.0	86.4
SR-TSG (levels 1 + 2)	79.4	89.7
SR-TSG (levels 1 + 2 + 3)	81.7	91.1

The results obtained in the previous study [4] indicate that the best model, SR-TSG (level 1 + 2 + 3), performed the best on both training sets. This suggests that the conventional CFG and TSG models trained naively from the treebank are insufficient to fit the training data due to the context-free assumption and coarse symbol annotations. SR-TSG also assumes context-freeness; however, as we expected, symbol refinement can be helpful with the TSG model for further fitting of the training data and for improving the parsing accuracy.

The performance of the SR-TSG parser was strongly affected by its backoff models. SR-TSG (level 1) performed poorly compared with the best model. This result suggests that the SR-TSG rules extracted from the training set are very sparse and cannot cover the space of unknown syntax patterns in the testing set. Therefore, well-designed backoff modeling is essential for the SR-TSG parser.

5. Summary

This article reported on recent progress in statistical grammar induction for natural language parsing and presented probabilistic TSG and SR-TSG for modeling syntax trees and a Gibbs sampling algorithm for extracting grammar rules. SR-TSG successfully outperformed the TSG model in a standard English parsing task by using a symbol refinement technique and three-level backoff smoothing.

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G.epon and Current Status of Related Standardization

Ken-Ichi Suzuki

Abstract

G.epon is an ITU-T (International Telecommunication Union, Telecommunication Standardization Sector) version of the system-level EPON (Ethernet passive optical network) standard that uses generic OMCI (ONT (optical network terminal) management and control interface) in SIEPON (Service Interoperability in EPON) package B. It was given consent in July 2013 and approved in September 2013. This article reports on G.epon, which is expected to be deployed in emerging nations and developing countries, and explains the current status of related standardization.

Keywords: EPON, SIEPON, OMCI

1. Introduction

The use of optical access systems based on passive optical networks (PONs) has increased along with the expansion of broadband services. GE-PON[*1], a type of EPON (Ethernet based PON), has been widely deployed in Japan. However, the scope of IEEE (Institute of Electrical and Electronics Engineers) EPON standardization has been limited to the PHY (physical) and MAC (media access control) layers and other system specifications that depended on implementations by system vendors or telecommunication carriers to provide their services. The scope of IEEE 802.3 [1] standardization using the layer model of the EPON system is shown in **Fig. 1**. There is no specification of higher layers in IEEE 802.3 standardization, as shown in the figure, so telecommunication carriers desiring system deployment in multivendor environments require additional development or modification of firmware and hardware. Moreover, system vendors have had difficulty doing business globally because they could not ensure that their systems would be interoperable with other systems even if they had been developed in compliance with IEEE standards. In view of these situations, IEEE initiated system-level EPON standardization in order to ensure the interoperability between optical line terminals (OLTs) and optical network units (ONUs). That standardization was approved in June 2013 [2]. By contrast, the trend to introduce de jure standards in developing countries and emerging nations has become an issue that must be addressed in the global promotion of EPON. In view of the fact that future networks were expected to be packet-oriented, we began proposing that the International Telecommunication Union, Telecommunication Standardization Sector (ITU-T) create EPON standards through the Full Service Access Network (FSAN) [3] in 2001, when IEEE started work on EPON standardization. However, this proposal was not realized. Consequently, a variety of EPON systems with different specifications were developed. We have continued to seek a way to create EPON standardization in ITU-T ever since then. By contrast, IEEE started SIEPON[*2] standardization, which is a system-level EPON standard, in 2010. We decided to grab this SIEPON standardization opportunity to work on G.epon standardization in order to incorporate a full set of specifications of widely used EPON systems into ITU-T standardization. To make a breakthrough in EPON

*1 GE-PON: Gigabit Ethernet PON; the term GE-PON is used in this article since it is widely used in Japan. However, the term 1G-EPON is recommended for use in the standard.

*2 SIEPON: Service Interoperability in EPON specified in IEEE 1904.1 WG (Working Group); a corporate project sponsored by the IEEE Communication Society.

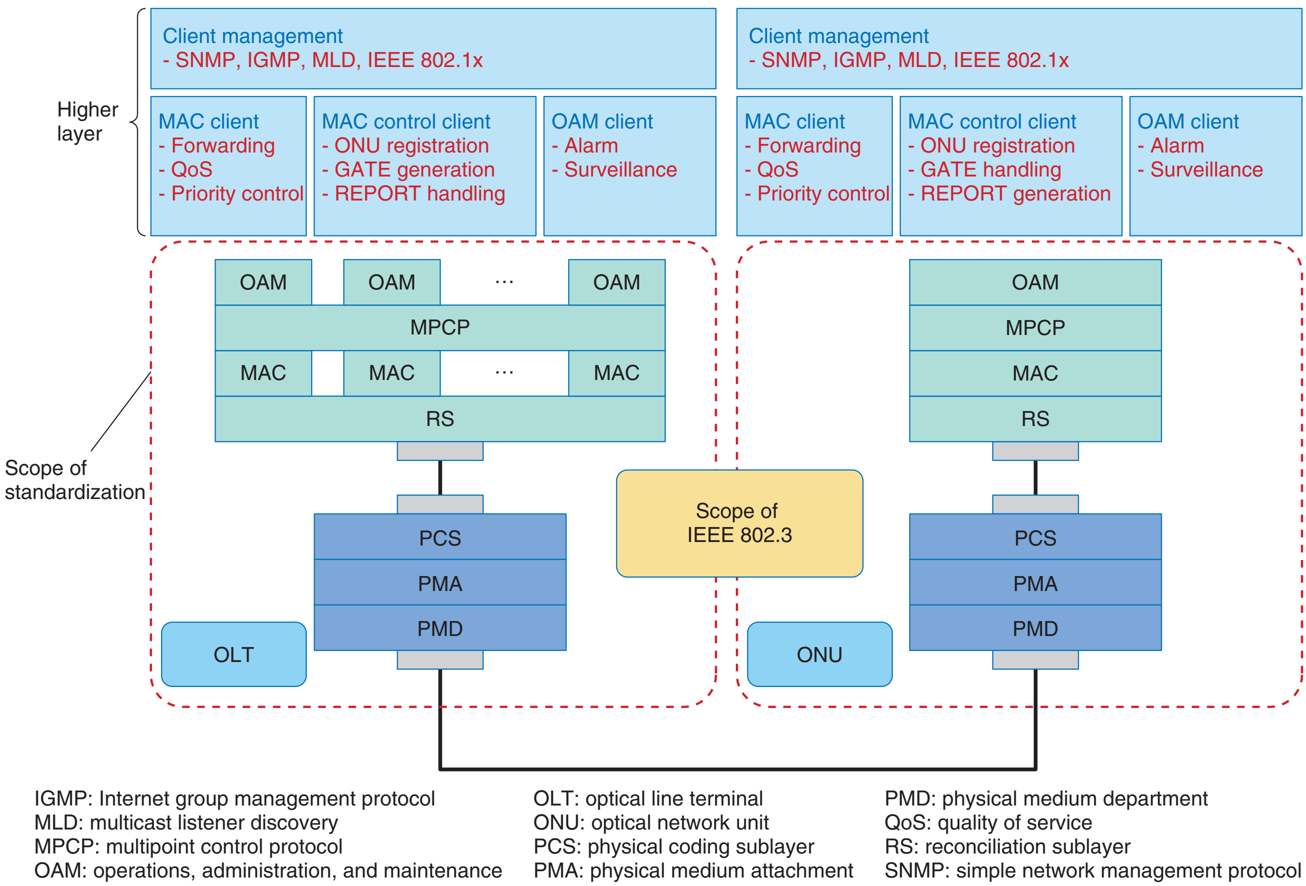


Fig. 1. Scope of IEEE 802.3 standardization.

standardization in ITU-T, we focused on SIEPON package B for G.epon standardization in the Japanese market and aimed for early completion of G.epon standardization. We took into consideration the future replacement (or coexistence) with G-PON and decided to apply OMCI (ONT (optical network terminal) management and control interface), which is widely used in ITU-T standards, to G.epon. The G.epon standard was given consent in July 2013 and approved in September 2013. This article reports on ITU-T G.epon and the current status of related standardization.

2. Overview of ITU-T Recommendation G.epon (G.9801)

2.1 SIEPON standardization and G.epon

I briefly introduce SIEPON standardization as a reference document of G.epon. SIEPON is intended to realize service interoperability among 1G-EPON or 10G-EPON equipment. In order to achieve this, the SIEPON standard specifies a system-level EPON standard that consists of three specification packages according to the market (Package A: North American MSOs (multiple system operators); Package B: Japan; Package C: China). The difference between G.epon and SIEPON in terms of constituent standards and principal functions is shown in **Fig. 2**. G.epon is an ITU-T version of the EPON standard specified by applying OMCI, which is widely used in ITU-T standards, to SIEPON package B. That standardization is being done under a Japanese initiative as a part of the Telecommunication Technology Committee (TTC)'s [4] upstream activity. On the contrary, SIEPON uses extended operations, administration, and maintenance (eOAM). However, hardware commonalization between G.epon and SIEPON compliant systems is anticipated because OAM functions can be realized with firmware. The principal functions newly specified in G.epon/SIEPON standards are listed in **Table 1**. Because the existing EPON standards did not specify these functions, it was

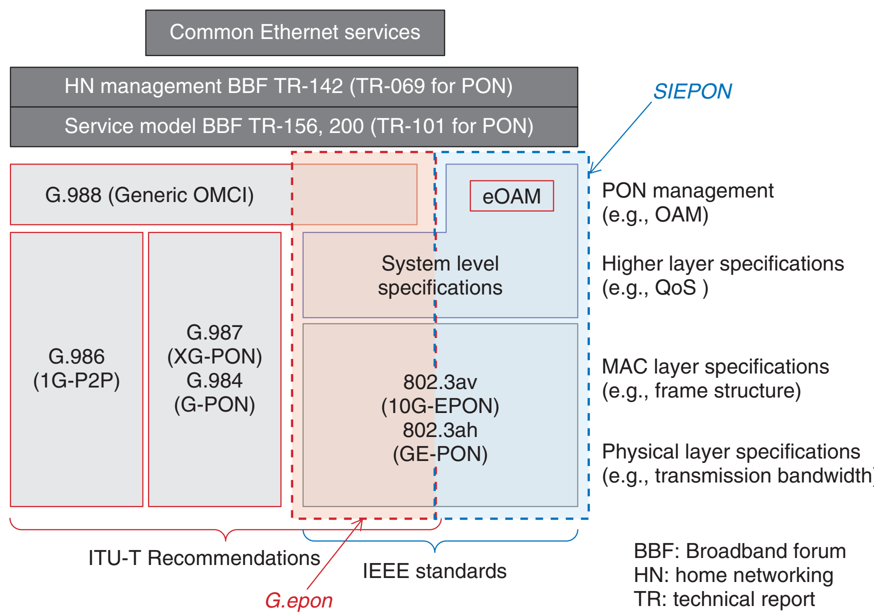


Fig. 2. Differences between G.epon and SIEPON.

Table 1. Principal functions newly specified in G.epon/SIEPON standards.

Item	Main specifications	Remarks
Client management	Encryption/authentication, protection, power saving, service management, system monitoring	Various functions
OAM client	OAM discovery, alarm handling, statistical information processing (surveillance)	Surveillance and control functions
MAC client	Queue control, shaping, priority control, policing, etc.	Main signal control functions
MAC control client	Bandwidth control, report generation, discovery control	PON access control functions

difficult to realize interoperability even with standard-compliant devices.

2.2 Architecture model for G.epon/SIEPON

The architecture model for G.epon/SIEPON is shown in **Fig. 3**. The architecture model defines Line OLT/Line ONU having functions covered by the IEEE 802.3 standards, Client OLT/Client ONU having functions covered by G.epon/SIEPON standards, and Service OLT/Service ONU having additional functions for specific services provided by the communication carrier or system vendors. Moreover, the architecture model newly defines OLT_CI/ONU_CI as logical interfaces on the core network/user network side of Client OLT/Client ONU and OLT_LI/ONU_LI as a logical interface on the core network/user network side of Line OLT/Line ONU.

2.3 Logical function model for G.epon/SIEPON

The logical function model for G.epon/SIEPON is shown in **Fig. 4**. G.epon/SIEPON defines ESPs (EPON service paths), which provide basic functional blocks of the MAC client model to achieve provisioning, connection, and QoS in services. The basic functional blocks (input/output, classifier, modifier, policer, cross-connect, packet queue, and scheduler) in ESPs provide data forwarding in OLTs and ONUs. A set of ESPs in an OLT and an ONU represents a unidirectional connection. The example in this figure shows ESP configurations for the bidirectional unicast connection between an OLT and an ONU. The ESP concept is intended to be of help in understanding standard specifications because it simplifies and conceptualizes behaviors of MAC client functions, thus absorbing implementation differences

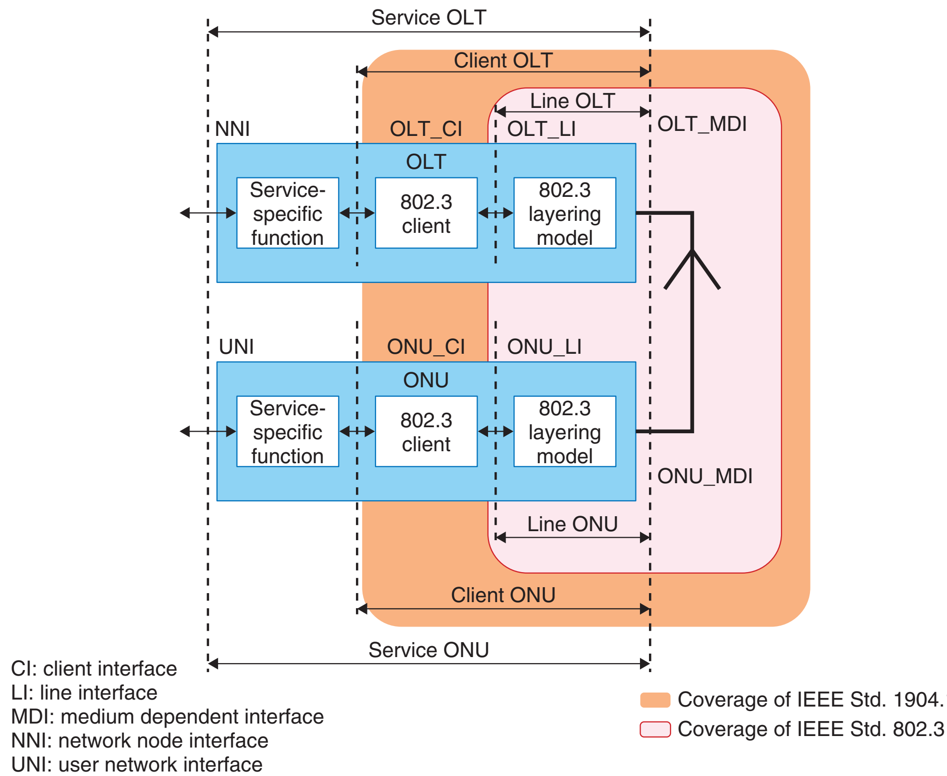


Fig. 3. Architecture model for G.epon/SIEPON.

such as single LLID (logical link ID) and multiple LLID configurations.

3. Status of G.epon-related standardization

This section describes the current status of G.epon-related standardization.

3.1 Interoperability test specifications for G.epon

A proposal to standardize a G.epon implementers' guide was accepted in the ITU-T SG15/Q2 (Study Group 15; Question 2) interim meeting in February 2013. The G.epon implementers' guide is intended to develop two kinds of test specifications for a conformance test, which is conducted by connecting an ONU under test to an OLT emulator, and an interoperability test, which is conducted by connecting one or multiple ONUs to an OLT in a multi-vendor environment. The IEEE 1904.1 WG is working on developing specifications for a conformance test (IEEE P1904.1 SIEPON/Conformance) that is performed by connecting an OLT and an ONU to an ONU emulator and OLT emulator, respectively. Although there are differences in each test configuration, the G.epon implementers' guide is being developed in reference to SIEPON/Conformance standard documents. The development of the implementers' guide is expected to be done through a Japanese initiative as part of upstream activities in TTC in common with G.epon.

3.2 Interoperability tests in Japan

The development of the G.epon implementers' guide and SIEPON/Conformance have accelerated the movement to carry out EPON interoperability tests in Japan. Various organizations are cooperating in the interoperability tests, as shown in **Fig. 5**. The Optical Access Ad-hoc WG was established in the HATS (Harmonization of Advanced Telecommunication Systems) conference [5] of Japan in August 2012. This WG is an operating organization for conducting interoperability tests of G.epon/SIEPON compliant equipment. Hereafter, the Optical Access Ad-hoc WG is expected to conduct interoperability tests in cooperation with the SIEPON certificate program and TTC.

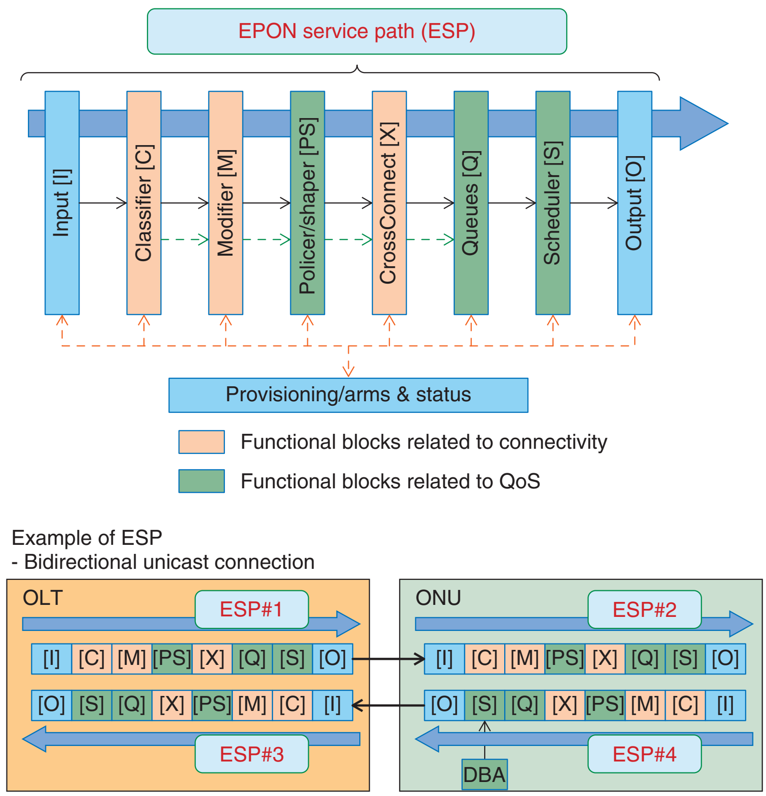
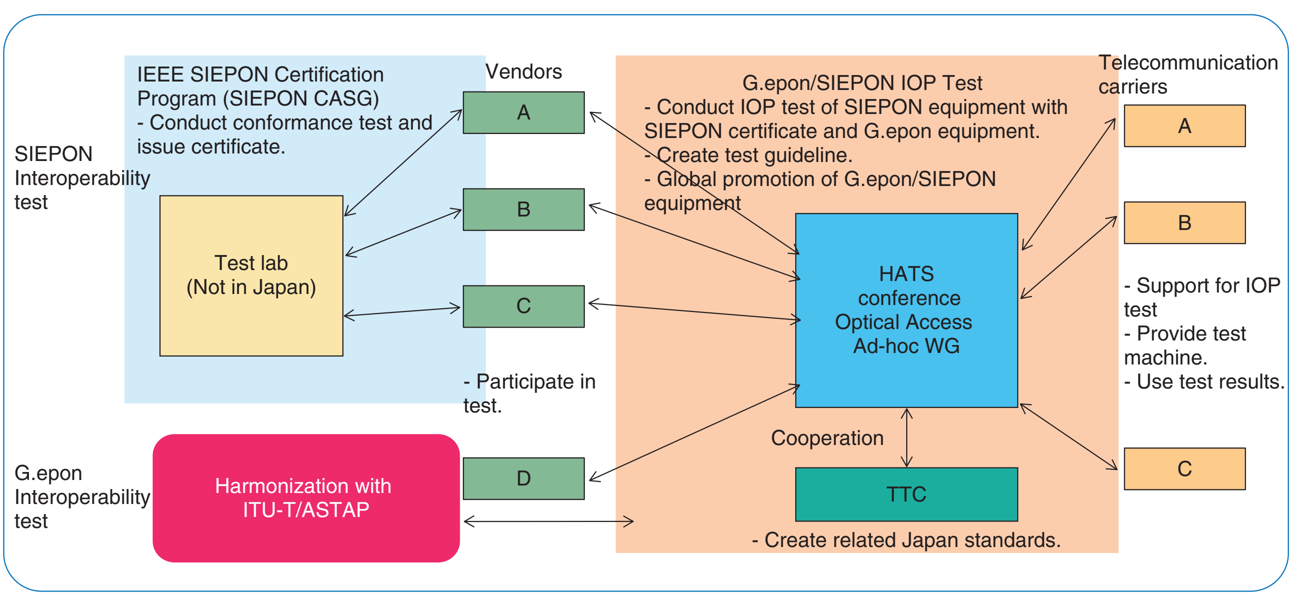


Fig. 4. Logical function model for G.epon/SIEPON.



ASTAP: Asia-Pacific Telecommunity Standardization Program
CASG: Conformity Assessment Steering Group
IOP: interoperability

Fig. 5. Cooperation between related organizations for interoperability test.

4. Future perspectives

This article reported on G.epon, which was given consent this July, and the status of related standardization. G.epon is an ITU-T version of the EPON standard based on SIEPON package B for the Japanese market, which uses generic OMCI[*3] instead of eOAM. G.epon is expected to be deployed in emerging nations and developing countries that place importance on de jure standards. The development of the G.epon implementers' guide, which is a reference document for interoperability tests, and the corresponding movement to carry out interoperability tests in Japan are expected to accelerate activities related to interoperability test for G.epon and SIEPON. Moreover, successful G.epon standardization is expected to promote further cooperation between ITU-T and IEEE such as IEEE's request to issue an ITU-T Recommendation number for the entire SIEPON standard including all packages.

*3 Generic OMCI: ONT (optical network terminal) management and control interface specified in ITU-T G.988, which has been generalized for application to various PON systems.

References

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http://www.ieee802.org/3/index.html

[2] IEEE 1904.1 SIEPON (service interoperability in EPON) WG.
http://grouper.ieee.org/groups/1904/1/index.html

[3] FSAN (Full Service Access Network).
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[4] TTC (Telecommunication Technology Committee).
http://www.ttc.or.jp/e/

[5] HATS (Harmonization of Advanced Telecommunication Systems) conference.
http://www.ciaj.or.jp/hats/english/about.html

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He received the B.E. and M.E. degrees in electronic engineering from Utsunomiya University, Tochigi, in 1988 and 1990, respectively, and the Ph.D. degree in information science and technology from Hokkaido University in 2009. He joined NTT laboratories in 1990, where he has been working on R&D of optical communication systems including PON based optical access systems. He currently leads the Full Service Access Group, which is investigating optical access related services/technologies. His current research interests are 10G-EPON related optical access systems/technologies and optical-amplifier-based long-reach PON systems/technologies. He is an IEEE 802.3 WG voter and was an active member of the IEEE P802.3av Task Force creating 10G-EPON standardization. He has been a Vice Chair of IEEE P1904.1 SIEPON WG since 2011 and was an executive secretary of IEEE P1904.1 SIEPON WG during 2009–2011. He has been a Director of the Optical Access Ad-hoc WG in HATS conference of Japan for EPON family interoperability tests since 2012. He is a member of IEEE, the Institute of Electronics, Information and Communication Engineers (IEICE), and the Optical Society of America. He has also been a member of the Technical Committee on Communication Systems in IEICE Communication Society since 2008 and was an associate editor of IEICE Transactions on Communications during 2007–2011. He is the TPC Secretary of IEEE CQR2012, 2013, and 2014.

Papers Published in Technical Journals and Conference Proceedings

Definition, Implementation and Evaluation of Generic Search Function for Current Sensor Status in Database for Sensor Networks

T. Nakamura, Y. Higashijima, M. Nakamura, and M. Matsuo

IEICE Trans. on Information and Systems, Vol. J96-D, No. 5, pp. 1132–1144, 2013 (in Japanese).

We propose a search function for the current sensor status provided by a database management system (DBMS) for sensor networks. Previous studies have investigated two practically important search functions in DBMSs specially designed for sensor networks: accumulated data history search and continuous search (immediate data delivery). We determined the necessity of and the problems with a third search function that returns a list of current sensor statuses by implementation of sensor network application systems. We also developed a formal definition of this search function. This definition clarifies the semantics of a search and can be used as a guide in designing the input/output parameters in a new generic search API for a DBMS. We implemented the proposed search function and applied it to the development of several application systems used in field trials.

Improving Nonlinear Degradation by Combining Optical and Digital Compensation Techniques

K. Shibahara, Y. Sakamaki, T. Kawai, K. Mori, H. Kishikawa, and M. Fukutoku

Proc. of the 18th OptoElectronics and Communications Conference held jointly with 2013 International Conference on Photonics in Switching (OECC/PS 2013), Vol. OECC, No. 2013, pp. WR4–6, Kyoto, Japan.

We investigate the combined effect of optical and digital compensation techniques for nonlinear degradation by numerical simulation. Q-factor improvement by digital compensation increases when nonlinearity is optically suppressed in a dispersion-managed system.

409-Tb/s + 409-Tb/s Crosstalk Suppressed Bidirectional MCF Transmission over 450 km Using Propagation-direction Interleaving

A. Sano, H. Takara, T. Kobayashi, H. Kawakami, H. Kishikawa, T. Nakagawa, Y. Miyamoto, Y. Abe, H. Ono, K. Shikama, M. Nagatani, T. Mori, Y. Sasaki, I. Ishida, K. Takenaga, S. Matsuo, K. Saitoh, M. Koshiba, M. Yamada, H. Masuda, and T. Morioka

Opt. Express, OSA, Vol. 21, No. 14, pp. 16777–16783, 2013.

We demonstrate bidirectional transmission over 450 km of newly developed dual-ring structured 12-core fiber with a large effective area and low crosstalk. Inter-core crosstalk is suppressed by employing propagation-direction interleaving, and 409-Tb/s capacities are achieved for both directions.

Dynamic Optical Transport Connection with a 100 Gbit/s Digital Coherent Optical Transponder for Disaster-resilient Networking

T. Hirooka, M. Nakazawa, H. Kubota, T. Komukai, and T. Sakano

Proc. of the IEEE Region 10, Humanitarian AdHoc Committee, Vol. 1, No. 1, p. TS10, Sendai, Miyagi, Japan, 2013.

We demonstrate dynamic optical transport connectivity to various lengths and types of fiber (SMF, DSF, GI-62.5/125 fiber) with a 100-Gbit/s digital coherent optical transponder. The outage time associated with connection was only about 70 ms (potentially as fast as 20 ms) in all configurations. This feature provides great simplicity and flexibility as regards immediate broadband connection to the backbone networks in case of a devastating disaster.

Impact of Transponder Architecture on the Scalability of Optical Nodes in Elastic Optical Networks

T. Tanaka, A. Hirano, and M. Jinno

IEEE Communications Letters, Vol. 17, No. 9, pp. 1846–1848, 2013.

The elastic optical network has proven to be a promising network architecture for handling the rapid growth in IP traffic in the optical layer in a spectrum-efficient manner. This study reveals the optical node requirements in elastic optical networks by comparing multiple network architectures using an integrated resource allocation scheme that considers both network and node parameters. Evaluations show that the multiflow transponder-based elastic optical network architecture is superior to two other architectures in terms of scalability of optical nodes and network costs.

Silica-based 100-GHz-spacing Integrated 40-λ 1×4 Wavelength Selective Switch

T. Yoshida, H. Asakura, T. Mizuno, H. Takahashi, and H. Tsuda

Proc. of the 39th European Conference and Exhibition on Optical Communication (ECOC 2013), Vol. We.4.B.3, No. 1, pp. 1–3, London, UK.

A densely integrated 1 × 4 wavelength selective switch was designed and fabricated. The channel spacing is 100 GHz and the number of channels is 40. The transmission losses and the crosstalk are less than 8.8 dB and -19.4 dB, respectively.

Impact of Multi-flow Transponder on Equipment Requirements in IP over Elastic Optical Networks

T. Tanaka, A. Hirano, and M. Jinno

Proc. of the 39th European Conference and Exhibition on Optical Communication (ECOC 2013), Vol. We.1.E.3, No. 1, pp. 1–3, London, UK.

We evaluate the elastic optical network performance from the network to node equipment level using a multi-layer network design scheme. Results show that the multi-flow transponder-based network model reduces equipment requirements such as router IFs and transponders compared to mixed-line-rate and bandwidth-variable models.

Noise Model Transfer: Novel Approach to Robustness Against Nonstationary Noise

T. Yoshioka and T. Nakatani

IEEE Trans. on Audio, Speech, and Language Processing, Vol. 21, No. 10, pp. 2182–2192, 2013.

This paper proposes an approach called a noise model transfer (NMT), for estimating the rapidly changing parameter values of a feature-domain noise model, which can be used to enhance feature vectors corrupted by highly nonstationary noise. Unlike conventional methods, the proposed approach can exploit both observed feature vectors, representing spectral envelopes and other signal properties that are usually discarded during feature extraction but that are useful for separating nonstationary noise from speech. Specifically, we assume the availability of a noise power spectrum estimator that can capture rapid changes in noise characteristics by leveraging such signal properties. NMT determines the optimal transformation from the estimated noise power spectra into the feature-domain noise model parameter values in the sense of maximum likelihood. NMT is successfully applied to meeting speech recognition, where the main noise sources are competing talkers; and reverberant speech recognition, where the late reverberation is regarded as highly nonstationary additive noise.

Usefulness of Acoustical Telepresence Robot for Auditory Psychophysics

T. Iwaki, S. Aoki, H. M. Kondo, M. Kashino, and T. Hirahara

Journal of the Robotics Society of Japan, Vol. 31, No. 8, pp. 788–796, 2013 (in Japanese).

We devised an acoustical telepresence robot, "TeleHead", that has a user-like dummy head and can be synchronized with the user's head movement. We performed several psychophysical experiments to assess sound localization, delay discrimination, and auditory perceptual grouping ability in humans. The errors of the sound localization via TeleHead were less than 10 deg. Head posture changes during the discriminable delay time ranged from 10 deg to 17 deg. The performance of auditory perceptual grouping did not differ between conditions with and without TeleHead. In addition, we used TeleHead to divide head movement effects on perception into three factors: self-movement, sound source movement, and acoustical change. The results indicate that TeleHead can mirror the 3D motion of users with minimal latency and distortion, suggesting that it is a useful tool for measurements of human auditory perception.

Image Context Discovery from Socially Curated Contents

A. Kimura, K. Ishiguro, M. Yamada, A. M. Alvarez, K. Kataoka, and K. Murasaki

Proc. of the 21st ACM International Conference on Multimedia (MM'13), Vol. 1, No. 1, pp. 565–568, Barcelona, Spain, 2013.

This paper proposes a novel method of discovering a set of image contents sharing a specific context (attributes or implicit meaning) with the help of image collections obtained from social curation platforms. Socially curated contents are promising for analyzing various kinds of multimedia information, since they are manually filtered and organized based on specific individual preferences, interests or perspectives. Our proposed method fully exploits the process of social curation: (1) How image contents are manually grouped together by users, and (2) how image contents are distributed in the platform. Our method reveals the fact that image contents with a specific context are naturally grouped together and every image content item includes various contexts that cannot necessarily be verbalized by texts.

Heat Blueprint

T. Natsume

The OpenStack Summit Hong Kong 2013

We suggest adding a retry function and the resource type of NVP network gateway for "Heat", which realizes orchestration in OpenStack.

Clustering-based Anomaly Detection in Multi-view Data

A. M. Alvarez, M. Yamada, A. Kimura, and T. Iwata

Proc. of the 21st International Conference on Information and Knowledge Management (CIKM 2013), Vol. 1, No. 1, pp. 1545–1548, Burlingame, CA, USA.

This paper proposes a simple yet effective anomaly detection method for multi-view data. The proposed approach detects anomalies by comparing the neighborhoods in different views. Specifically, clustering is performed separately in the different views and affinity vectors are derived for each object from the clustering results. Then, the anomalies are detected by comparing affinity vectors in the multiple views. An advantage of the proposed method over existing methods is that the tuning parameters can be determined effectively from the given data. Through experiments on synthetic and benchmark datasets, we show that the proposed method outperforms existing methods.

Exploiting Socially Generated Side Information in Dimensionality Reduction

A. M. Alvarez, M. Yamada, and A. Kimura

Proc. of the 2nd International Workshop on Socially-aware Multimedia, Barcelona, Spain, 2013.

In this paper, we show how side information extracted from socially curated data can be used within a dimensionality reduction method and to what extent this side information is beneficial to several tasks such as image classification, data visualization and image retrieval. The key idea is to incorporate side information of an image into a dimensionality reduction method. More specifically, we propose a dimensionality reduction method that can find an embedding transformation so that images with similar side information are close in the embedding space. We introduce three types of side information derived from user behavior. Through experiments on images from Pinterest, we show that incorporating socially generated side information in a dimensionality reduction method benefits several image-related tasks such as image classification, data visualization and image retrieval.

High-charge-sensitivity Radio-frequency Field-effect Transistor with Large and Tunable Readout Frequency

K. Nishiguchi, H. Yamaguchi, A. Fujiwara, H. S. J. van der Zant, and G. A. Steele

Proc. of the 26th International Microprocesses and Nanotechnology Conference (MNC 2013), 7B-4-1, Sapporo, Hokkaido, Japan.

We introduce the RF-FET composed of double LC matching circuits. The double matching circuits provide an additional resonance condition tuned by a variable capacitor, which allows the extension of the readout frequency to 200 MHz.

Dual-gate Silicon Single-electron Transistor Threshold Voltage Mapping at Nanoscale with a Scanning Microwave Microscope

N. Clément, F. Wang, K. Nishiguchi, A. Fujiwara, G. Patriarche, D. Troadec, B. Legrand, G. Dambrine, and D. Théron

Proc. of the 26th International Microprocesses and Nanotechnology Conference (MNC 2013), 7B-4-2, Sapporo, Hokkaido, Japan.

Using a scanning microwave microscope (SMM) with F sensitivity, we demonstrate spatial mapping of the threshold voltage of a silicon single-electron transistor whose conductivity is fully controlled by dual gates composed of a back gate and an SMM cantilever. The SMM is a reliable alternative tool for electrical characterization of emerging nanoscale devices.

Ultimate Integration of a PDMS-based Lab-on-a-Chip with Nanotransistor Biosensors

R. Sivakumarasamy, K. Nishiguchi, A. Fujiwara, D. Vuillaume, and N. Clément

Proc. of the 26th International Microprocesses and Nanotechnology Conference (MNC 2013), 8C-8-3, Sapporo, Hokkaido, Japan.

We address the question of the maximum integration possible for such PDMS-based lab-on-chips (LOCs) and show that there is a critical distance (typically a few tens of micrometers) between the channel and electrical contacts, below which we observed leakage.