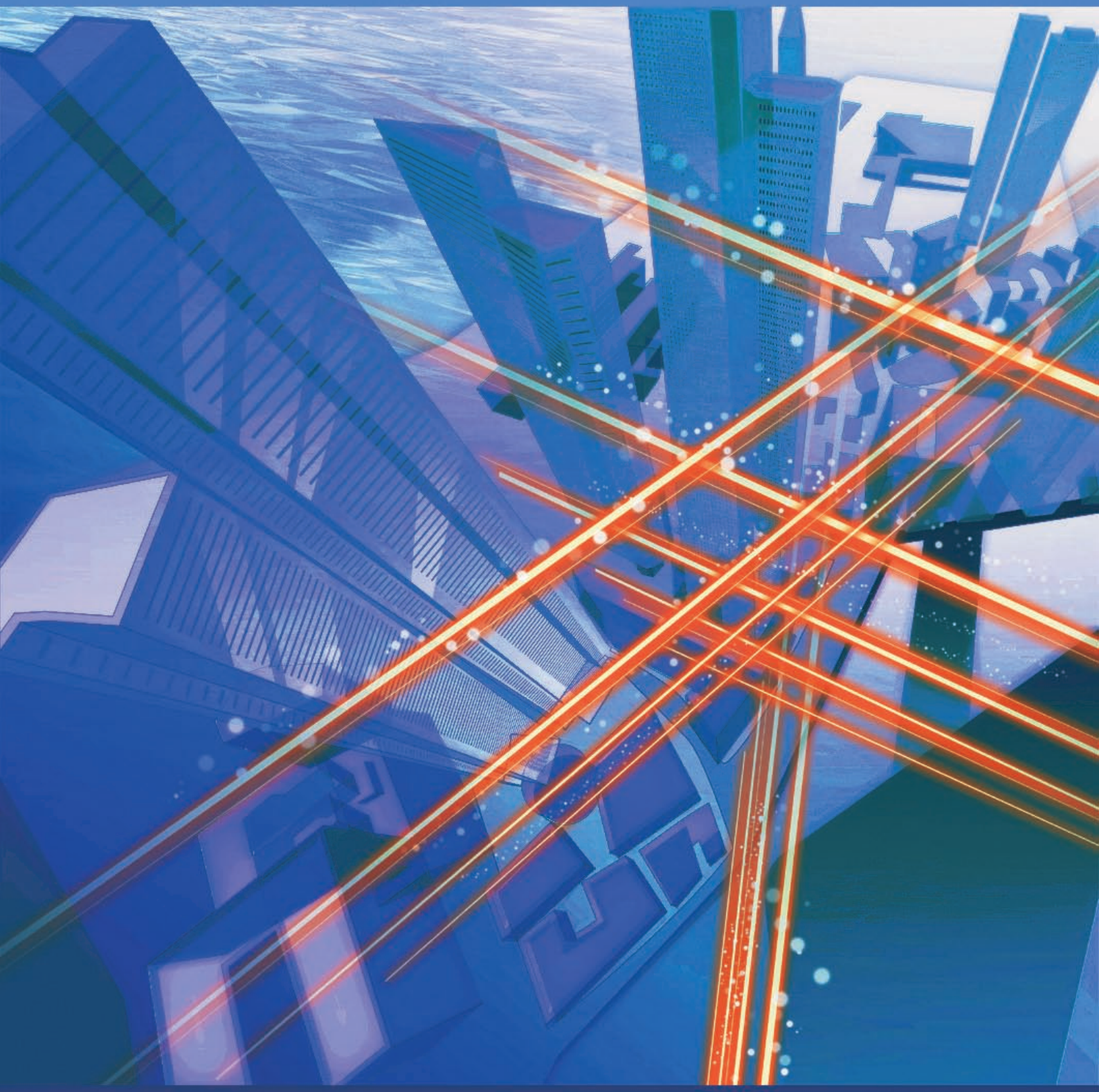
NTT Technical Review

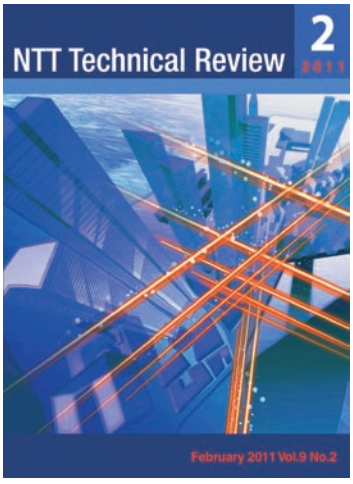
2
2011



February 2011 Vol.9 No.2

NTT Technical Review

February 2011 Vol. 9 No. 2



Researching What Should Be Researched

Hiroshi Saito
Senior Distinguished Researcher, NTT Service Integration Laboratories

Hiroshi Saito, an NTT Senior Distinguished Researcher, was the first in the world to propose *Interdisciplinary Network Science* as a field that attempts to systematically bring together existing traffic theories. We asked him about the present state of traffic research and the future outlook for this field.

Traffic research today

—Dr. Saito, what exactly is communications traffic?

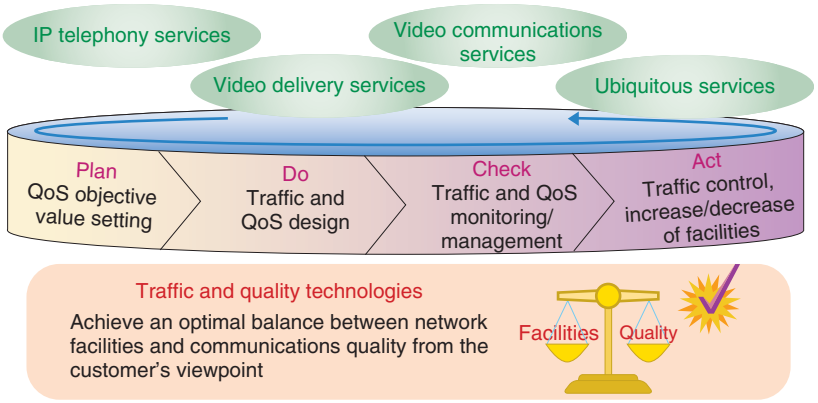
Well, since traffic in communications is something that we cannot see with the naked eye, we can draw an analogy with traffic on city streets. To begin with, *communications traffic design* corresponds to street design in which the number of lanes expected to be needed must be determined. We can see how, if only one lane is provided, the arrival of many cars will result in a huge traffic jam. *Communications traffic control*, meanwhile, corresponds to the switching between red and green traffic signals. Here, we can imagine the traffic jam that would ensue at an intersection if the intersecting road with fewer cars were given a long green light and while the other road were made to endure a red light for the same period of time.

Now, lying between design and control, there is also *traffic management* or simply *traffic monitoring*, which serves to measure present conditions and take immediate measures. In a similar manner, the state of major traffic intersections is continuously monitored. Here, the extent of congestion and the waiting time required at an intersection as well as the time needed to arrive at the destination are all related to quality.

Finally, *traffic theory* is what helps to determine such traffic phenomena and execute suitable measures. Traffic theory is not so much the principles of communications but rather a set of principles supporting communications as a public service. If applied correctly, traffic theory will not only provide correct values, but also help to provide optimal control methods and system configurations (**Figs. 1** and **2**).

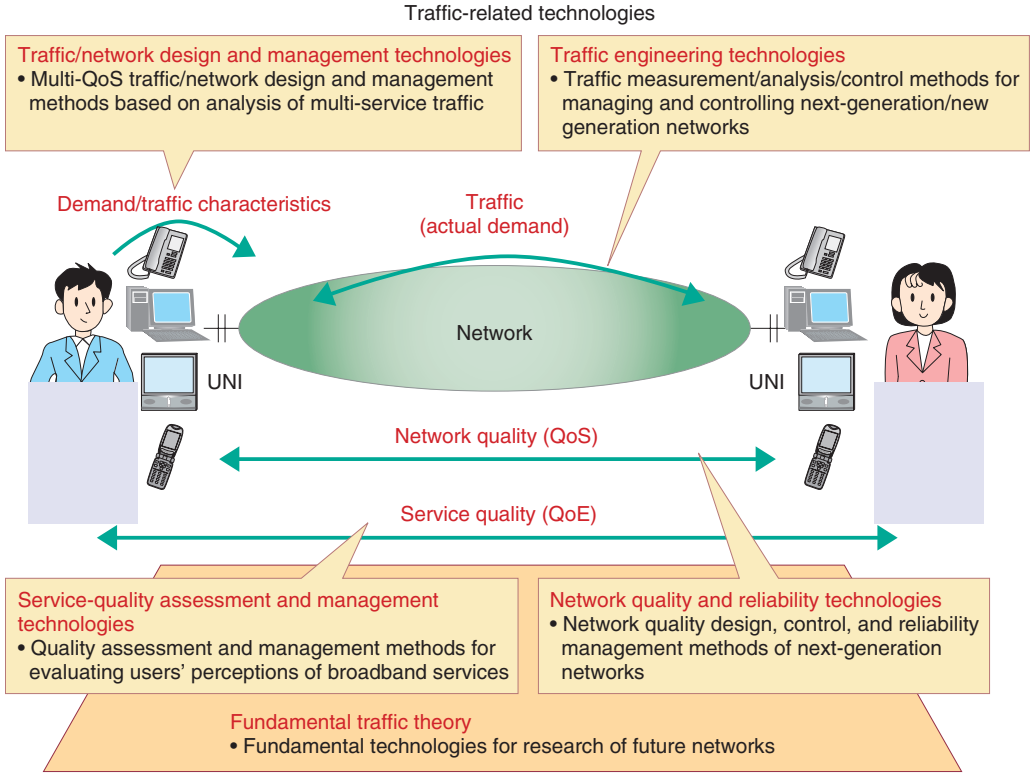
—Isn't traffic research in Japan making good progress on the global scene?

Some twenty years ago, AT&T (Bell Laboratories) in the USA had an overwhelming presence in this field in terms of the number and quality of papers and number of researchers. At that time, it was said that NTT was the next AT&T (Bell Laboratories), and with the breakup of AT&T (Bell Laboratories), I believe that NTT is leading from the global perspective.



IP: Internet protocol
QoS: quality of service

Fig. 1. Communications services and traffic-quality technologies.



QoE: quality of experience
UNI: user-network interface

Fig. 2. Traffic-related technologies.

—How has traffic research progressed since you came to be involved in this field? And for that matter, how does one measure progress in traffic research?

The principles of traffic theory as reflected by the formulas created by A. K. Erlang, the founder of traffic theory, have been around for more than a hundred

years. But the target systems are no longer just telephones, and even in the case of telephone systems, networks have become increasingly complicated. In traffic research, the communications systems that we apply traffic theory to are changing rapidly, and our task is to ensure that mathematical theory keeps up with those changes.

In the period from the 1960s to the 1980s, great progress was made in the application of mathematics in many areas of traffic research. Perhaps the fact that computers came into practical use during this period, enabling rigorous computations to be made, had a lot to do with this development. Here, the clarification of a mathematical principle in one area served to inspire and promote progress in surrounding areas. As a result, this period saw a peak in the number of papers published in the field of traffic research.

And speaking of advances in systems targeted by traffic theory, we have seen great changes take place at a rate of about one new system every ten years, as reflected by the transitions from the telephone network to ISDN (integrated services digital network), ATM (synchronous transfer mode), and the Internet. There is now great variation in the equipment used and services provided by communications systems, and as target systems expand, traffic theory must expand as well.

—Do you mean to say that these changes continue to this day?

That's right. During the hundred-odd years of the telecommunications business, traffic theory has played an integral role, but it is now at a turning point. This is because of the following significant changes in the business environment.

(1) Customer equipment (such as personal computers) has diversified and is reaching high levels of performance and functionality with the result that control performed only within the network prevents satisfactory control from being achieved.
(2) The significance of highly accurate network design has fallen with the coming of the Internet as a best-effort service and notable drops in the cost of equipment.
(3) Theory cannot keep up with the changes occurring in mainstream applications. The basic assumptions and hypotheses that have held since the Erlang era are losing their validity.
(4) Alternatives to traffic theory such as computer simulation are emerging.

In the face of this changing environment, a number of phenomena have appeared that contradict traffic theory originating in the Erlang era.

—In what direction, then, will traffic research proceed in the years to come?

Looking forward, one of our concerns is the direction that traffic characteristics will take. Specifically, of great interest here is whether that direction will conform to conventional traffic theory as shown by the blue plot in **Fig. 3** or be completely different as shown by the red plot. At first, many researchers predicted that traffic characteristics would take a direction completely at odds with existing traffic theory, but I am of the opinion that they have recently been returning to a direction conforming to existing traffic theory.

For example, Internet users often obtain desired information in an abrupt manner, and then, after a relatively long period of inactivity, suddenly obtain more information. This kind of activity leads to burst-like traffic characteristics. However, user traffic that has been increasing dramatically of late is of the stream type as in watching videos. In the case of stream-type traffic, the network is used in a semi-continuous manner. This means that traffic characteristics are also moving in a direction similar to that of telephone use, and in a sense, in a network-friendly direction. Of course, the dramatic increase in traffic volume requires a dramatic increase in network capacity, but in the case of a quantitative treatment, it may be possible to use methods based on existing traffic theory in an efficient manner. At the same time, traffic characteristics must be continuously monitored to see whether they are actually moving in that direction. Theoretical studies must also be performed if traffic characteristics should be found to be moving in a completely different direction.

Interdisciplinary network science

—Is traffic research flourishing worldwide?

No, it's not. Because of the four environmental changes I described earlier, research related to traffic theory is somewhat sluggish around the world. One major reason for this may be the slowdown in research and development (R&D) at network operators. In such an environment, we might wonder what role traffic theory will play over the next hundred years, and we can consider that traffic theory as we have

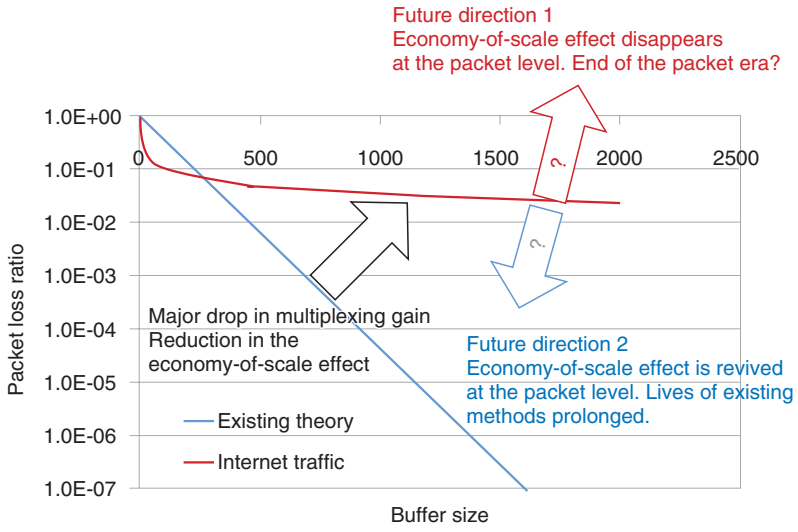


Fig. 3. Directions of traffic characteristics.

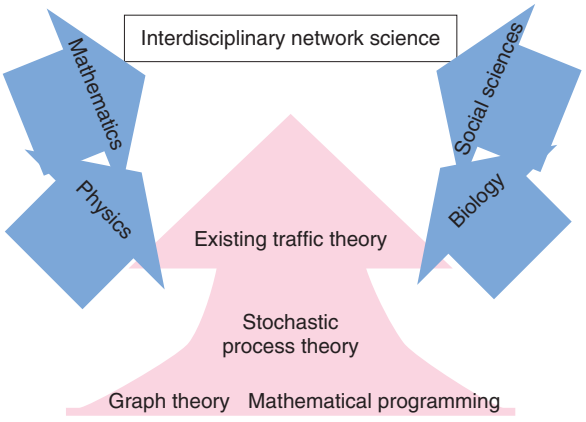


Fig. 4. From traffic theory to interdisciplinary network science.

known it may need to be revised.

In this regard, I would like to establish *interdisciplinary network science* as an orderly theoretical system that incorporates elements of peripheral fields such as biology, the social sciences (economics etc.), mathematics (integral geometry etc.), and physics (statistical physics etc.) in traffic theory, which is based on stochastic process theory (statistical theory), using graph theory and mathematical programming as supplementary tools (**Fig. 4**).

—Are there researchers who are spurred on by the ideas that you espouse?

Well, though not exactly the same, there are people in Japan researching network control using living things for reference, as in bio-inspired networking, and in the social sciences, there are people working on wireless protocol design using game theory. Workshops related to such endeavors have been held in recent years. Various types of interdisciplinary research have therefore been pursued but in a separate, independent manner. My desire is to bring these fields together in a systematic way.

Researching what should be researched

—Dr. Saito, how did you come to be involved in traffic research?

Well, all I can say is that when I entered the company, I was simply assigned to the traffic research laboratory. Although I've been holding management-related positions the last ten years or so and have been in charge of ubiquitous service systems, I spent about twenty years in the traffic research laboratory. Actually, my original desire was to perform basic research on speech, but in 1983 when I entered the company, preparations were being made to set up a special laboratory for traffic research. The personnel manager called me and told me that traffic research "was on the verge of becoming a very significant field". After he persuaded me of its importance and received my agreement, my assignment was finalized. Come to think of it, at that time the only thing I knew about

NTT Laboratories was speech research, and I had not even been specializing in speech studies at school. All things aside, my career since entering the company has been involved with traffic research, which initially was an unknown world to me. I can see now that this is how a researcher can develop a specialty.

—Do you find traffic research, which is always presenting new challenges, an attractive field? Have you had real feelings of achievement here?

Yes, I do find it an attractive field. Network and traffic research are essential areas of research at NTT Laboratories, and I realize that I am working near the center of things. As for having real feelings of achievement, it's hard to say. For example, when evaluating achievements in control systems, if at least one achievement has already been obtained, it will become apparent when a second achievement can be obtained. However, to obtain achievements in traffic research, you need the help of third-party developers who provide the hardware and software to make your research a reality—without them, specified targets cannot be achieved. Thus, even if journal papers have been completed and experimental results obtained, it may be some years before your research is fully implemented. In this sense, it is somewhat difficult to determine when achievements have actually been obtained.

—Times in research when no clear answers can be obtained must be psychologically difficult to handle. How do you feel about this?

Traffic research is not a field in which you can draw a blueprint indicating what specifically can be obtained a certain number of years later. The more difficult the research is, the more likely it is that no answers will be obtained. Of course, it's a great relief if answers are eventually obtained. Obtaining an answer is really a great moment, but the time taken up by research to get to that answer may be quite long. We go through this all the time. Looking back twenty years or so, I think there have been only twenty or thirty such moments, some more important than others. There have also been periods when no answers at all were forthcoming and I was just wondering what to do. Such answers could not be obtained simply because I wanted to absolutely obtain such and such a result within that period, so until that moment of relief arrived, my stomach was all tied up in knots. That's because there was no one around that could help me! (smiles).

—How would you characterize your own research style?

I work regular hours and take home as little work as possible. Perhaps I don't fit the stereotype of a researcher, contrary to your expectations. A research style that is overly earnest to the point of frequently working late hours is not conducive to a healthy body. It's like being awfully tired when studying for a test in a difficult subject during one's student days. That's the feeling. If you push yourself too hard, you will damage your health. The content of research is also important. I believe that it is essential to research what you should be researching. If you understand what you should be researching, I think your research is already half done. That's why I'm always thinking about what I should be researching.

At the beginning of a research phase, if a researcher can envision what will be important over the next ten years, it will become clear what to place more weight on during that research and what outputs to expect. Furthermore, as that research gradually comes to an end, the researcher should look around to determine what research to do next and then repeat the research cycle. I believe that a researcher who is very clear about what he or she should be doing next is a very fortunate person. After twenty years of continuous research, the world has become quite diversified, and I find myself in a situation in which major objectives and clear directions cannot be obtained at all. Under these circumstances, I look around again to see what research is needed.

To this end, I monitor what researchers around the world are thinking and trends in peripheral fields. For this, my main survey tool is the Internet, but I think it is also important to actually meet with a variety of researchers to exchange opinions. Recently, on visits to manufacturers, research laboratories at NTT DOCOMO, overseas institutions, and university research laboratories, I've been able to engage in such discussions as a step prior to preparing a journal paper. In this way, I can learn more not just about traffic theory itself but also about how the targets of traffic theory are changing and how its use is changing from various perspectives, which becomes great reference material.

To young researchers

—On listening to what you have to say about research, it appears that researchers have a very solitary existence.

Well, that depends on the type of research. Some researchers are part of a group, and I myself get research tips by talking to fellow researchers. It sometimes happens that talking to researchers with a slightly different specialty to my own can suddenly reveal a solution that previously eluded me. I don't know if that answers your question, but I think that solitude is a problem associated with one's frame of mind. For example, even a researcher carrying out research as a member of an organization may feel a sense of solitude. However, individual researchers who feel a sense of solitude must keep in mind that, in a research organization, 1 + 1 in terms of research output does not equal 2 but rather 3 or 4.

At NTT Laboratories, total R&D strength is not simply the sum of all individual researcher expertise—individual strengths have a mutually augmenting effect on each other. This is what I would like researchers to keep in mind.

—What, then, should young researchers do? Could you leave us with a message for them?

Even if you're working as if the world depended on it, leave some energy to spare. While working on research that can realistically result in output, save enough physical energy for answers to problems that potentially lie ahead. Rushing around without leaving yourself any reserve cannot last forever. In this regard, I would like young researchers to interpret the saving of energy in research work as an actual ability. You need different approaches to find an answer that is needed soon and one that will be needed far in the future. Even updating consecutive answers in a sequential manner will not necessarily result in the far-future answer. I would like young researchers to be aware of this.

As I explained earlier, it's vitally important to consider what to research next. After saving some energy for future research, I would like young researchers to always be thinking about what they should be researching.

Hiroshi Saito

Senior Distinguished Researcher, NTT Service Integration Laboratories.

He received the B.E. degree in mathematical engineering, the M.E. degree in control engineering, and the Dr.Eng. degree in teletraffic engineering from the University of Tokyo in 1981, 1983, and 1992, respectively. He joined Nippon Telegraph and Telephone Public Corporation (now NTT) in 1983. He received the Young Engineer's Award from the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan in 1990, the Telecommunication Advancement Institute Award in 1995 and 2010, and the Excellent Papers Award from the Operations Research Society of Japan (ORSJ) in 1998. His research interests include traffic technologies of communications systems, network architecture, and ubiquitous systems. He is a fellow of IEEE, IEICE, and ORSJ and a member of IFIP WG 7.3.

Environment and Energy Technologies Toward a Green Society

Morito Matsuoka†

Abstract

This article provides an overview of NTT Energy and Environment Systems Laboratories' research and development (R&D) objectives and initiatives to move the country toward a green society. Our ambitious R&D agenda is based on three key concepts—*Green ICT*, *Green materials*, and *Governance by Green*—with the goal of completely eliminating CO_2 emissions and waste generated by the NTT Group's business activities by the year 2050.

1. Introduction

Countries all over the world are stepping up efforts to reduce greenhouse gas (GHG) emissions following the onset of the Kyoto Protocol's first commitment period in 2008. Japan is also moving aggressively to reduce global warming with recent revisions to its Law Concerning the Promotion of Measures to Cope with Global Warming, Law Concerning the Rational Use of Energy, Tokyo Metropolitan Ordinance on Environmental Preservation, and other statutes.

The research and development (R&D) work of NTT Energy and Environment Systems Laboratories is helping mitigate global warming and move us toward a zero-waste society by reducing CO_2 emissions and saving natural resources associated with the NTT Group's business activities.

2. R&D policies of NTT Energy and Environment Systems Laboratories

Committed to a vision of creating technologies that will steadily reduce CO_2 emissions and make the NTT Group into a zero-waste company by the year 2050, NTT Energy and Environment Systems Laboratories is pushing ahead with three basic R&D objectives: *Green ICT* to reduce CO_2 emissions, *Green Materials* to save natural resources, and *Governance by Green* to promote environmental management (**Fig. 1**).

Green ICT is the concept of technologies for reducing CO_2 emissions of and by information and communications technology (ICT). It has two aspects: *Green of ICT* seeking to reduce the environmental impact of ICT equipment itself and *Green by ICT* seeking to reduce the environmental impact on society by utilizing ICT services.

Green Materials is the concept of technologies for saving natural resources that will impose minimal environmental loads and reduce waste disposal costs. Green Materials similarly has two aspects: *Green of Materials* seeking to reduce waste of materials themselves and *Green by Materials* seeking to reduce waste by exploiting the functional properties of materials.

Governance by Green is the concept of leading the way through the activities of the NTT Group and NTT R&D to CO_2 emissions reductions and natural resources savings.

These concepts are based upon our belief that no matter how good the performance of the products and services provided by the NTT Group, customers will not be really satisfied with them unless they are eco-friendly.

The main R&D themes being addressed by NTT Energy and Environment Systems Laboratories are overviewed in **Fig. 2**. These themes reflect our core competencies in the following areas.

- Power supply: Design of direct current (DC)

† NTT Energy and Environment Systems Laboratories
Musashino-shi, 180-8585 Japan

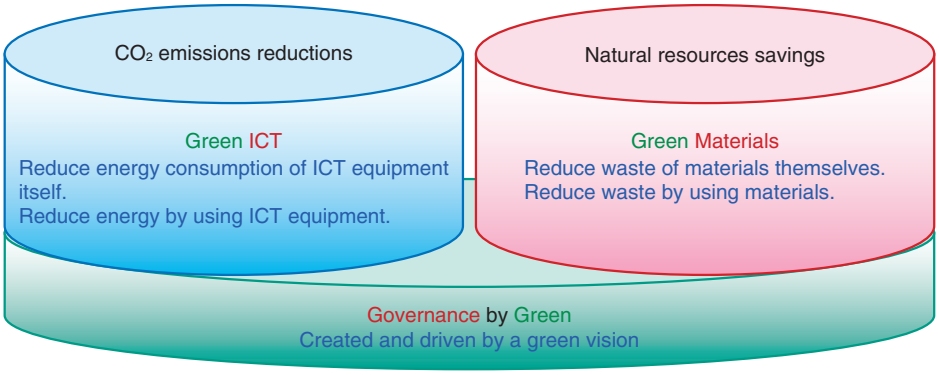


Fig. 1. R&D policies of NTT Energy and Environment Systems Laboratories.

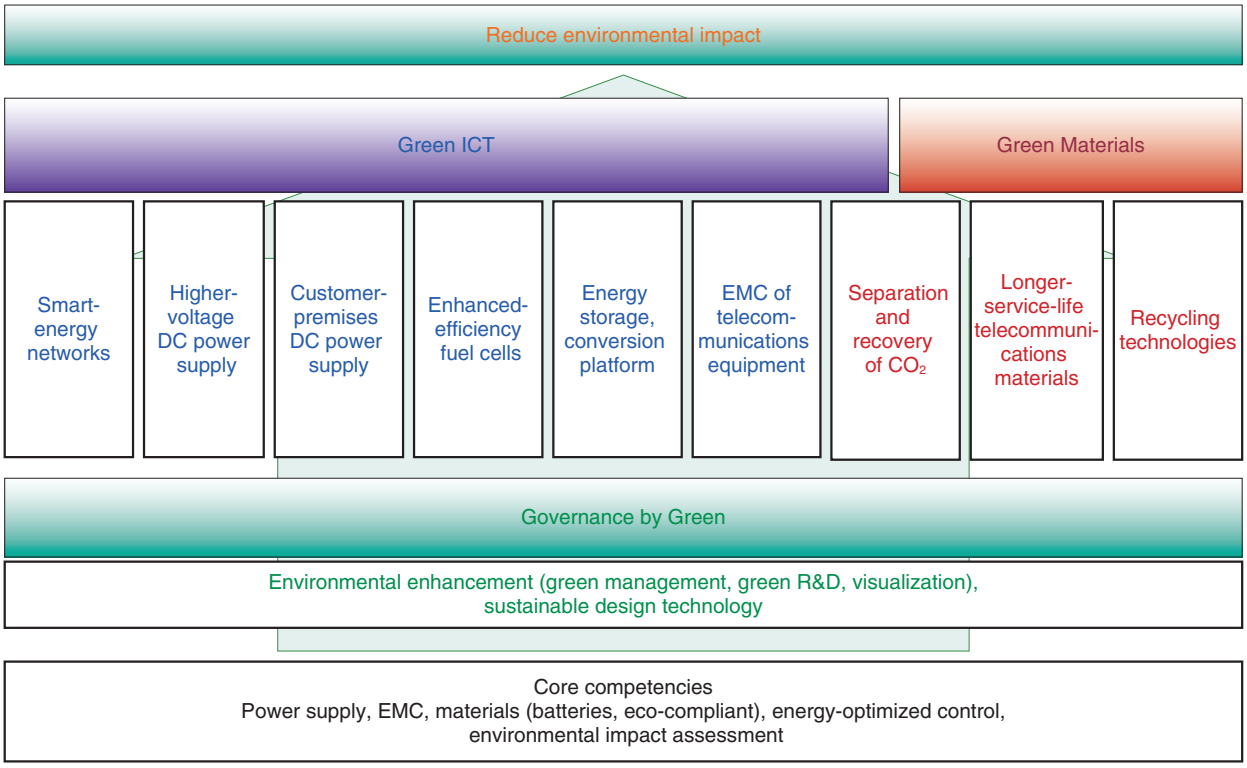


Fig. 2. R&D themes of NTT Energy and Environment Systems Laboratories.

supply systems for communications, technologies for improving reliability, techniques for analyzing and assessing power supply systems.

- Electromagnetic compatibility (EMC): Techniques including ones for testing, evaluating, and countering electromagnetic emissions (EMC problems), immunity, and overvoltage (lightning protection).
- Materials: Controlling interfacial reactions using nanoporous structures, regulating surface properties of materials by adding corrosion resistance or lubrication, and so on.
- Optimal control of energy: Optimal operation and design of distributed energy sources.
- Environmental impact assessment: Quantitative techniques for evaluating the environmental

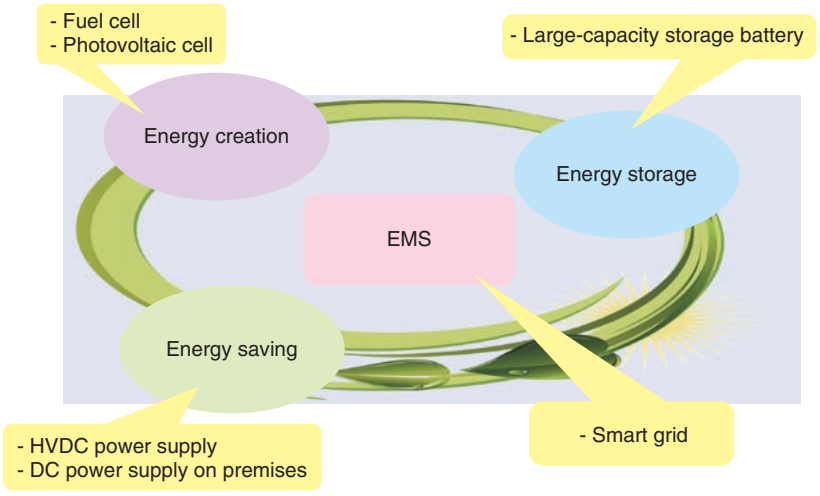


Fig. 3. R&D to reduce CO_2 emissions (Green ICT).

impact of telecommunications equipment and ICT services based on life cycle assessment.

These technologies are described in detail in the other Feature Articles in this issue. Here, I merely outline some of the main research initiatives related to the three R&D concepts: Green ICT, Green Materials, and Green by Governance.

3. R&D to reduce CO_2 emissions (Green ICT)

As illustrated in **Fig. 3**, Green ICT helps reduce CO_2 emissions through a medium-to-long-term commitment to energy-saving technologies, energy-creating technologies, energy-storing technologies, and an energy management system (EMS) for controlling and fully exploiting these technologies.

3.1 Energy-saving technologies

Energy-saving technologies encompass a wide range of equipment and systems designed to reduce the energy requirements of ICT equipment itself, enhance the efficiency of power supply systems, and reduce the energy demands of air conditioners and other facilities closely associated with ICT equipment.

One energy-saving technology under development at NTT Energy and Environment Systems Laboratories is a higher-voltage direct current (HVDC) power supply system [1]. Replacing alternating current (AC) supplies with DC supplies in datacenters and other facilities reduces power losses by approximately 15% since fewer power conversion steps are involved. Moreover, stepping up the voltage means that a lower current can supply the required power, which permits the use of smaller diameter cables. This represents a double win: energy is saved and less copper is used in the cables. We are also working on an energy-thrifty customer-premises DC power supply system for deployment in households [2].

3.2 Energy-creating technologies

Energy-creating technologies can generate low-carbon clean energy. One project currently under way at NTT Energy and Environment Systems Laboratories is a collaborative effort to produce a high-efficiency solid oxide fuel cell (SOFC). The SOFC is expected to yield an enormous increase in power generating efficiency to over 50% in power generating efficiency [3]. Another project exploits a characteristic feature of fuel cells by recovering and reusing the pure CO_2 emitted from the cells.

3.3 Energy-storing technologies

Energy-storing technologies are essential to safeguard the reliability of communications networks by providing a backup power source in the event that the main power source fails. In this area, NTT Energy and Environment Systems Laboratories is working on a large-capacity storage battery for communications that reduces the footprint of the backup power system, is cost-effective, and has a very long operating life.

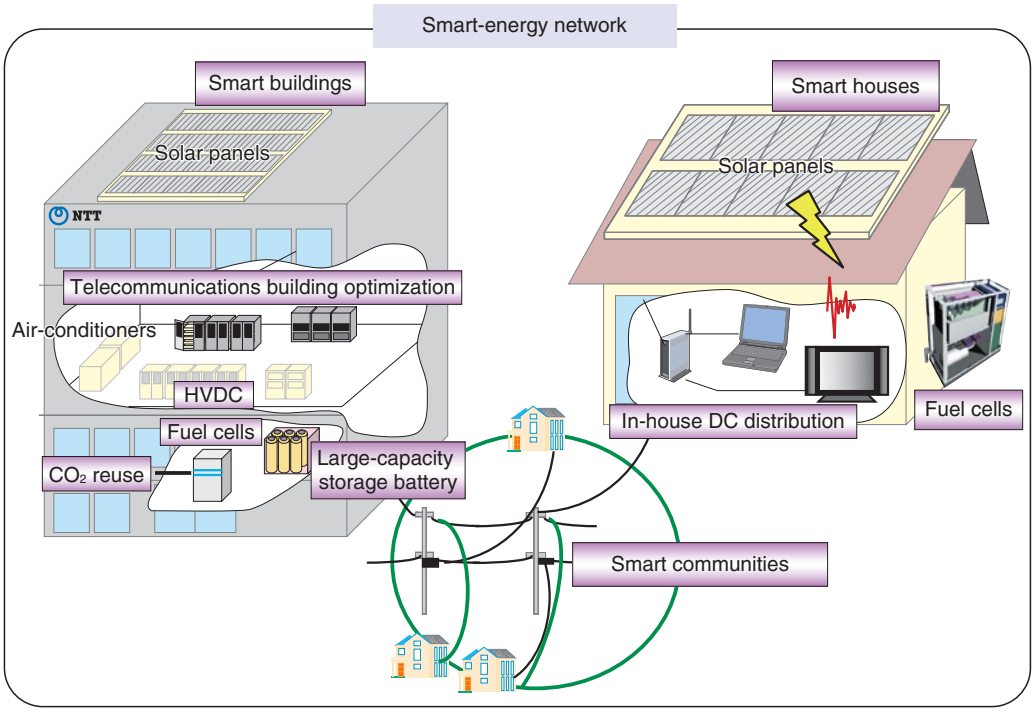


Fig. 4. Technologies supporting the smart-energy network.

3.4 Energy management system

While pursuing research on energy-saving, -creating, and -storing technologies, we must maintain optimum control over these technologies. This is done by the EMS (Fig. 3). NTT Energy and Environment Systems Laboratories has focused on the control of distributed power sources by ICT and on developing a smart energy network that maintains an optimal balance between supply and demand for electrical power.

A schematic of a smart energy network encompassing smart buildings, smart houses, and smart communities based on technologies developed by NTT Energy and Environment Systems Laboratories is shown in **Fig. 4**.

This field is showing increasing promise, so we have been pouring more resources and effort into this technology.

4. R&D to save natural resources (Green Materials)

As shown in **Fig. 5**, NTT Energy and Environment Systems Laboratories has stepped up resource-saving Green Materials efforts with emphasis on (1) lifetime-control technologies that extend the useful service life of natural resources as long as possible and (2) recycling technologies that promote reuse of value-added materials.

NTT Group discards close to 300,000 tons of obsolete telecommunications equipment every year. The sheer volume of waste strains the capacity of landfills and has other adverse effects on the environment, not to mention disassembly and processing costs. NTT Energy and Environment Systems Laboratories is pursuing R&D of various technologies to extend the useful service life of products and materials. This includes investigating the deterioration mechanisms of materials and technologies to extend the life of materials and developing diagnostic tools for visualizing corrosion caused by marine environments (salt damage) and other adverse conditions [4]. Moreover, we are trying to establish design-for-zero-waste and recycling technologies with the goal of minimizing the use of natural resources in telecommunications equipment throughout its life cycle.

5. R&D to promote environmental initiatives (Governance by Green)

NTT Energy and Environment Systems Laboratories is working to develop a way of quantifying

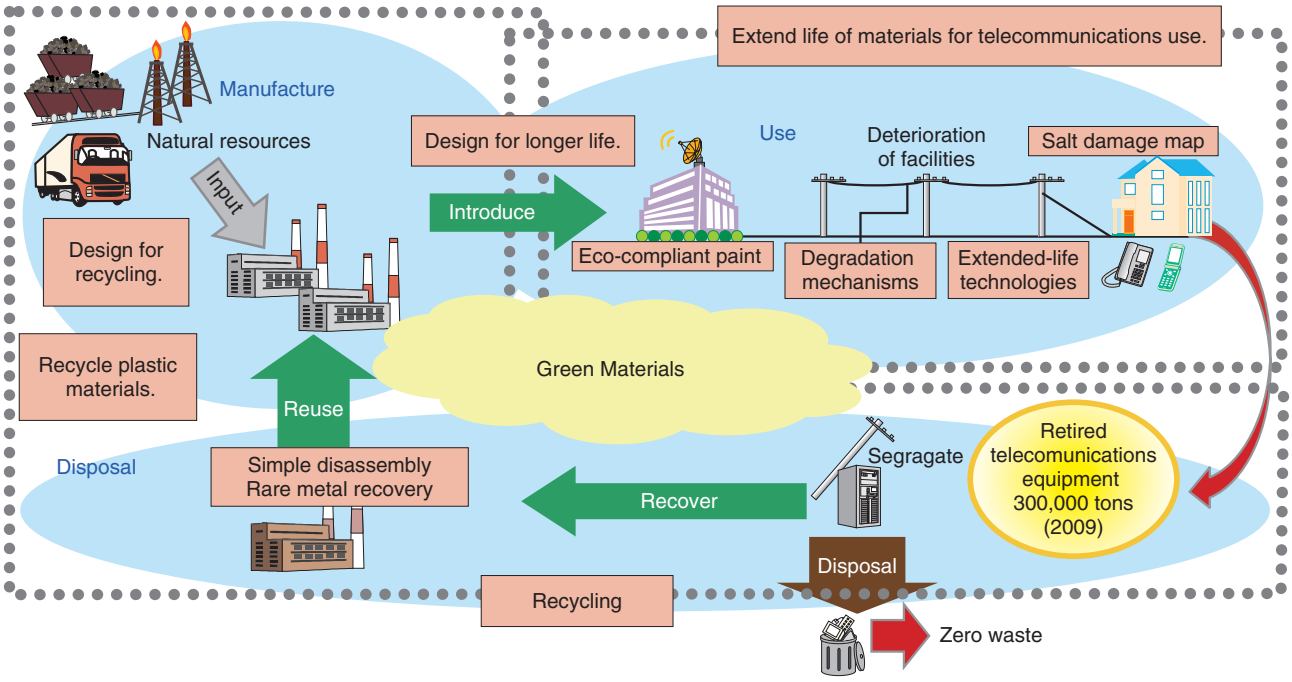


Fig. 5. R&D to save resources (Green Materials).

Governance by Green

Fig. 6. Logo of NTT Energy and Environment Systems Laboratories.

environmental load reduction effects by utilizing ICT (Green by ICT) as one activity in Governance by Green. Green by ICT requires some quantifiable and objective means of assessing how effective ICT services are at reducing CO_2 emissions. Once users become aware of the environmentally friendly nature of ICT services, this should enhance the popularity and the competitiveness of ICT services. While seeking to establish techniques for assessing the environmental impact of ICT services, NTT Energy and Environment Systems Laboratories is promoting the NTT Group's *Solution Eco Label* [5] system and other group environmental measures and strongly supports the adoption of these practices as international standards.

6. Future prospects

This article provided an overview of NTT Energy and Environment Systems Laboratories' R&D objectives and initiatives. Considering how NTT addresses environmental issues in a way that cuts across the NTT Group as a whole as well as NTT R&D, collaboration and cooperation among society at large, NTT Group companies, and other research institutes will become increasingly important in the years ahead. We created the Governance by Green logo shown in **Fig. 6** to represent the NTT Group's commitment to environmental research and the tremendous role this research plays in addressing the environmental challenges of today. While maintaining open dialog and working in line with public interests, NTT Group companies, and other NTT R&D laboratories, we plan to step up our commitment to R&D in the fields of energy and the environment to help bring about the green society.

References

[1] Y. Nozaki, "Development of Higher-voltage Direct Current Power Feeding System for ICT Equipment," NTT Technical Review, Vol. 7, No. 10, 2009.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr2009URL10sf2.html

[2] M. Yamamoto and T. Babasaki, "Customer Premises DC Power Supply, Energy-saving Services, and Other Energy-saving Initiatives for General Households," Business Communication, Vol. 47, No. 1, pp. 10–11, 2010 (in Japanese).
[3] K. Hayashi, M. Yokoo, Y. Yoshida, and H. Arai, "Solid Oxide Fuel Cell Stack with High Electrical Efficiency," NTT Technical Review, Vol. 7, No. 10, 2009.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr2009URL10sf3.html
[4] T. Sawada, Y. Takeshita, H. Saito, Y. Higashi, S. Sakada, and T. Handa, "Recent Strides to Make Telecommunications Plant More Environmentally Friendly and Reliable," NTT Technical Review, Vol. 7, No. 10, 2009.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr2009URL10sf4.html
[5] NTT Group's *Solution Eco Label*.
http://www.ntt.co.jp/kankyo/label/index.html

Morito Matsuoka
Executive Director, NTT Energy and Environment Systems Laboratories.
He received the B.E., M.E., and D.Eng. degrees in electrical engineering from Tokyo Institute of Technology in 1980, 1982, and 1985, respectively. He joined NTT in 1985. He moved to NTT Energy and Environment Systems Laboratories in 2009. His research in NTT has been concerned mainly with thin-film processes, photonic communication systems, and environmental technology. He is a member of IEEE, the Institute of Electronics, Information and Communication Engineers of Japan, and the Japan Society of Applied Physics.

Higher-voltage Direct Current Power-feeding System

Kaoru Asakura†, *Toshimitsu Tanaka, and Tadatoshi Babasaki*

Abstract

In this article, we introduce activities aimed at spreading the use of higher-voltage direct current (HVDC) power-feeding systems. We introduce the state of development of HVDC systems, improvements in operability, and standardization trends.

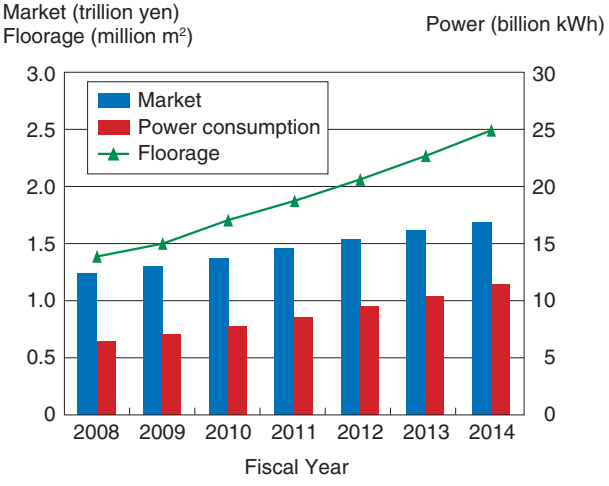
1. Introduction

With the recent spread of optical fiber services, the resulting improvement in environments for Internet use has made the use of high-volume content such as video commonplace, and the overall volume of Internet traffic has increased sharply. According to a report by the Ministry of Economy, Trade, and Industry (METI), the power consumed by information and communications technology (ICT) equipment such as servers and routers continues to increase every year. It is expected to exceed five times the 2006 levels by 2025 and to account for more than 20% of domestically generated electrical power [1].

Trends and forecasts for the Japan datacenter market and its power consumption are shown in **Fig. 1**. All items show a year-to-year increase, and yearly power consumption is expected to exceed 10 billion kWh in FY2013. Power consumption at datacenters running large amounts of ICT equipment, such as servers and routers, is already a major issue.

Examples of energy saving initiatives at datacenters are shown in **Fig. 2**. Power consumption is being reduced by replacing ICT equipment in the datacenter by low-power equipment. Utilization rates are being improved through technologies such as virtualization and cloud computing, which also contribute to power saving in datacenters, and improvements are also being made to datacenter facilities, such as the air conditioning and power supplies for ICT equipment.

Higher-voltage direct current (HVDC) power-supply technology improves the supply of power to ICT equipment and also contributes to energy savings in the overall system, including aspects such as air conditioning. For these reasons, organizations around the world have begun studying the use of DC power for datacenters, where AC power supply has been the norm.



Source: MIC Research Institute Ltd.

Fig. 1. Trends and forecasts for the Japan datacenter market and its power consumption.

† NTT Energy and Environment Systems Laboratories
Musashino-shi, 180-8585 Japan

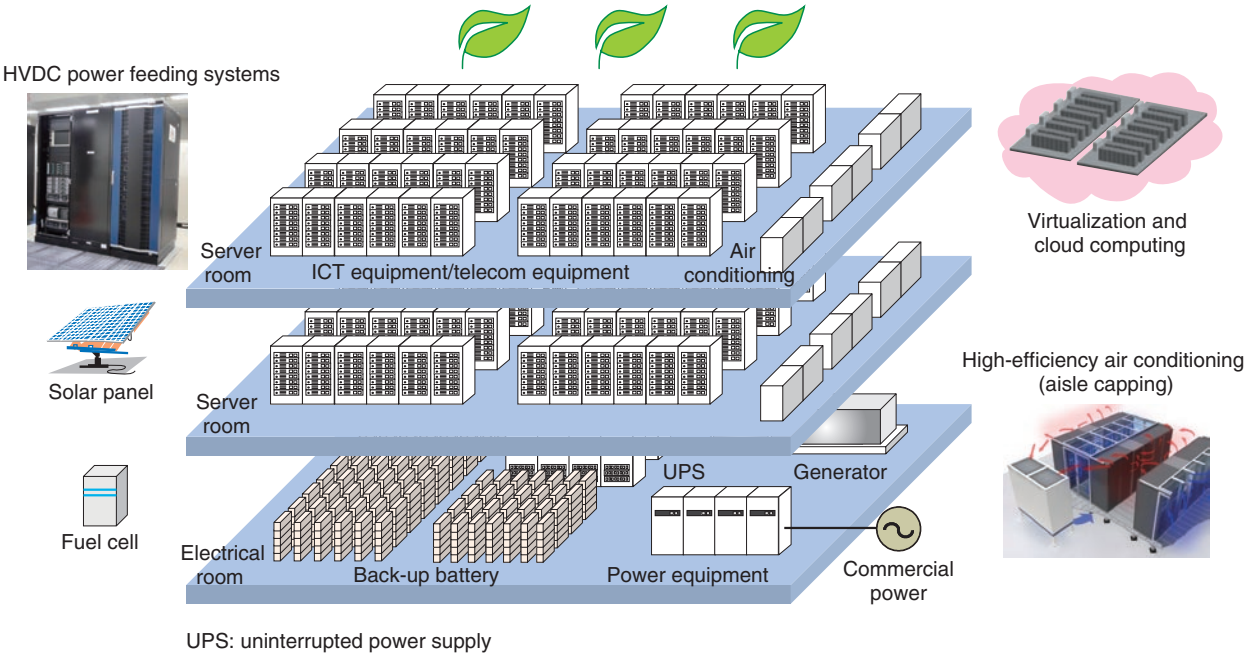


Fig. 2. Examples of energy saving initiatives at a datacenter.

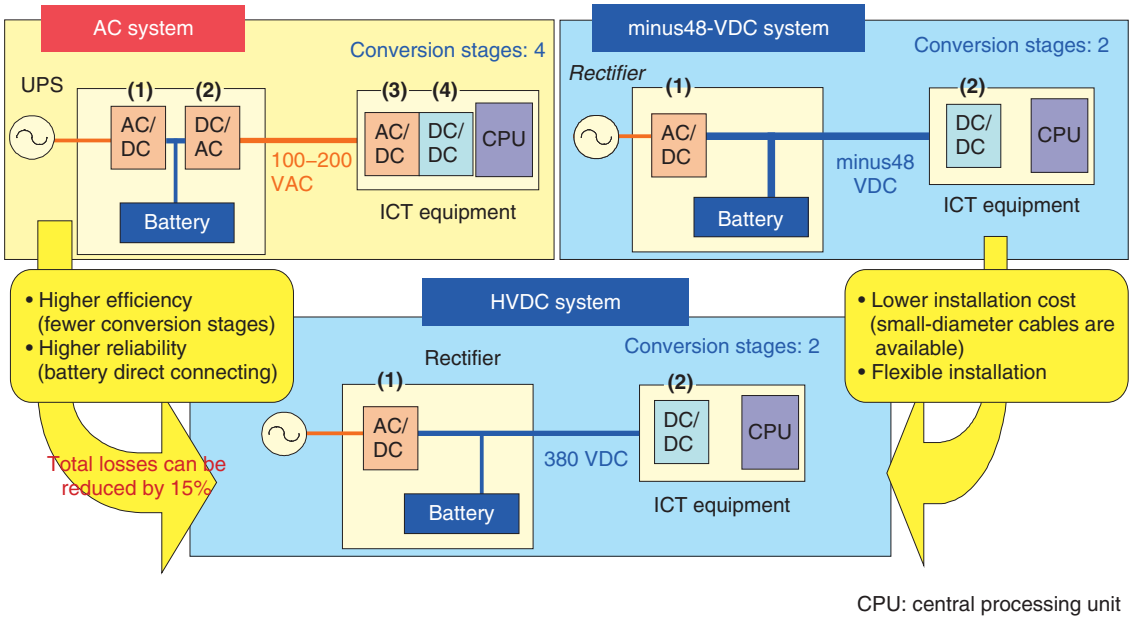


Fig. 3. Advantages of HVDC power supply systems.

2. HVDC power supply systems

The advantages of DC power supply systems are shown in **Fig. 3**. Compared with AC power, DC power uses fewer conversion stages from AC to DC and from DC to AC, which reduces conversion losses, and the reliability of DC systems is 5×10^{-7}, which is more than an order of magnitude better than that of

AC power systems.

A –48-VDC power supply system is already in wide use for telecommunications systems, making maximum use of its energy savings and high reliability. Increasing the voltage to 380 V reduces the amount of current required to supply power, so power cables can be made thinner, which reduces facilities costs for cabling.

An example of the breakdown of power consumption in a datacenter using an AC power supply system, together with the expected reductions due to switching to HVDC system are shown in **Fig. 4**. Compared with the AC power supply system in Fig. 3, the DC/AC conversion at (2), and the AC/DC

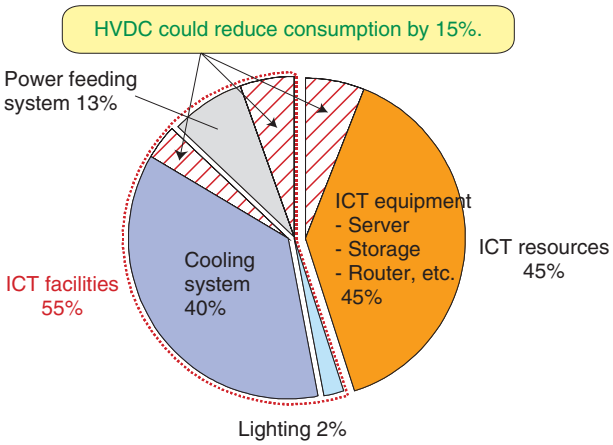


Fig. 4. Power consumption breakdown for datacenter.

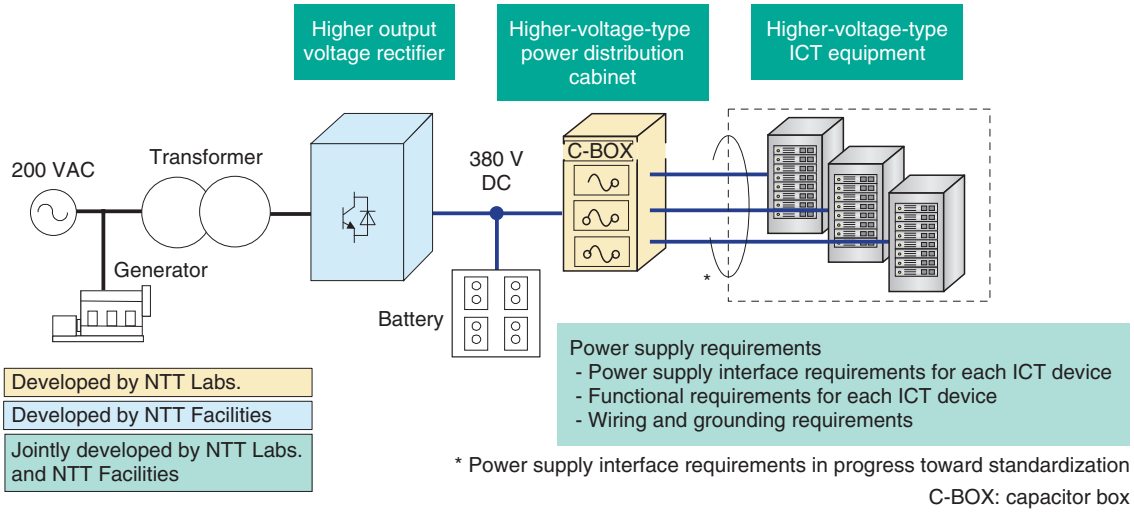


Fig. 5. Architecture of the HVDC power supply system.

PDC: power distribution cabinet

Fig. 6. External view of the HVDC power supply system.

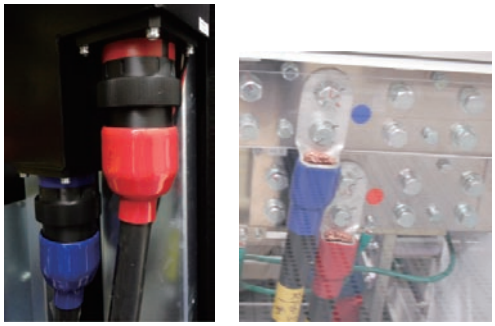
Table 1. Specifications for rectifier and power distribution cabinet

Input voltage		3-phase 180–240 VAC
Output voltage		383 VDC ±1%
Rated power (per cabinet)		100 kW
Rated power (per unit)		15 kW
No. of rectifier units		8 (N+1 redundancy)
Conversion efficiency		92% (min.) (at 30% load) 94% (min.) (at 50% load)
Input	Max capacity	100 kW × 2 systems
Output	Max. capacity	7.9 kW/port
	No. of ports	20 ports × 2 systems

conversion at (3) will be unnecessary with DC power, so conversion losses will be lower. Furthermore, the heat generated by ICT equipment and power supply systems and the accompanying power consumption will also be reduced, so effective overall consumption is expected to be reduced by 15% or more [2].

3. HVDC development

The architecture and external views of the HVDC power supply system being developed by the NTT Group are shown in **Figs. 5** and **6**, respectively. The architecture is similar to the conventional –48-VDC system. The HVDC system is composed of a rectifier, batteries, a power distribution cabinet, and ICT equipment designed to run on higher voltages (see **Table 1**). The system is rated for 100 kW output at 380 VDC. It takes commercial AC power and rectifies and converts it to 380 VDC, and this is used to float-charge batteries and supply power to the DC power distribution equipment, which distributes it to the ICT equipment. The power distribution equipment also has internal capacitors that stabilize the power supply system, suppressing faults such as oscillations, as well as fuses that immediately disconnect ICT devices in the unlikely case of a fault occurring. This minimizes any effect on other ICT equipment. The equipment also provides continuous, uninterrupted power through batteries or emergency generator equipment, which act as backup power sources during power outages. All power supply requirements for providing stable and safe power were studied and regulated, including power supply interface requirements, functional requirements, and wiring and earthing requirements.



(a) HVDC (b) -48 VDC (for reference)

Fig. 7. Input terminals.

4. Improvements for safety and deployment

Since an HVDC power supply system uses higher voltages than conventional –48-VDC power supplies, human safety must be considered carefully. Equipment must be developed with attention paid to additional safety issues, especially for direct current, such as arcing that can occur when a connection is cut while current is flowing through it.

The architecture of our system includes a grounding mechanism to avoid cases of shock at all costs and to minimize any effect on the human body. Moreover, connectors are constructed as shown in **Fig. 7**, concealing any electrically live parts to prevent any contact.

NTT Facilities has also developed an HVDC power bar and power plugs which enable ICT equipment to be connected and disconnected safely. These are structured so that electrically live elements cannot be touched, and when the plug is removed, a mechanical switch with an internal safety mechanism that forcibly breaks any arc is moved to the off position.

These improvements not only enable safe operation, but also make connecting and disconnecting power easier.

5. Migration to new equipment

When an HVDC power supply system is introduced, ICT equipment supporting HVDC power, such as servers and communications equipment, must also be procured in addition to power equipment such as rectifiers and distribution equipment. It is likely that initially, not all of the required server and communications equipment will support higher-voltage power, so rather than changing the entire power system framework, we have developed migration equipment which converts 380 VDC to 100 VAC, 200 VAC, and –48 VDC. This allows partial use of equipment that requires these conventional formats. This migration equipment enables the HVDC power supply system to be introduced smoothly, including during the transitional period as products supporting HVDC spread.

6. System testing

Since FY2008, the NTT Group has conducted repeated practical tests of safety and other factors at three demonstration sites within Tokyo, including basic power supply operation, long-term operating characteristics, and safety tests for potential incidents

such as short circuits.

Commercial devices have been developed with improvements to overcome issues found in early prototypes, such as circuit-breaking characteristics and increased density, and we have confirmed that these products can supply stable power safely for the range of ICT operating voltages [3]–[5].

Moreover, a demonstration test conducted last year by NTT DATA received the Green IT Award 2009 from METI [6]. For this demonstration, the HVDC power supply system exhibited stable operation and achieved a significant energy saving effect of 17% compared with AC power [5].

7. Standardization trends

HVDC power supply systems are attracting worldwide attention as a way to decrease ICT power consumption as it continues to increase each year. In order for such systems to spread widely, it is desirable for the interfaces between power supply equipment and ICT devices be standard and of uniform specification globally and for devices to be built, purchased, and used according to these specifications.

Standardization activities are in progress at the International Telecommunication Union, Telecommunication Standardization Sector (ITU-T) and the European Telecommunications Standards Institute (ETSI) on HVDC power-supply interface requirements specifications for ICT equipment in telecommunications facilities and datacenters. Requirements such as the range of power-supply voltages, requirements for grounding and safety, and environmental impact are all being studied [7].

Awareness of DC power supply and distribution has also increased dramatically recently, with the growing use of solar panels and fuel cells, electric automobiles using DC power, and next-generation smart grid technology. Considering these factors, the International Electrotechnical Commission (IEC) established a new strategic group in 2009, Strategic Group 4 (SG4), to begin studying low-voltage* DC power distribution. HVDC power supply systems are also being examined as one aspect of DC power distribution and specific standardization work is planned in Technical Committees regarding electrical facilities; distribution protection equipment such as switches, breakers, fuses, etc.; ICT and audio-visual equipment such as digital electronic equipment; outlets; and electromagnetic compatibility, insulation, and safety, etc.

8. Future developments

The advantages, development status, and standardization activities of an HVDC system were described. The NTT Group has evaluated it in practical tests and confirmed the power supply operation characteristics. We intend to introduce the system into actual use and establish an environmentally friendly datacenter.

References

[1] Green IT Promotion Council, "FY2008 Green IT Promotion Council Technical Study Committee Report," 2009 (in Japanese).

[2] Y. Nozaki, "Development of Higher-voltage Direct Current Power Feeding System for ICT Equipment," NTT Technical Review, Vol. 7, No. 10, 2009.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr200910sf2.html

[3] T. Babasaki, T. Tanaka, Y. Nozaki, T. Tanaka, T. Aoki, and F. Kurokawa, "Developing of Higher Voltage Direct-current Power-feeding Prototype System," Proc. of INTELEC 2009, pp. 1–5, Incheon, Korea.

[4] A. Matsumoto, A. Fukui, T. Tanaka, K. Hirose, and M. Yamasaki, "Development of 400Vdc Power Distribution System and 400Vdc Output Rectifier," Proc.of INTELEC 2009, pp. 1–5, Incheon, Korea.

[5] M. Noritake, K. Hirose, M. Yamasaki, T. Oosawa, and H. Mikami, "Evaluation Results of Power Supply to ICT Equipment Using HVDC Distribution System," Proc. of INTELEC 2010, pp. 1–8, Orlando, FL, USA.

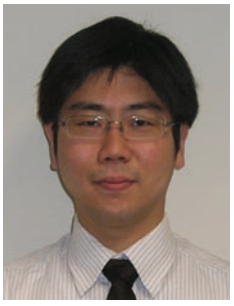
[6] Press release from the Green IT Promotion Council (in Japanese).
http://www.greenit-pc.jp/topics/release/091002.html

[7] ITU Question 19/5 – Power feeding systems.
http://www.itu.int/ITU-T/studygroups/com05/sg5-q19.html

* Low voltage: defined at IEC to include voltages from 120 to 1500 VDC. For this reason, we use the term higher-voltage in describing our work rather than high-voltage.

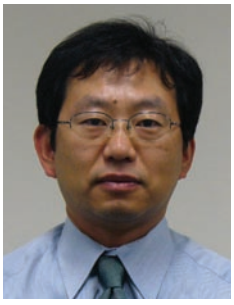
Kaoru Asakura
Senior Research Engineer, Energy Systems Projects, NTT Energy and Environment Systems Laboratories.

She received the B.E. and M.E. degrees in applied chemistry from Keio University, Tokyo, in 1993 and 1995, respectively. She joined NTT Interdisciplinary Research Laboratories in 1995. Since then, she has been engaged in R&D of battery management systems and DC power feeding system for telecommunication.



Toshimitsu Tanaka
Research Engineer, Energy Supply Technology Group, Energy Systems Project, NTT Energy and Environment System Laboratories.

He received the M.S. and Ph.D. degrees in electronic engineering from Chiba University in 2001 and 2007, respectively. He joined NTT in 2007. He has been engaged mainly in the analysis of the stability of DC power feeding systems for telecommunication. He received the Young Researcher's Award from the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan in 2006.



Tadatoshi Babasaki
Group Leader of Energy Supply Technology Group, Energy Systems Project, NTT Energy and Environment System Laboratories.

He received the B.S. and M.S. degrees in electronic engineering from Nagasaki University in 1988 and 1990, respectively. He joined NTT Applied Electronics Research Laboratories in 1990. He has been engaged mainly in R&D of DC power feeding systems and batteries for telecommunication. He is a member of IEEE, IEICE, and the Institute of Energy Economics, Japan.

Recent Activities Concerning NTT Technical Requirements for Electromagnetic Compatibility

Norihito Hirasawa, Yasuhiro Honma, and Yoshiharu Akiyama†

Abstract

In this article, we describe the backgrounds of and present summaries of the revisions to the technical requirements for electromagnetic emission and resistibility to overvoltage and overcurrent. We also summarize the newly published technical requirements for electromagnetic emissions from lighting equipment installed in telecommunication centers.

1. Introduction

The NTT Group has developed and maintains electromagnetic compatibility (EMC) requirements in order to develop and procure telecommunication equipment and systems that emit sufficiently small electromagnetic disturbances that they do not interfere with radio communication and other equipment and are not susceptible to electromagnetic disturbances. These requirements will help to create a good electromagnetic environment, which is a corporate social responsibility, continuously provide high-quality and reliable telecommunication services to customers, and cut maintenance costs.

The EMC requirements in the NTT Group are the "EMC Standards for Telecommunication Equipment" and "Technical Requirements" (TRs) [1], as shown in **Fig. 1**. The EMC Standards for Telecommunication Equipment describe how we control the EMC characteristics of telecommunication equipment used to provide our telecommunication services and our sales, leases, and rentals to customers. The TRs are distributed to telecommunication equipment manufacturers and venders to notify them of our minimum requirements for EMC. Current TRs are "Technical requirements for electromagnetic disturbances emitted from telecommunication equipment (TR550004)", "Technical requirements for electromagnetic immunity of telecommunication equipment (TR549001)", and "Technical requirements for resistibility of telecommunication equipment to overvoltage and overcurrent (TR189001)". These TRs are cited in the specification documents for procuring telecommunication equipment and systems. The requirements in TR550004 are mandatory, while those in TR549001 and TR189001 are currently recommendations. These TRs can be obtained from the International Procurement Homepage.

In this article, we describe the revisions to TR550004, which was amended in December 2009, summarize TR189001, which was scheduled to be amended in 2010, and describe the technical requirements for electromagnetic disturbances emitted from lighting equipment installed in telecommunication centers, which will be published soon.

2. Revision of TR550004

2.1 Background

The electromagnetic disturbances emitted from telecommunication equipment in Japan are voluntarily controlled by the VCCI Council (VCCI) [2], which was formerly called the Voluntary Control

† NTT Energy and Environment Systems Laboratories
Musashino-shi, 180-8585 Japan

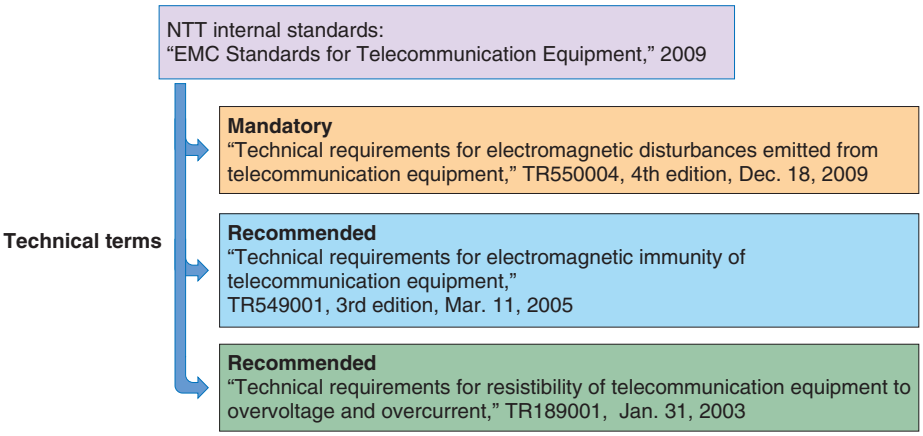


Fig. 1. EMC standards for telecommunication equipment and technical requirements.

Council for Interference by Information Technology Equipment, in cooperation with information technology equipment (ITE) manufacturers and telecommunication carriers. The NTT Group joined VCCI in August 1989 and complies with VCCI technical requirements, which are based on the international standard CISPR publication 22 published by the International Special Committee on Radio Interference (CISPR) in the International Electrotechnical Commission (IEC). CISPR 22 specifies the limits and measurement methods of radio disturbances from ITE. TR550004 must meet the VCCI technical requirements, CISPR 22, and other equivalent standards.

The main radiation or propagation paths of electromagnetic disturbances are (1) printed patterns on circuit boards and wiring between the boards and (2) telecommunication, signal, and power lines. The emitted disturbances might interfere with radio communication systems, such as televisions (TVs) and radios, and other equipment. The electromagnetic disturbances emitted from telecommunication equipment have been becoming more wideband and high-frequency because the transmit signals are high-speed and high-capacitive and the clock frequency of telecommunication equipment such as Next Generation Network (NGN) equipment is increasing. To prevent interference, the electromagnetic disturbances radiated from telecommunication cables and the higher frequency should be reduced.

For these purposes, international standardization organizations, such as CISPR, have been discussing limits and measurement methods of disturbances radiated from telecommunication cables. NTT Energy and Environment Systems Laboratories joined this discussion and proposed measurement methods. On the basis of these activities, we contributed to the revisions of CISPR 22 and VCCI technical requirements. As a result of these activities, new regulations on conducted disturbances at telecommunication ports and radiated disturbances from 1 to 6 GHz will be put into practice.

2.2 Summary of revisions

The NTT Group revised TR550004 in December 2009 on the basis of the abovementioned external standards. The old version of TR550004 regulated the radiated disturbances from telecommunication equipment and the conducted disturbances at the mains AC power supply ports of the equipment. The revised TR550004 additionally regulates the conducted disturbances at telecommunication ports and the 1–6-GHz radiated disturbances from telecommunication equipment (**Fig. 2**).

CISPR 22 describes the limits and measurement methods of conducted disturbances at telecommunication ports. The NTT internal standards dealt with the limits of the recommendations because the measurement circuit specified in CISPR 22 edition 3 had technical problems. At this point, NTT Energy and Environment Systems Laboratories developed a new measurement circuit that resolved the technical problems and proposed it to CISPR. As a result, our measurement circuit was used as the international standard. Therefore, we changed the limits for conducted disturbances at telecommunication ports to mandatory regulation ones in TR550004. The limits for 1–6-GHz radiated disturbances have been added to our

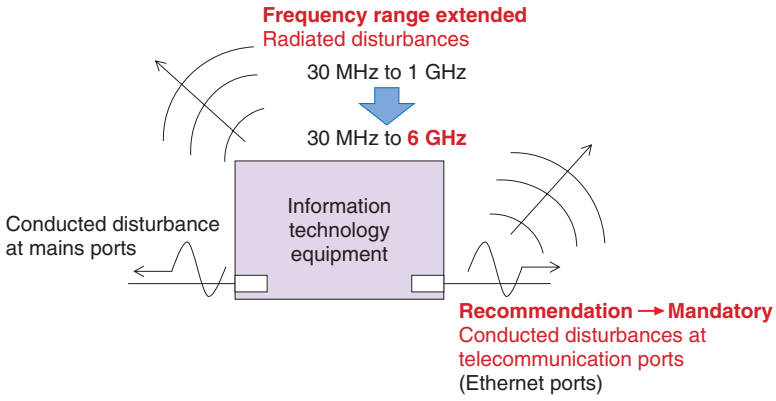


Fig. 2. Radiated disturbances regulated by the emission TR.

EMC requirements to protect radio systems, such as cell phones and wireless local area networks.

We discussed the contents of TR550004 for revision within the EMC Liaison Group, which was joined by relevant departments of our operating company, i.e., NTT EAST, NTT WEST, NTT Communications, and NTT DOCOMO. The focus of the EMC Liaison Group is sharing information and resolving methods related to EMC issues and reflecting requests from these companies because EMC requirements may impact costs.

3. Revision of TR189001

3.1 Background

The Ministry of Internal Affairs and Communications' plan to add requirements for overvoltage/current resistibility and safety to the Telecommunication Business Act was reported on July 28, 2009. These requirements aim to prevent problems related to lightning strikes, combustion, and so on. According to the report from the Information and Communications Council, the overvoltage/current resistibility requirements will be harmonized with those specified in the international K-series recommendations published by the International Telecommunication Union, Telecommunication Standardization Sector (ITU-T) (**Fig. 3**). Safety requirements will be harmonized with those specified in international standard IEC60950-1 published by IEC.

3.2 Summary of revisions

Following the above trend, NTT plans to revise TR189001 to specify technical requirements for resistibility of telecommunication equipment to overvoltage and overcurrent. Three important points must be considered.

1. Requirements for resistibility to overvoltage and overcurrent related to earthing configurations in Japan.
2. Reduction in the cost of satisfying requirements through revised requirements for resistibility to overvoltage and overcurrent.
3. Compatibility of requirements for resistibility to overvoltage and overcurrent with those for safety.

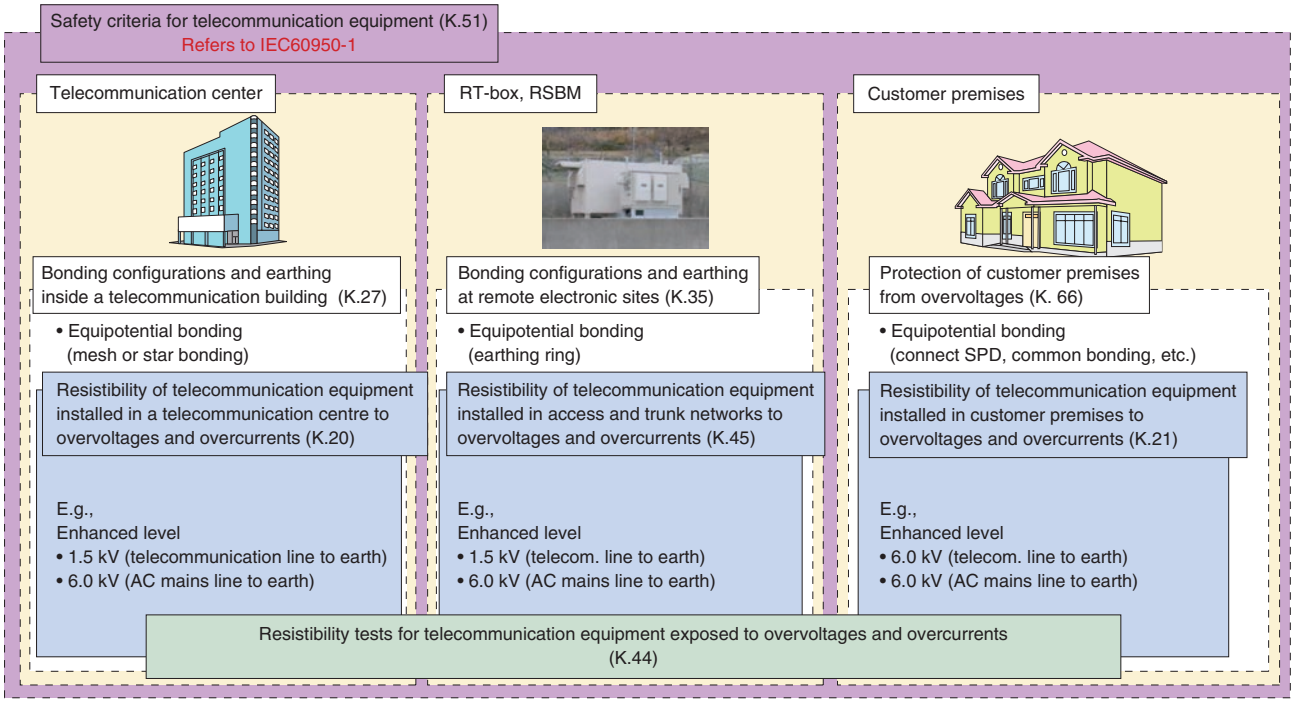
There are several K-series recommendations such as K.20: Resistibility of telecommunication equipment installed in a telecommunication centre to overvoltages and overcurrents and K.44: Resistibility tests for telecommunication equipment exposed to overvoltages and overcurrents—Basic recommendation, as shown in **Fig. 4**. The resistibility requirements and test conditions are based on the TN power distribution system, a major power distribution system throughout the world specified in these recommendations. The neutral and protective earth conductors of the TN system are connected to earth at the same place, and the protective earth conductors are distributed with the power conductors so that the potential of the earth conductors is equivalent. This is called equipotential bonding. However, the TT power distribution system is used in Japan. Neutral conductors of the TT system are connected to earth at a single point, e.g., the transformer on a utility pole. Protective earth conductors are independently connected to the earth at another point, e.g., an outlet for connecting a washing machine.

There are three levels of overvoltage/current resistibility requirements in the K-series: basic, enhanced, and special. The basic level has the lowest requirements.

Act on telecommunication equipment (telecommunication carrier use)	Act on telecommunication terminal equipment (customer installed and use)
Related to requirements for resistibility to overvoltage/overcurrent	Related to requirements for resistibility to overvoltage/overcurrent
• Voltage induction (Article 12) • Maintenance device (Article 21)	(no article)
Related to safety requirements	Related to safety requirements
• Spare (Article 4) • Error detection (Article 5) • Protection measure (Article 6) • Unexpected congestion (Article 8) • Earthquake (Article 9) • Power source (Article 10) • Power failure (Article 11) • Fire prevention (Article 13) • Injury prevention (Article 19) • Malfunction prevention (Article 20) • Anti-information leakage (Article 20-2) • Confirmation of functions (Article 24)	• Prevent recognition of leaked information (Article 4) • Resonance prevention (Article 5) • Isolation (Article 6) • Prevent generation of loud sounds (Article 7) • Cabling (Article 8)

* Revised points are indicated in red.

Fig. 3. Revision items for facility regulations.



RSBM: remote subscriber line module
RT: remote terminal

Fig. 4. Kinds of ITU-T Recommendations and applicable scope related to overvoltage and safely.

Since the TT system is susceptible to the overvoltage/current caused by earthing conductors being separately connected to earth, a high resistibility level to the equipment used in Japan is necessary.

According to K.44, if equipotential bonding cannot be achieved in the TT system, the special level, i.e., withstanding 10–13 kV overvoltage, shall be required for the equipment. However, it is difficult to achieve this resistibility level only by insulating the equipment, so external protective devices or surge protective devices (SPDs) implemented in the equipment are necessary. We must consider the adequate protection level to minimize the cost impact because such mitigation generally adds to the cost.

Moreover, it is sometimes difficult to implement SPDs in equipment for lightning protection. For example, making a bridge over double insulation by using SPDs for lightning protection is not permitted by IEC60950-1 for safety reasons. In this case, both the special level specified in K.44 and the safety requirement in IEC60950-1 should be met simultaneously. If it is difficult to satisfy the special level, the enhanced level specified in K.21 and other documents should be required, giving preference to the safety requirements. If necessary, an external SPD must be attached to the equipment to satisfy the overvoltage/current resistibility and safety requirements.

On the basis of the policy described above, we will revise the TR and propose that ITU-T and IEC discuss harmonizing the requirements specified in the K-series and IEC60950-1.

4. Publishing technical requirements for electromagnetic disturbances emitted from lighting systems installed in telecommunication centers

4.1 Background

The electromagnetic emission of fluorescent lights is currently low enough not to disturb the normal operation of telecommunication equipment, so these lights are used in telecommunication centers. To reduce energy consumption, a lighting system using light-emitting diodes (LEDs) is being considered for installation in the machine rooms of telecommunication centers. However, the emission limits of LED lighting systems are not specified in the current EMC requirements.

4.2 Summary of the TR

Two types of emission are considered when the limits of the electromagnetic emission from lighting systems are specified. One is the emission continuously emitted from the systems when they are illuminating, and the other is the transient emissions from the systems when they are turned on and off. The electromagnetic emission levels of rapid-start-type and low-noise-inverter-type fluorescent lights are almost the same. These lights are currently used in the machine rooms of telecommunication centers. This use is based on evaluation results for whether typical telecommunication equipment is disturbed by the emissions from the lights.

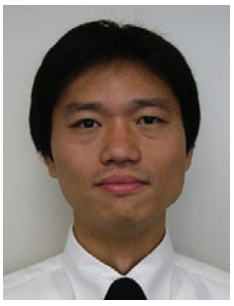
Thus, limits equivalent to the electromagnetic emission level of the rapid-start-type fluorescent lights will be specified in the TR. However, to specify adequate emission limits, we must investigate increases in the emission level due to many of the same lighting systems being used simultaneously in a machine room.

5. Conclusion

This article describes recent activities of the NTT Group related to revising and publishing EMC technical requirements. The revised TR for electromagnetic emission (TR550004) has been in force since April 2010. The revised TR for resistibility to overvoltage/overcurrent (TR189001) and the new TR for electromagnetic emission from lighting systems installed in the machine rooms of telecommunication centers will be published by the end of fiscal year 2010. The NTT Group intends to maintain a good electromagnetic environment and provide high-quality and highly reliable telecommunication services by meeting EMC requirements.

References

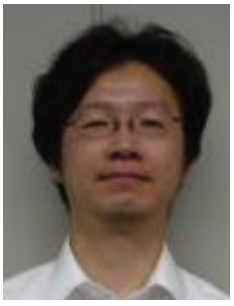
[1] NTT TRs. http://www.ntt.co.jp/ontime/tr/tr.html
[2] VCCI Council. http://www.vcci.jp/vcci_e/



Norihito Hirasawa

Engineer, EMC Technology Group, NTT Energy and Environment Systems Laboratories.

He received the B.E. degree in electrical engineering from Tokyo University of Science in 1998. He joined NTT Electrical Telecommunication Laboratory in 1998. From 2001 to 2008, he worked at the corporate business headquarters of NTT EAST. He joined NTT Energy and Environment Systems Laboratories in 2008. His research field is the evaluation of low-frequency noise from telecommunication systems.



Yasuhiro Honma

Engineer, NTT Energy and Environment Systems Laboratories.

He received the B.E. and M.E. degrees in electrical and electronic engineering from Kitami Institute of Technology in 1998 and 2000, respectively. He joined NTT EAST in 2000. He moved to NTT Energy and Environment Systems Laboratories in 2008. He has been engaged in R&D of lightning protection and grounding for telecommunication systems. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.

Yoshiharu Akiyama

Senior Research Engineer, Leader of EMC Technology Group, NTT Energy and Environment Systems Laboratories.

He received the B.E. and D.E. degrees from the University of Electro-Communications in 1990 and 2010, respectively. Since joining NTT in 1990, he has been researching radiated electromagnetic field immunity testing methods, EMC of wireless communication systems, broadband communication systems such as xDSL and power line communication, and shield effectiveness measurement methods.

Energy Network Optimization Technology

Akira Takeuchi†*, Toshihiro Hayashi, Noboru Iwasaki, and Yousuke Nozaki*

Abstract

Energy network optimization technology achieves operational control and system construction for purposes such as reducing the environmental load by efficiently matching energy demand and supply from numerous facilities. This article describes demonstrative optimal scheduling research and a system configuration simulation as applications of this technology.

1. Introduction

Interest in reducing CO_2 emissions and using energy efficiently has increased recently, and the technology for achieving these goals has become important. An energy network is a system that utilizes energy effectively by controlling a large number of energy supply and demand facilities of various types by using a communication network.

The concept of the energy network is shown in **Fig. 1**. Energy supply facilities include renewable energy (such as photovoltaic (PV) cells and wind power generation), cogeneration (such as a fuel cell (FC) system), energy storage (such as batteries and a hot water tank), and a heat supply facility (such as a boiler and air conditioner). Energy demand facilities need electric power or heat and some, such as information and communications technology (ICT) equipment, require both power and heat (cold air flow). These supply and demand facilities are monitored and controlled via the communication network, and highly reliable energy is supplied efficiently.

2. Optimal control

Energy supply and demand facilities must be operated with consideration given to their characteristics. This will sufficiently demonstrate effects such as economic efficiency and the environmental impact of an energy network with various facilities.

An example of an energy control flow chart is shown in **Fig. 2**. Projected temperature and weather conditions for the next day are obtained from a weather forecast. This information is then combined with past performance data to estimate the amount of electricity and heat available as natural energy generation sources and also estimate the demand for electricity and heat. These estimates are then used to determine the optimal scheduling that will minimize CO_2 emissions or energy costs over a one-day or one-week period. The output is an operation plan optimized for the required purpose by considering various energy characteristics and operating constraints. This optimized operating schedule is then used to control the energy system.

3. Optimal configuration design

The configuration of an energy network—types, capacities, and quantities of energy devices—greatly affects the environmental and economic benefits of forming that network at a target site. The actual design of energy devices usually considers reserve power to respond to energy demand growth. However, a huge excess capacity for energy devices may lead to a longer period of partial-load operation, which results in increased energy consumption and operation costs. One must determine a system configuration that can supply energy to meet the demand,

† NTT Energy and Environment Systems Laboratories
Musashino-shi, 180-8585 Japan

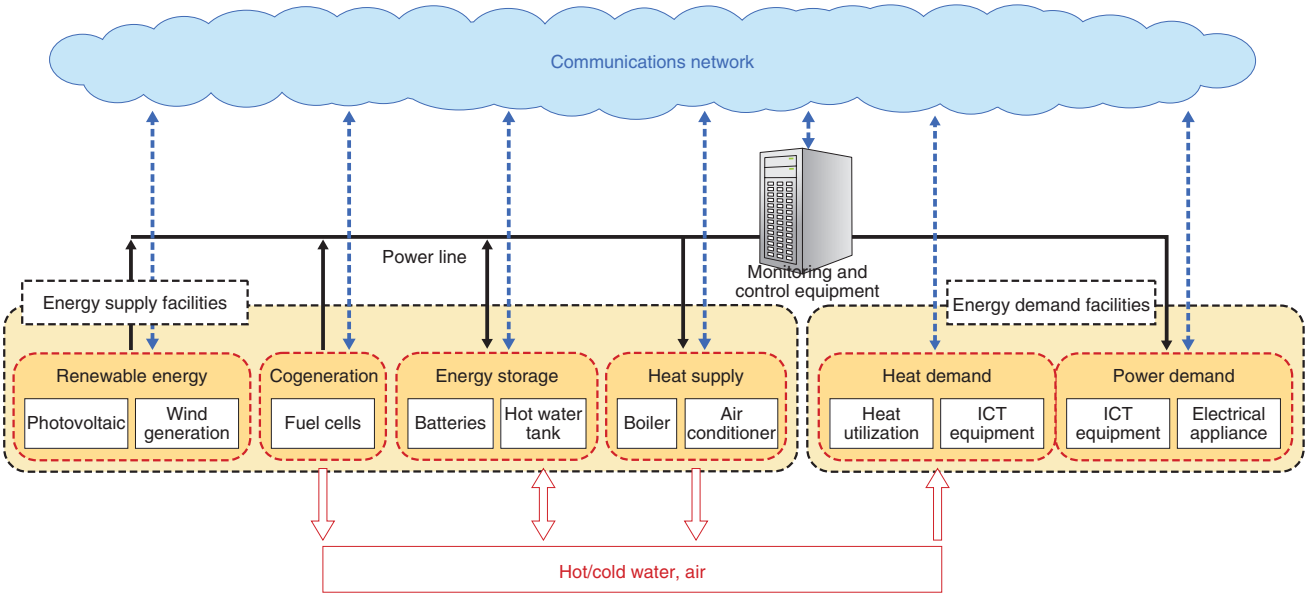


Fig. 1. Concept of energy network.

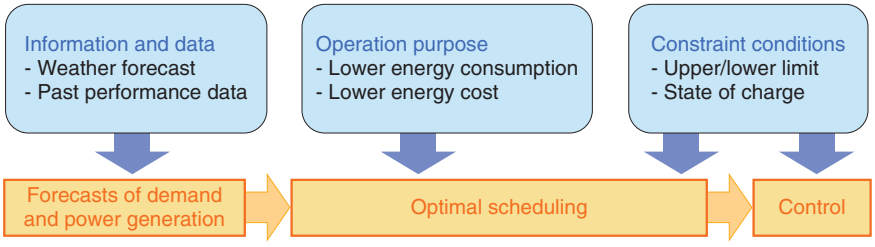


Fig. 2. Optimal control flow.

which fluctuates seasonally so this imbalance does not occur all year round.

In deciding the system configuration, one must consider the construction purpose and constraint conditions, such as initial cost and service life (**Fig. 3**). Information such as demand forecast and facility characteristic data is used to decide the type and number of facilities that are thought to be suitable to meet the users' requests.

4. Application of meta-heuristics

Optimal scheduling and configuration design may be formulated as optimization problems that must satisfy constraint conditions, such as the operation constraint of each energy facility. These problems find the best solution, such as minimized CO_2 emissions. Mathematical programming for optimization problems requires an inordinate calculation time due to the nonlinear and discontinuous nature of energy facilities, and it can only produce local optimal solutions.

Meta-heuristics are uniform methodologies based on heuristics testing for efficiently finding solutions to optimization problems. They can obtain highly accurate approximate solutions to global optimization problems quite quickly regardless of the type of evaluation function or constraints.

A wide range of meta-heuristics have been proposed and improved. The algorithms applied to optimize the energy network are listed in **Table 1**. These algorithms simulate human memory, the evolution process of an organism, and the movement of an organism group. They offer a general-purpose frame

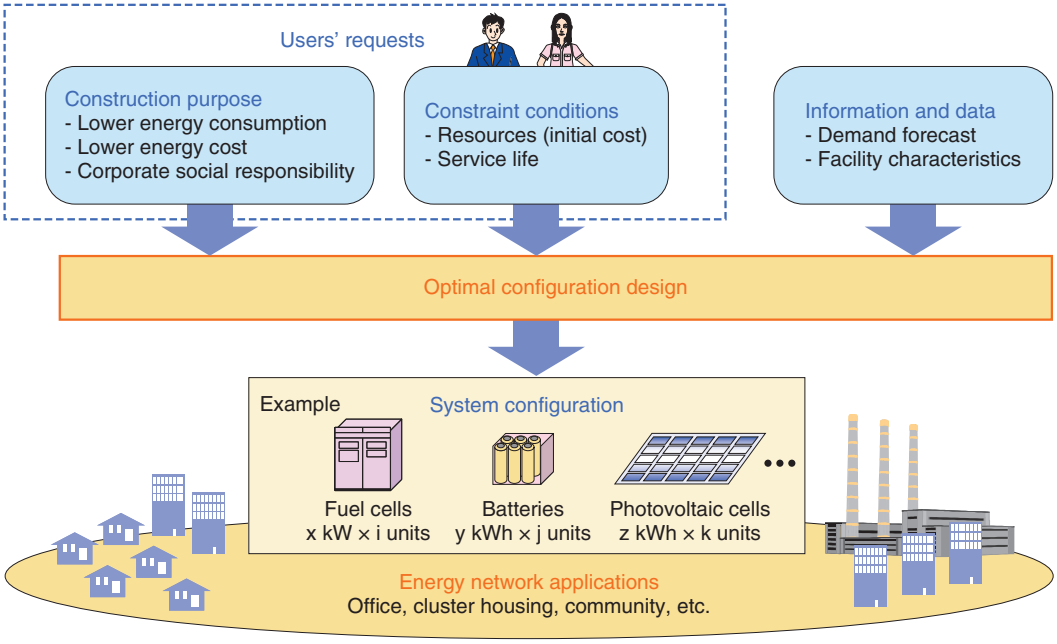


Fig. 3. Optimal configuration design.

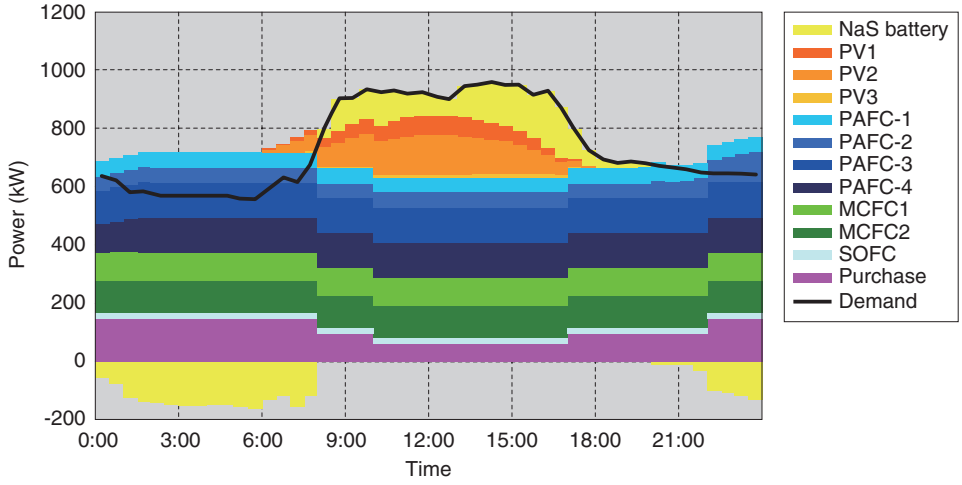
Table 1. Optimal algorithms applied to energy network.

	Summary	Features
Tabu Search (TS)	TS is analogous to the human memory process. It moves toward the evaluation that is most improved using a tabu list, which memorizes search histories. Going back to solutions that have already been traversed and moving to similar solutions are forbidden, so TS can leave the local minimum to find a global optimal solution.	Highly precise solutions are obtained in the searched region for scrupulous evaluation of the neighbors of the solution candidate.
Genetic Algorithm (GA)	GA imitates the evolution process of an organism. Each candidate solution in the population is expressed in gene form The next generation of solutions is generated by genetic operators, such as selection, crossover, and mutation. The advantageous features of a high-scoring solution are transmitted to the next generation with a high probability.	GA is suitable for a global search because of its multipoint search and genetic manipulation with multiple solutions.
Particle Swarm Optimization (PSO)	PSO was originally inspired by behavioral models of bird flocks. The population of candidate solutions (particles) moves through the search space of an optimization problem. Each particle searches for better positions in the search space by changing its velocity according to the best solution it has achieved so far and the best solution obtained so far by any particle in the population.	Since the update process of the solution is simple, PSO can search at comparatively high speeds despite performing a multipoint search.

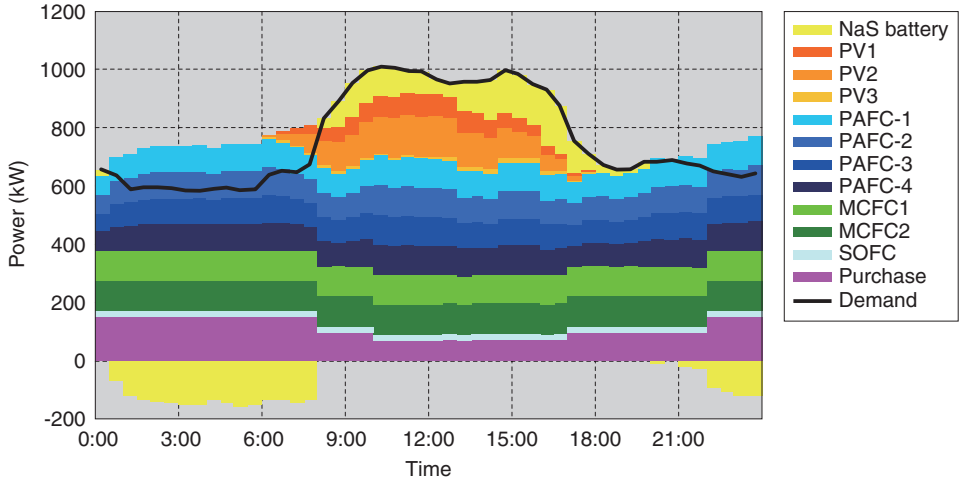
that does not depend on the problem. Therefore, various application techniques are possible for optimizing the energy network. These techniques must be adjusted and contrived according to the characteristics of the problem in order to conduct a solution search that is stable regardless of the condition.

5. Demonstrative optimal scheduling research

The New Energy and Industrial Technology Development Organization (NEDO) commissioned the world's first trial implementation of a new large-scale energy system at Expo 2005 and at the Central Japan Airport City, both located in Aichi Prefecture, Japan. Demonstrative research on the energy system was conducted. NTT Facilities, Inc. was put in charge of



(a) Optimal scheduling result



(b) Power generation result

MCFC: molten carbonate fuel cell

Fig. 4. Example of demonstrative results.

developing the energy control system, and it commissioned us to develop the optimal scheduling programs that applied tabu search and a genetic algorithm.

As the demonstrative research advanced from Expo 2005 to Central Japan Airport City, various research subjects, such as increasing the number of control units and extending the optimization period, were tackled, and the algorithms were also improved. Both algorithms were verified to be flexibly applicable for calculating the scheduling under required conditions.

An example of our optimal scheduling results and the power generation results are shown in **Fig. 4**. The power generation plan was calculated for economic efficiency, so the commercial power consumed changed according to the hourly electricity prices. Realtime control throughout a day was carried out on the basis of the power generation plan. Phosphoric acid fuel cells (PAFCs) were operated at the output corrected from the daytime-plan to achieve control in proportion to the PV generation prediction error and the FC model error. Charging and discharging of sodium-sulfur (NaS) batteries and commercial power were conducted almost as planned.

For each season and various demand patterns, such as weekdays and holidays, the optimal scheduling results were continuously calculated automatically for more than a year. The results demonstrated that the pilot implementation met the performance target.

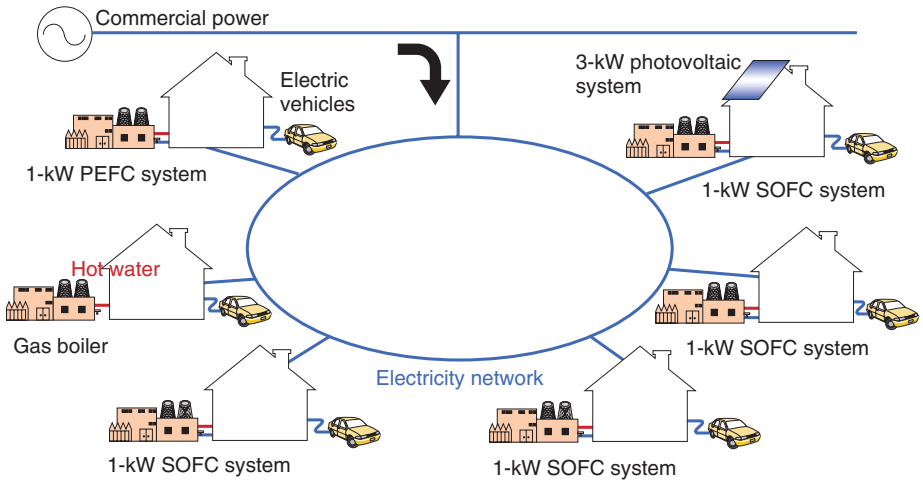


Fig. 5. Example of system configuration results.

6. System configuration and environmental evaluation

To optimize the system configuration featuring an optimal operating schedule, one must consider nonlinearity due to the characteristics of the energy facilities and logic in operational constraints. Therefore, it is preferable to regard this problem as a mixed integer nonlinear programming problem. We examined system configuration optimization and environmental evaluation by using a method based on particle swarm optimization, which is effective for such problems.

As shown in **Fig. 5**, we assumed a target site consisting of six residences with power and hot water demand to form an energy network. Power is purchased from the commercial grid and/or generated by FC and PV systems to meet the demand, including that of electric vehicles, and assumed to be shared among residences. In addition, hot water is supplied from the FC system and gas boilers to meet the demand.

Either an FC system or a gas boiler is assumed to be installed in each residence. An FC system consists of an FC unit, a hot water tank unit, and a backup boiler. Two choices of FC system were considered in this simulation: a solid oxide fuel cell (SOFC) system, which has high generation efficiency and operates continuously, or a polymer electrolyte fuel cell (PEFC) system, which operates in a daily start-stop mode.

In many optimal cases, SOFCs were introduced to most residences, as a result of the optimization simulation for minimizing CO_2 emissions. However, a PEFC was introduced instead of an SOFC when the CO_2 emission factor was considered independent of day and night. In the residence with low heat demand, an optimum solution was a gas boiler instead of an FC system. Therefore, a two-part CO_2 emission factor and a shift in electrical load need to be considered in determining the system design of energy networks.

7. Conclusion

Systems in which energy supply and demand are efficiently matched through the use of energy network optimization technology have a wide range of application. In the future, the technology will be improved and expanded for application to complicated systems in which modeling is difficult, such as air flow, and to systems with large-scale controlled targets.

Reference

[1] A. Takeuchi, M. Kudo, A. Nakazawa, and H. Endo, "Energy Network Optimal Control Technology," NTT Technical Review, Vol. 4, No. 3, pp. 42–47, 2006.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr200603042.pdf

Akira Takeuchi

Senior Research Engineer, Energy Optimization Technology Group, Energy System Project, NTT Energy and Environment Systems Laboratories.

He received the B.E. and M.E. degrees in electronics engineering from Kyushu University, Fukuoka, in 1990 and 1992, respectively. He joined NTT Interdisciplinary Research Laboratories in 1992. His research interests are power converters, energy control technologies, and optimization techniques. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.

Toshihiro Hayashi

Energy Optimization Technology Group, Energy System Project, NTT Energy and Environment Systems Laboratories.

He received the B.E. and M.E. degrees in geosystem engineering from the University of Tokyo in 2004 and 2006, respectively. He joined NTT Energy and Environment Systems Laboratories in 2006. His research interests are energy control technologies, optimization techniques, and environmental impact assessment of ICT services. He is a member of IEICE.

Noboru Iwasaki

Senior Research Engineer, Supervisor, Development Project, NTT Energy and Environment Systems Laboratories.

He received the B.E. and M.E. degrees in applied physics from Tohoku University, Miyagi, in 1984 and 1986, respectively. In 1986, he joined NTT Electronics and Mechanics Technology Laboratories, where he researched and developed high-density packaging and module techniques for high-speed ICs and optical components. Since 2010, he has been studying energy management technologies at NTT Energy and Environment Systems Laboratories. He is a member of IEEE and IEICE.

Yousuke Nozaki

Project Manager, Senior Research Engineer, Supervisor, Energy System Project, NTT Energy and Environment Systems Laboratories.

He received the B.E. and M.E. degrees in mechanical engineering from Tohoku University, Miyagi, in 1987 and 1989, respectively. He joined NTT Laboratories in 1989. Since then, he has been engaged in R&D of switching power regulators, photovoltaic and fuel cell power systems, and higher-voltage direct current power systems for telecommunications systems. He is a member of IEEE, IEICE, and the Institute of Energy Economics, Japan.

Development of SOFC Power Generation Module with High Electrical Generation Efficiency

Yoshiteru Yoshida†, *Katsuya Hayashi, and Masayuki Yokoo*

Abstract

This article reports on the development of a 3-kW class solid oxide fuel cell (SOFC) power generation module being developed jointly by NTT, Sumitomo Precision Products Co., Ltd., and Toho Gas Ltd. as an industrial stationary power generation system. NTT has been developing cell materials, anode-supported cells, and SOFC stack technologies. The 3-kW class SOFC power generation module uses two 40-cell SOFC stacks. This module provided long-term and maximum electrical efficiencies of 56% and 59%, respectively.

1. Introduction

We are in the middle of the first commitment period of the Kyoto Protocol (2008–2012), and greenhouse gas reduction is an urgent worldwide problem. Developing fuel cells is one approach to greenhouse gas reduction. Fuel cells produce electric power via a direct reaction between oxygen and a fuel. Since a fuel cell has only one conversion step, its power generation efficiency tends to be higher than that of a thermal power generation plant.

There are four main types of fuel cells. Among them, the solid oxide fuel cell (SOFC) can provide the highest power generation efficiency. It contains a solid oxide electrolyte made from a ceramic, which acts as a conductor of oxide ions at temperatures from 873 K to 1273 K. This ceramic material allows oxygen atoms to be reduced on its porous cathode surface by electrons and converted into oxide ions, which are then transported through the ceramic body to a fuel-rich porous anode zone where the oxide ions can react, giving out electrons to an external circuit. Generating electricity by transferring oxygen ion makes it possible to use many kinds of gases, such as town gas, gaseous kerosene, and biogas, as fuels that react with oxygen.

Because an SOFC does not need large equipment such as a turbine to generate electric power, it can be used as a distributed generation power system with a low noise level. Since there is a great need for clean quiet distributed generation power systems, e.g., in hospitals, hotels, and sports facilities, the stationary power market has attracted considerable attention.

We have been developing SOFCs to reduce the CO_2 emissions produced by electric power use [1], [2]. An SOFC power generation system is composed of stacks of several cells in series and a module to maintain the temperature, as shown in **Fig. 1**. When electricity is generated with a power generation efficiency of more than 50% (lower heating value (LHV)) or more, the CO_2 emissions can be reduced to less than those produced by existing electric power suppliers.

2. Cell/stack configuration

We had to develop a cell with high power generation efficiency, an electrolyte with high ion conductivity, and an electrode with high durability. We chose to use planar anode-supported cells consisting of a

† NTT Energy and Environment Systems Laboratories
Atsugi-shi, 243-0198 Japan

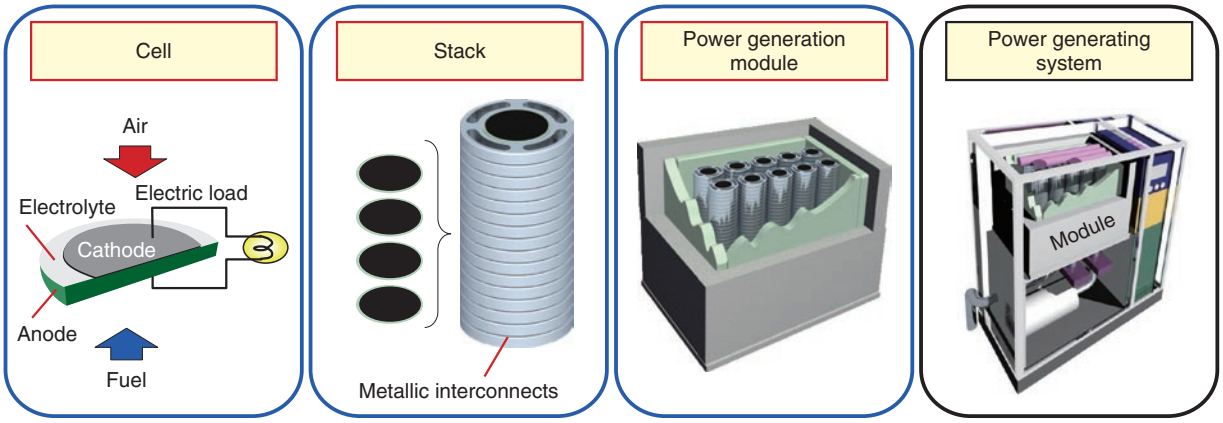


Fig. 1. Configuration of SOFC power generation system.

lanthanum nickel ferrite (LNF) cathode [3]–[5], a scandia-alumina stabilized zirconia (SASZ) electrolyte, and a nickel/SASZ anode [6], [7]. This cell has been shown to be able to provide a high power density of over 1.5 Wcm^{-2} and operate stably for thousands of hours.

We developed stacks by combining power generation units, each of which is composed of an anode-supported cell with a diameter of 120 mm and interconnects made of corrosion-resistant ferritic stainless steel. The stack has not only a fuel feed manifold and an air feed manifold but also two fuel exhaust manifolds, as shown in **Fig. 2** [8]–[10]. The exhaust manifolds will allow us to recycle unused fuel gas. In addition, it should also be possible to reduce the amount of CO_2 exhaust to zero by collecting CO_2.

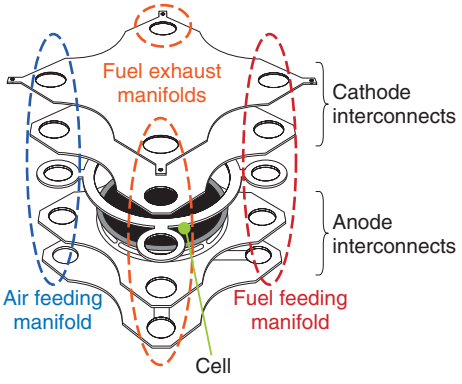


Fig. 2. Configuration of SOFC power generation unit.

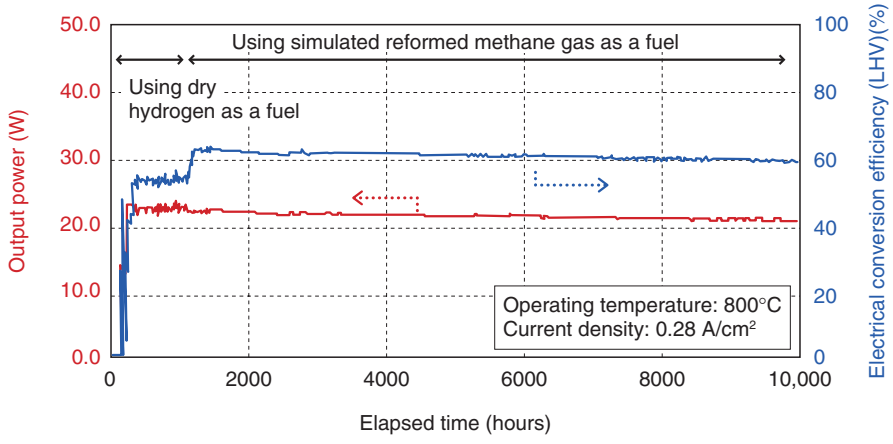


Fig. 3. Output power of power generation unit and behavior of power generation efficiency.

The behaviors of the output power and power generation efficiency of the power generation unit are shown in **Fig. 3**. When driven for 10,000 hours or more, the unit maintained a power generation efficiency of around 60% (LHV) [11]. The output power and the power generation efficiency of a stack composed of 40 cells in series are shown in **Fig. 4**. Output power of more than 1.5 kW was achieved with power generation efficiency of 63.9% (LHV) when the fuel utilization was 85%. By using this stack, we expect to be able to supply electric power stably with lower CO_2 emissions than those of a business electric power supply or commercially available electric power supply.

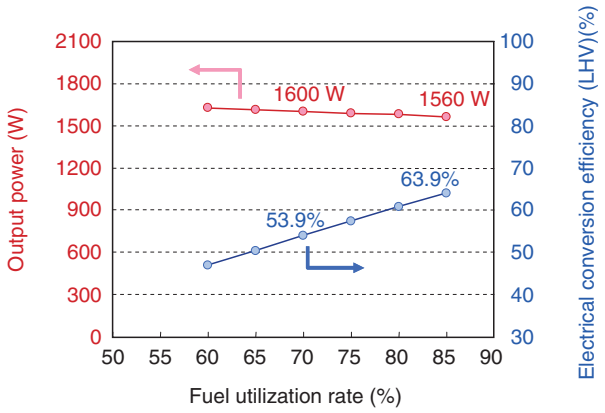


Fig. 4. Output power and electrical conversion efficiency of 40-cell stack.

3. Construction of power generation module

If a lot of electricity is needed to maintain the operating temperature at over 873 K, the electric conversion efficiency of an SOFC power generation system will be inferior to that of an SOFC stack. To control the generation of, for example, Joule heat and endothermic heat, such as that produced by the reforming reaction, it is very important to maintain the operating temperature using little energy. NTT is developing the SOFC power generation module jointly with Sumitomo Precision Products Co., Ltd. (SPP) and Toho Gas Ltd. (THG) because THG has abundant experience operating fuel cells and SPP has both considerable experience and the technology needed for the heat exchanger [12].

Two stacks were integrated in a power generation module equipped with a steam generator, a steam reformer, a post combustor, heat exchangers and a start-up burner, surrounded by thermal insulators, as shown in **Fig. 5**. The module was designed so that the heat produced by the stacks and the post combustor was appropriately consumed by steam generation, the steam reforming reaction, and inlet gas heating. We used town gas as a fuel and air as an oxidant to evaluate the power generation performance. The water rate was determined so that the steam-to-carbon ratio was approximately 3. The current load was controlled by using external electronic load equipment.

The developed module is shown in **Fig. 6** and the output power, operating temperature, and power generation efficiency characteristics are shown in **Fig. 7**. The initial heating process lasted 10 hours and the thermal insulating behavior was observed after the start-up burner was turned off. The subsequent heating

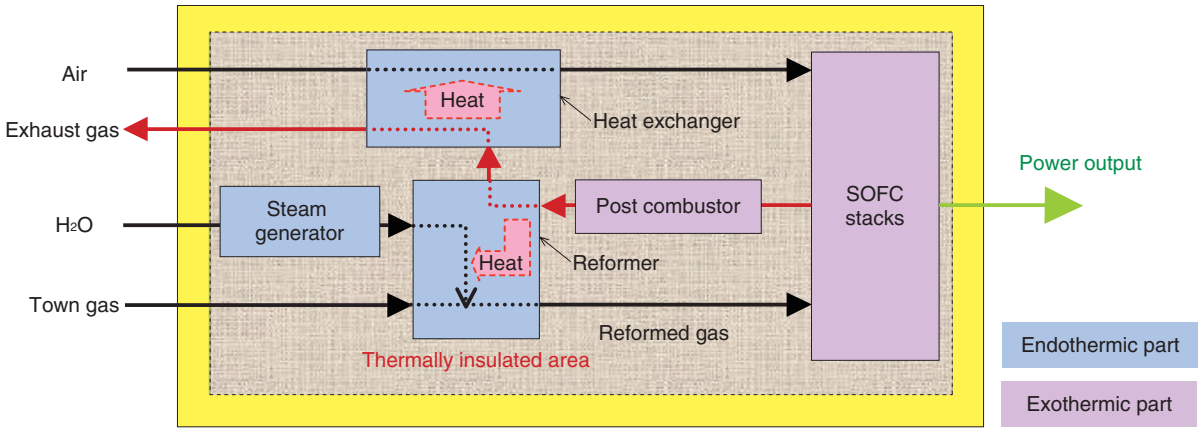


Fig. 5. Configuration of power generation module.

process with the burner raised the stack temperature to around 1073 K. The stacks started generating electrical power while the burner output was gradually decreased. A constant current load of 50 A was then applied to the stacks and the burner was turned completely off.

Thermally self-sustainable operation was achieved during operation for 200 hours with stable power output of 3.1 kW and power generation efficiency of 56% (LHV). Since the power generation efficiency was the same as that of the stack, as shown in Fig. 4, the module successfully controlled the heat with little energy consumption. In addition, we conducted a half-load power generation test and a standby test with no power generation, which resulted in isothermal operation of the stack.

Fig. 6. Photograph of power generation module.

4. Concluding remarks

NTT, SPP, and THG have jointly developed an SOFC power generation module. The module can generate electrical power of over 3 kW and achieve power generation efficiency of more than 53% (LHV). With such high power generation efficiency, it is possible to reduce the CO_2 emissions. However, for industrial power use, we must develop the balance of plant (BOP), which includes blowers, pumps, and a gas flow controller to supply the fuel and oxidant gas. Then, more electrical power with higher efficiency will be necessary to supply the electricity for these devices.

One way to generate more electrical power with higher power generation efficiency is to use the exhaust heat from the module, which accounts for about 40% of the heat of the supply gas, as shown in **Fig. 8**. We believe that higher power generation efficiency will be obtained by using the exhaust gas heat with a gas turbine and also by recycling the unused fuel gas. Moreover, we plan to capture and store CO_2 gas from the exhaust gas and develop an SOFC power generation system with zero CO_2 emissions in the future.

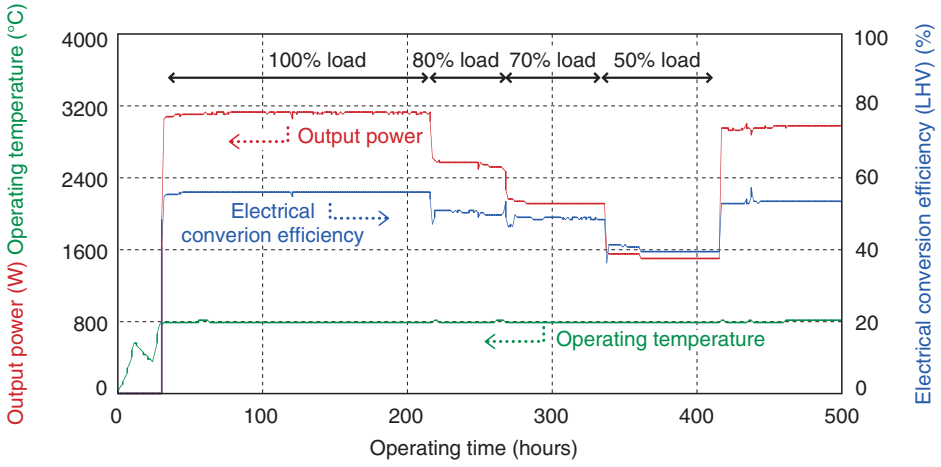


Fig. 7. Behavior of output power, electrical conversion efficiency, and operating temperature of SOFC power generation module.

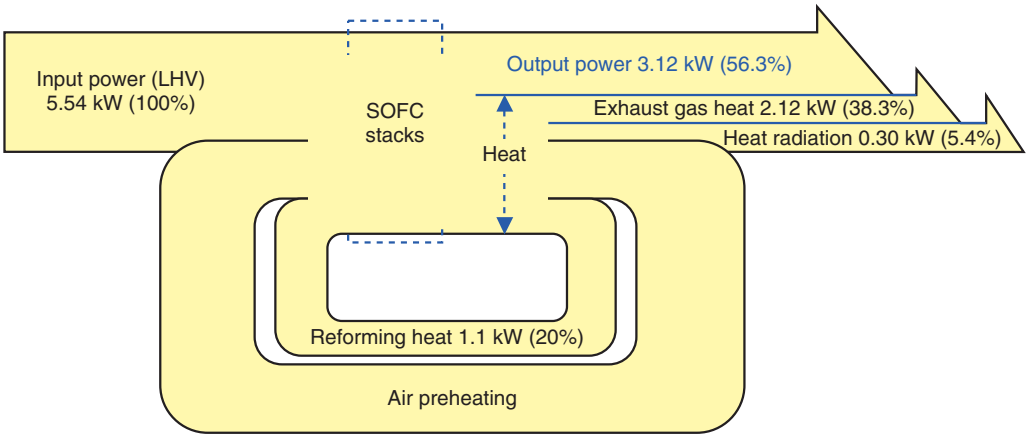


Fig. 8. Energy flow diagram of SOFC power generation module.

References

[1] K. Nozawa, H. Orui, T. Komatsu, R. Chiba, and H. Arai, "Development of Highly Efficient Planar Solid Oxide Fuel Cell," NTT Technical Review, Vol. 6, No. 2, 2008.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr2008URL02sf4.html

[2] K. Hayashi, M. Yokoo, Y. Yoshida, and H. Arai, "Solid Oxide Fuel Cell Stack with High Electrical Efficiency," NTT Technical Review, Vol. 7, No. 10, 2009.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr2009URL10sf3.html

[3] R. Chiba, F. Yoshimura, and Y. Sakurai, "An Investigation of $LaNi_{1-x}Fe_xO_3$ as a Cathode Material for Solid Oxide Fuel Cells," Solid State Ionics, Vol. 124, No. 3, pp. 281–288, 1999.

[4] T. Komatsu, H. Arai, R. Chiba, K. Nozawa, M. Arakawa, and K. Sato, "Cr Poisoning Suppression in Solid Oxide Fuel Cells Using $LaNi(Fe)O_3$ Electrodes," Electrochem. Solid-State Lett., Vol. 9, No. 1, pp. A9–A12, 2006.

[5] T. Komatsu, H. Arai, R. Chiba, K. Nozawa, M. Arakawa, and K. Sato, "Long-term Chemical Stability of $LaNi(Fe)O_3$ as a Cathode Material in Solid Oxide Fuel Cells," J. Electrochem. Soc., Vol. 154, No. 4, pp. B379–B382, 2007.

[6] H. Orui, K. Watanabe, R. Chiba, and M. Arakawa, "Application of $LaNi(Fe)O_3$ as SOFC Cathode," J. Electrochem. Soc., Vol. 151, No. 9, pp. A1412–A1417, 2004.

[7] H. Orui, K. Nozawa, K. Watanabe, S. Sugita, R. Chiba, T. Komatsu, H. Arai, and M. Arakawa, "Development of Practical Size Anode-supported Solid Oxide Fuel Cells with Multilayer Anode Structures," J. Electrochem. Soc., Vol. 155, No. 11, pp. B1110–B1116, 2008.

[8] M. Yokoo, Y. Tabata, Y. Yoshida, K. Hayashi, K. Nozawa, Y. Nozaki, and H. Arai, "Highly Efficient and Durable Anode-supported SOFC Stack with Internal Manifold Structure," J. Power Sources, Vol. 178, No. 1, pp. 59–63, 2008.

[9] M. Yokoo, Y. Tabata, Y. Yoshida, H. Orui, K. Hayashi, Y. Nozaki, K. Nozawa, and H. Arai, "Development of 1 kW Class Solid Oxide Fuel Cell Stack Using Anode-supported Planar Cells," J. Power Sources, Vol. 184, No. 1, pp. 84–89, 2008.

[10] K. Hayashi, M. Yokoo, Y. Yoshida, Y. Tabata, H. Orui, K. Nozawa, Y. Nozaki, and H. Arai, "Development of a 1 kW Solid Oxide Fuel Cell Stack with Anode Supported Planar Cells at NTT," ECS Trans. Vol. 17, No. 1, pp. 53–61, 2009.

[11] Y. Yoshida, T. Komatsu, R. Chiba, M. Yokoo, K. Hayashi, H. Orui, and H. Arai, "Durability of Anode-supported SOFCs Stack Using $La(Ni,Fe)O_3$ Cathode," ECS Trans., Vol. 25, No. 2, pp. 421–428, 2009.

[12] H. Arai, K. Hayashi, Y. Yoshida, M. Yokoo, Y. Mizutani, K. Ukai, K. Katsurayama, H. Orishima, M. Hirakawa, H. Uwani, and S. Kashima, "3kW SOFC Power Generation Module Developed by NTT/THG/SPP," ECS Trans., Vol. 25, No. 2, pp. 125–132, 2009.

Yoshiteru Yoshida

Energy Systems Project, NTT Energy and Environment Systems Laboratories.

He received the B.S. degree in engineering from the University of Hokkaido and the M.S. degree in engineering from the University of Tokyo in 2000 and 2003, respectively. He joined NTT in 2003 and mainly engaged in SOFC development. He received the Young Engineer's Award from the Institute of Electronics, Information and Communications Engineers (IEICE) of Japan in 2008.

Katsuya Hayashi

Senior Research Engineer, Energy Systems Project, NTT Energy and Environment Systems Laboratories.

He received the B.S. and M.S. degrees in chemistry from Waseda University, Tokyo, in 1990 and 1992, respectively. He joined NTT in 1992 and mainly engaged in research on lithium battery technology. Since 2004, he has been working on SOFC development. He has received awards from the Chemical Society of Japan (CSJ) and the Electronics Division of the Ceramics Society of Japan. He is a member of CSJ and the Electrochemical Society of Japan.

Masayuki Yokoo

Research Engineer, Energy Systems Project, NTT Energy and Environment Systems Laboratories.

He received the B.S. and M.S. degrees in mechanical engineering from the University of Tokyo and the Ph.D. degree in engineering from Tokyo Institute of Technology in 1998, 2000, and 2007, respectively. He joined NTT in 2000 and mainly engaged in research on fuel cells, especially SOFCs.

Anti-corrosion Technologies for Telecommunications Structures and Equipment

Takashi Sawada, Hiroyuki Saito†, Yasuhiro Higashi, and Hidetomo Sakaino

Abstract

In this article, we introduce research on anti-corrosion technologies with a focus on outdoor telecommunications facilities and equipment. This research is proceeding in two ways: by understanding individual corrosion mechanisms for metallic materials at the microscopic level and by rapidly visualizing corrosion risks from the macroscopic viewpoint. We explain these two approaches and present the latest research results.

1. Installation environment for telecommunications structures and equipment

Today's information and communications technology (ICT) is supported by many types of structures and equipment. A typical scenario is shown in **Fig. 1** [1]. These structures and pieces of equipment include many outdoor transmission paths such as optical fiber cables for conveying information from a switching center to the customer's home and equipment for physically supporting those paths such as utility poles.

Since these facilities are installed everywhere in Japan to provide universal service, they are placed in a wide variety of environments including mountainous regions, coastal areas, hot-spring areas, and regions with heavy snowfall. They are exposed to the natural environment, which means that they can be affected by the annual and daily range of temperature, annual rainfall, hours of daylight, and other natural phenomena. Since we cannot control the natural environment, we must find means of preventing corrosion and other types of deterioration in facilities caused by atmospheric factors.

† NTT Energy and Environment Systems Laboratories
Musashino-shi, 180-8585 Japan

2. Corrosion in telecommunications structures and equipment

Telecommunication structures and equipment are typically constructed from metals (especially steel) and plastics. These materials have very different characteristics, but both of them will deteriorate over the long term when exposed to the natural environment. Steel can give rise to corrosion products (rust) if exposed to water or salt, and plastics can suffer from blanching and degraded mechanical characteristics since ultraviolet rays from the sun can break down molecular chains and reduce the molecular mass. Moreover, guy wires swinging in the wind can suffer from metal fatigue, and cables can be bent by the weight of accumulated snow, leading to a deterioration phenomenon called galloping.

While many problems can arise from the mutual interaction between the natural environment and the material components of structures and equipment, the major one is metal corrosion. Corrosion has been a problem for a long time, and research into countermeasures at NTT has been ongoing since the establishment of the Technical Assistance Section in the Electrical Communication Laboratories of Nippon Telegraph and Telephone Public Corporation (the forerunner to NTT) in 1963 [2]. However, as new telecommunications technologies and facilities come

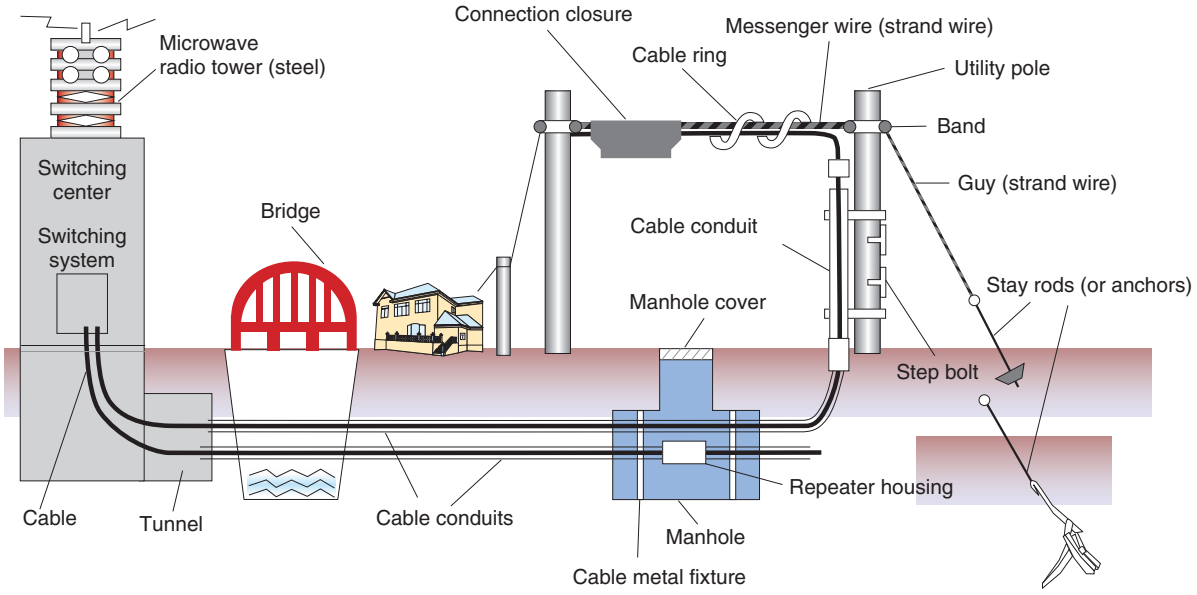


Fig. 1. Typical outdoor structures and equipment.

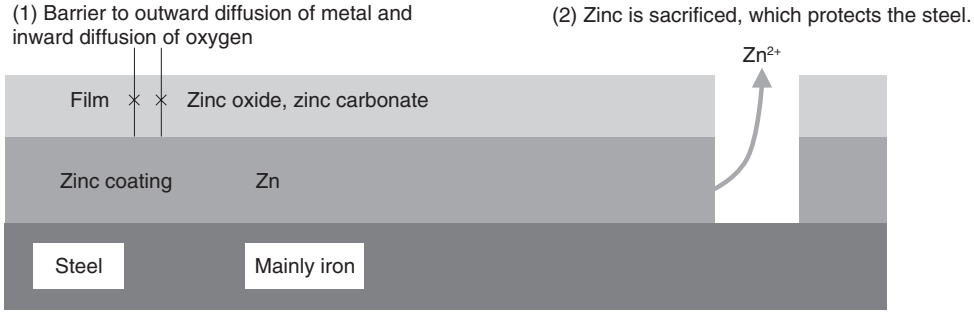


Fig. 2. Corrosion model of zinc-coated steel.

to be developed and structures and equipment come to be deployed in even more severe environments, the need for new anti-corrosion measures is growing. At the same time, concerns have been rising in recent years about corrosion in aging structures and equipment that was installed in great quantities during Japan's high-growth era. In short, we have entered an era that demands measures for protecting telecommunications facilities from corrosion and prolonging their life.

3. Corrosion mechanism in steel strand wires

Most steel used in outdoor structures is treated with anti-corrosion measures. Typically, steel is protected from corrosion by zinc coating. The ability of zinc coating to counteract corrosion in steel is explained by the following two functions (**Fig. 2**).

(1) When zinc corrodes by itself, it forms a film that delays further corrosion (by hindering the outward diffusion of metal and inward diffusion of oxygen).

(2) The electrical potential of zinc corrosion in water is lower than that of iron, so even if the zinc coating should be damaged and expose the iron, the zinc will corrode first and thereby protect the steel.

In other words, steel, if covered by a film of water generated, for example, by condensation, will turn into iron ions and bond with oxygen in the atmosphere,

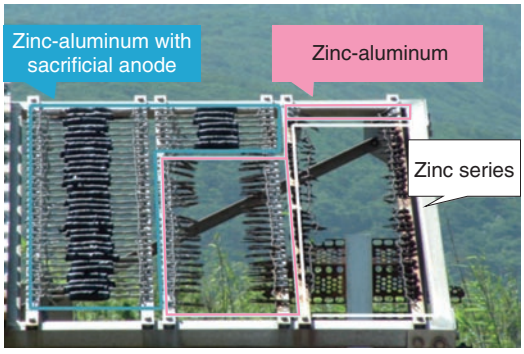


Fig. 3. Results of outdoor exposure test.

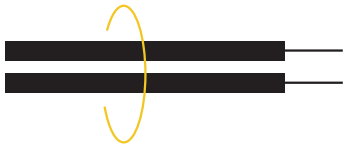


Fig. 4. Reed-shaped samples for indoor experiment.

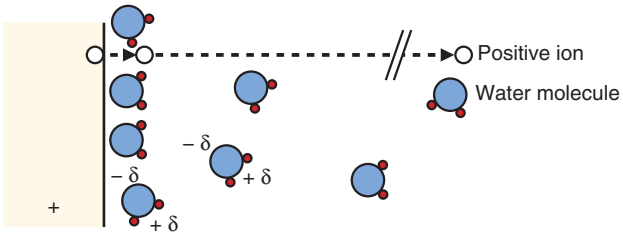


Fig. 5. Corrosion model near interface between metal and water film.

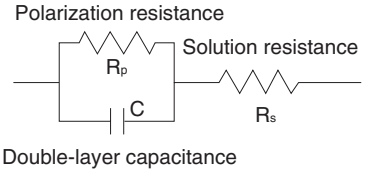


Fig. 6. Equivalent circuit of corrosion model.

thereby becoming an iron oxide, which has different characteristics to steel. The zinc-based anti-corrosion method works to defeat this process by preventing such diffusion and electrochemical reactions. In particular, the second of the above two effects, whereby steel is protected even if the zinc coating is slightly damaged, makes zinc coating more effective than paint.

On the other hand, the fact that zinc coating is effective in counteracting corrosion does not mean to say that it can completely prevent corrosion from occurring. In coastal areas, for example, sea-salt accelerates corrosion, which creates a need for coatings composed of materials such as aluminum or zinc-aluminum alloys that have greater anti-corrosion properties. In this regard, our research group conducted a study comparing corrosion among steel strand wires with various types of coatings after exposure for more than 20 years near the coast on an island group near Tokyo [3]. As shown in **Fig. 3**, steel strand wires with zinc plating lost their plating during the exposure period resulting in corrosion of the underlying steel, while the steel strand wires with aluminum cladding were generally sound except for sections with crevices. On the other hand, anti-corrosion processing involving the application of aluminum-series alloy tape protected those sections with crevices.

On the basis of the above results, we researched the corrosion mechanism with a focus on how corrosion begins in crevices in steel strand wires in the case of different types of coatings [4]. Corrosion in iron has already been explained in terms of electrochemical reactions (battery cell reaction) via ions, and with this in mind, we arranged two reed-shaped samples in parallel to form a crevice and performed an experiment to quantitatively determine how an electrical circuit can form and how corrosion can proceed using the crevice spacing and humidity as conditions (**Fig. 4**). The model that we used here for the metal/water-film interface during the corrosion process is shown in **Figs. 5** and **6**. If such an electrical circuit is formed, the impedance components between the samples can be described from circuit theory as a real part and an imaginary part that draw out a semicircle, as shown in **Fig. 7**. In other words, in a system in which AC voltage at a certain frequency is applied to a corroding system and the impedance is measured, the difficulty of corrosion (Rp) can be determined graphically. On the basis of this idea, we left a sample with a crevice spacing of 1 μm in an environment with relative humidity of 98%, and noted that, while no electrical circuit had formed after six hours, one had formed after 25 hours with a portion of an arc

appearing. We performed the same experiment for zinc, aluminum, and a zinc-aluminum alloy (55% aluminum) and obtained the arcs shown in **Fig. 8**. Examining these results, we can see that those for zinc have the largest radius with only part of the arc apparent. Those for the zinc-aluminum alloy, meanwhile, exhibit nearly the entire semicircle, and those for aluminum have the smallest radius. Thus, if we now determine the characteristics of the circuit elements from these results and measure the corrosion rate, we can tabulate our results (**Table 1**). Since current outflow is determined by the outflow of ionized metal, i.e., by the progress of corrosion, it can be seen that the corrosion of aluminum in crevices can easily progress.

To put it another way, two things have become qualitatively and quantitatively understood: (1) a battery cell can form and metal can begin to corrode depending on the size of the crevice even for a level of humidity that has not reached the dew point and (2) the progress of corrosion in crevices differs from one type of metal to another. It is therefore essential to give special attention to crevices when protecting metal structures with a coating of aluminum or other metal; this is more important than when protecting zinc-plated structures, even in sub-dew-point conditions.

A technique like the one described above lets one research where on structures or equipment metal corrosion can easily begin and under what conditions the risk of corrosion can increase.

4. Regional differences in corrosion

Japan features a variety of natural environmental conditions. The problem of humidity, for example, differs between Hokkaido and Okinawa. Even though the corrosion of specific structures and equipment is affected by the moisture conditions and the crevices in question, it must be considered that the average corrosion rate will be analyzed by regional corrosion conditions. The fundamental mechanism of metal corrosion, as explained above, is the transformation of metal to ions and the flow of current. However, given that salt dissolved in water creates an electrolyte solution with low resistance and that salt being deliquescent can instigate the formation of water films, it should be kept in mind that structures and equipment in locations where salt can easily adhere and be absorbed, such as in coastal regions, are especially susceptible to severe corrosion (saline damage).

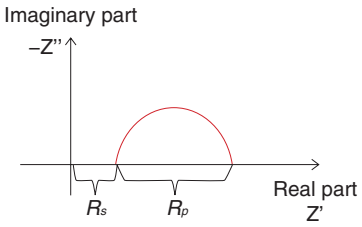


Fig. 7. Ideal impedance behavior of corrosion equivalent circuit.

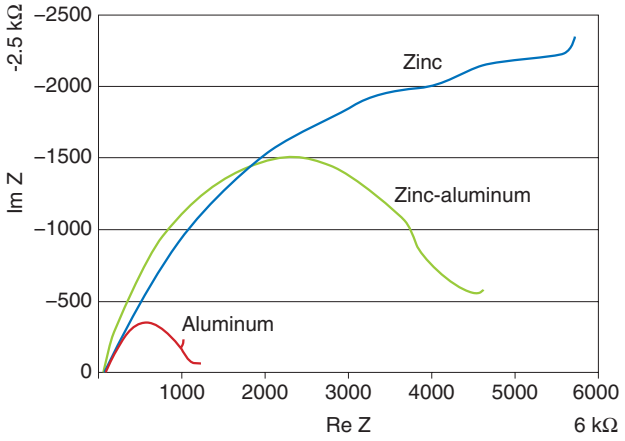


Fig. 8. Example of corrosion characteristics in crevices for different metal coatings.

Table 1. Corrosion-rate indices for different metal coatings in crevices.

	Zn	Zn-Al	Al
R_P at 12.5 cm^2	10 kΩ	5 kΩ	1 kΩ
index of corrosion rate	1 μA	2 μA	10 μA

Current outflow means the outflow of ionized metal, i.e., progress of corrosion

Accordingly, to investigate regional differences in assumed corrosion environments, we constructed a prototype system for estimating corrosion rates throughout Japan with special attention paid to saline damage.

The model for this system is based on a previously disclosed model researched by NTT [5]. The system is summarized in **Fig. 9**. Using actual measurement

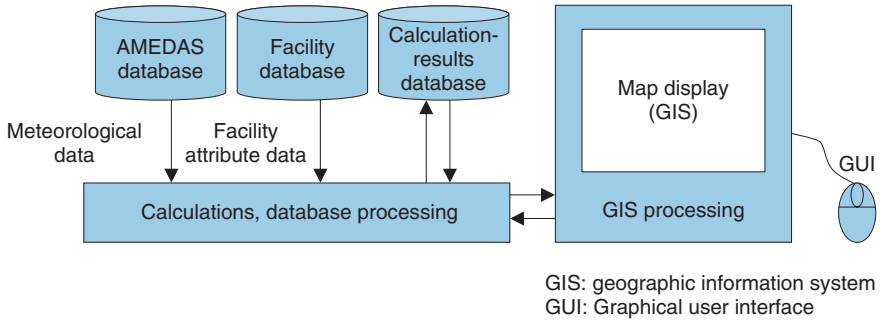


Fig. 9. Saline-damage map system.

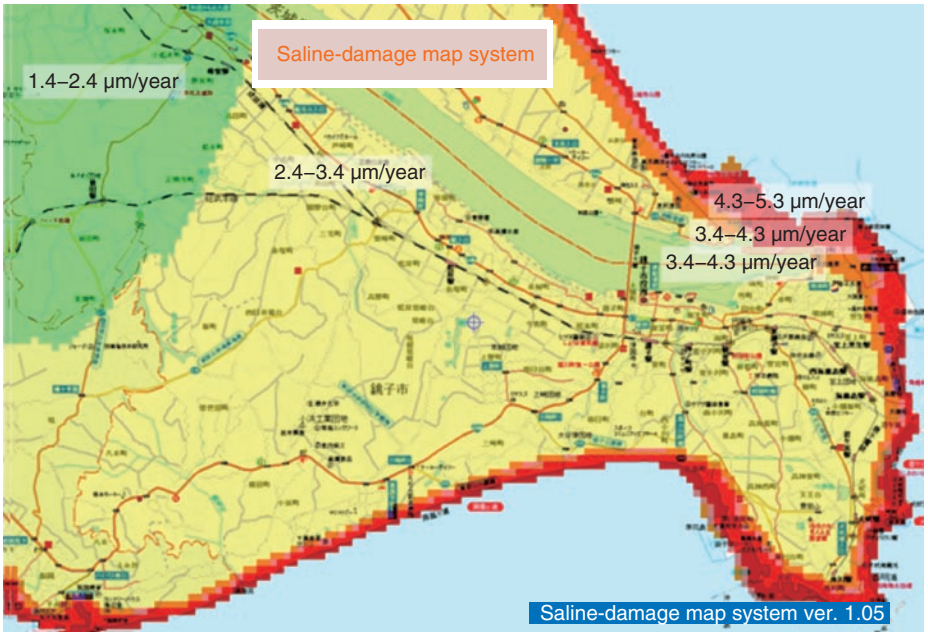


Fig. 10. Example of calculating zinc corrosion speeds by using the saline-damage map system (Choshi, Japan).

values from 21 observation regions throughout Japan, this system aims to visualize risk by estimating values (1)–(4) described below at any point on the Japanese map.

(1) Amount of sea-salt aerosol: Indicates the quantity of sea-salt particles adhering at a certain point per unit area per day (unit: mg/cm^2/day). Assuming that marine aerosols generated by the ocean can be transported by the wind, the quantity of sea-salt particles can be directly calculated from wind direction and speed for the day in question by incorporating a damping expression for the concentration of particles swept inland from the coast by using an exponential function. However, as meteorological data cannot be obtained for all points, the system extracts data from the nearest observation points in Japan's Automated Meteorological Data Acquisition System (AMEDAS) and interpolates data (using the same interpolation method as for calculating values (2)–(4) below).

(2) Corrosion rate: Indicates the wastage per unit time of metallic material covering the surface of the target structure (unit: μm/year). The corrosion rate is computed from the amount of sea-salt aerosol adhering to the metallic surface, the

metallic material used, temperature obtained from AMEDAS data, and moisture-related factors (number of days with condensation and amount of rainfall). At present, calculations can be performed for iron and zinc (the main component of plating).

(3) Amount of corrosion: Indicates the amount of wastage at a certain point in time (unit: μm). This is the integral of corrosion rate for the period in question, but in this model, we also consider that the corrosion rate decreases as the amount of corrosion increases (time to the -0.3 power) [6] (based on an empirical formula for quantifying function (2) in Fig. 2).

(4) Remaining life: Indicates the time required for the current plating thickness to reach either zero or a certain specified value (unit: months). This value is determined by extrapolating the amount of corrosion and the corrosion rate at the time of calculation. The initial value of film thickness and the year that the structure was built or installed must be given. These values and the quality of the material used are available from the facility database.

A screenshot of simulation results obtained using this system is shown in **Fig. 10**. This system supports interactive operation using a mouse: selecting a point or region on the map superimposes simulation results on the screen. Color is used to display corrosion results to enable the user to readily understand how corrosion spreads near the seashore. This system therefore enables the extent of saline damage for certain regions (shown by different colors) to be estimated from publically available meteorological data and geographical information. As such, we can expect it to be used as a reference source when upgrading or triage-operating equipment susceptible to saline damage. Moreover, since the system also provides the distribution of corrosion rate, it lets us enhance facility repairs more efficiently.

5. Concluding remarks

This article introduced research on anti-corrosion technologies with a focus on outdoor telecommunications facilities. We plan to increase the operation speed of our prototype system, test its validity for actual degradation phenomena, and develop it into a practical system while considering various usage scenarios.

References

[1] T. Sawada, Y. Takeshita, H. Saito, Y. Higashi, S. Sakata, and T. Handa, "Recent Strides to Make Telecommunications Plant More Environmentally Friendly and Reliable," NTT Technical Review, Vol. 7, No. 10, 2009.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr200910sf4.html

[2] H. Saito, "Hydrogen Embrittlement of Steel in Concrete," 2008 Reports on Weathering Technology Achievements, pp. 75–80, 2008 (in Japanese).

[3] M. Nakamura, H. Saito, Y. Higashi, T. Sawada, T. Handa, T. Kudo, M. Watanabe, and M. Matsumoto, "Corrosion of Steel Wire Strands for Telecommunication Exposed on Miyake Island," Corrosion Engineering, Vol. 59, No. 10, pp. 290–292, 2010.

[4] H. Saito, T. Sawada, and T. Handa, "Crevice Corrosion Test Method and Corrosion Analysis of Zn-coated Steel," Journal of Material Testing Research Association of Japan, Vol. 55, No. 3, pp. 109–114, 2010.

[5] Y. Higashi, H. Sakaino, S. Sakata, T. Sawada, and T. Handa, "Evaluation of Saline Environments for Telecommunications Line Facilities," Proc. of the 2010 IEICE Society Conference, 2010 (in Japanese).

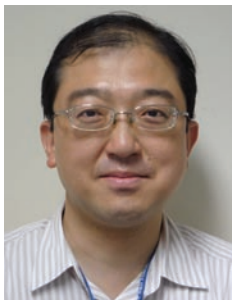
[6] Y. Miyata, R. Takekoshi, and H. Takazawa, "Estimation of Zinc Atmospheric Corrosion Rate in Coastal Areas," Corrosion Engineering, Vol. 38, No. 10, pp. 540–545, 1989 (in Japanese).

Takashi Sawada
Group Leader, Environmentally Adaptable Technology Group, NTT Energy and Environment Systems Laboratories.

He received the B.E. and M.E. degrees in electronics science from Nihon University, Tokyo, in 1989 and 1991, respectively. He joined NTT Electrical Communication Laboratories in 1992. Since then, he has been engaged in R&D of polymer optical devices and promoting environmental management in the NTT Group. He is currently engaged in making telecommunication plant materials and maintenance technologies more environmentally friendly and reliable.

Hiroyuki Saito
Senior Research Engineer, NTT Energy and Environment Systems Laboratories.

He received the B.E. degree in metallurgy, the M.E. degree in materials engineering, and the Ph.D. degree in materials science and engineering from Waseda University, Tokyo, in 1987, 1989, and 1999, respectively. After joining NTT in 1989, he worked as a telecommunications engineer. His career started in the field of line engineering including corrosion protection. He then worked in the development of water-repellent materials for wireless antennas, management of "Konet-plan" for an under-14-year-old kids education project including "Konet goo" search engine development, technical support for IP technologies for NTT technicians, and intellectual property rights management. Since 2008, he has been engaged in metallurgical and electrochemical research on the corrosion and delayed fracture control of telecommunication structures and equipment. He has a chief telecommunications engineer license. He is a member of the Institute of Electronics, Information and Communication Engineers of Japan, the Iron and Steel Institution, the Architectural Institute of Japan, the Chemical Society of Japan, and the Japan Society of Corrosion Engineering (JSCE). He is currently an editorial board member of the JSCE journal "Zairyo-to-Kankyo/Corrosion Engineering".



Yasuhiro Higashi
Senior Research Engineer, Environmental Information Systems Project, NTT Energy and Environment Systems Laboratories.

He received the B.E. and M.E. degrees in industrial chemistry from the University of Tokyo in 1988 and 1990, respectively. He joined NTT Applied Electronics Laboratories in 1990. He was engaged in R&D of secondary ion mass spectrometry and laser-ionization sputtered mass spectrometry (1990–1998) and material analysis services as the surface-analysis group leader in NTT AT (1998–2001). In 2001, he received the New Century Award from the Japan Society for Analytical Chemistry (JSAC). He is a member of JSAC, the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan, and the Iron and Steel Institute of Japan. He is also an environmental certified measurer and a chief telecommunications engineer (chief line engineer) certified by the Ministry of Economy, Trade and Industry (METI) and the Ministry of Internal Affairs and Communications (MIC), respectively.

Hidetomo Sakaino
Senior Research Engineer, Telecommunications Plant Materials Research Group, NTT Energy and Environment Systems Laboratories.

He received the B.S. degree in nuclear engineering and the M.S. degree in biomedical engineering from Hokkaido University in 1986 and 1988, respectively. He also received the Ph.D. degree from the University of Tokyo in 2011. He joined NTT Human Interface Laboratories in 1988. He moved to Advanced Telecommunication Research Institute International (ATR) in 1990 and NTT Communication Science Laboratories in 2001. His research interests are in computer vision and image processing for understanding the real world's spatio-temporal changes. His experience has been in physics-based modeling of optical flow, image synthesis, image prediction, and stochastic tracking. His weather radar prediction method with optical flow and fluid dynamics models has been commercialized for nowcasting all over Japan. More recently, he has been involved in atmospheric corrosion simulation of metals in facilities. He is a member of IEICE. He is also a member of IEEE Communication Society Multimedia Communications Technical Committee (IEEE MMTC).

Algorithm for Estimating Resource Input in ICT Industry

Minako Hara†*, Kazue I. Takahashi, Tatsuya Kunioka, and Jiro Nakamura*

Abstract

We present an algorithm for estimating the input resources consumed in managing equipment used in the information and communications technology (ICT) industry. It helps to produce appropriate plans for avoiding rising procurement costs and reducing the environmental impact of ICT equipment, which will enable us to prepare for the increase in the cost of resources caused by their depletion.

1. Introduction

In 1999, the NTT Group established the NTT Group Global Environmental Charter describing basic principles and policies for protecting the environment. The NTT Group analyzed achievement levels against specific goals in relation to preventing global warming, reducing waste products, and reducing paper consumption in terms of CO_2 emissions, the amount of final waste for disposal, and the consumption of virgin pulp. Along with the rising interest in corporate social responsibility, companies are becoming responsible for their supply chain activities such as procurement and waste treatment. The Global Reporting Initiative in partnership with the United Nations Environment Programme determines materials used by weight or volume as a core performance indicator in their guideline for sustainability reporting [1].

Progressive companies use the results of a material consumption analysis to promote resource savings. For example, several dozen companies disclose their environmental and economic improvements achieved by using material cost flow accounting [2].

The rapid increase in resource costs may have a serious impact on the information and communications technology (ICT) industry in the future because of its resource consumption as a result of its extensive infrastructure. Therefore, the resources required for the ICT industry must be estimated.

† NTT Energy and Environment Systems Laboratories
Atsugi-shi, 243-0198 Japan

2. Material flow analysis

Material flow analysis (MFA) is a methodology concerned with estimating the total amount, circulation amount, or balance of input and output amounts of materials systematically and quantitatively in entities such as countries and companies. The input represents the consumption of raw materials and energy and the procurement of parts. The output includes products, by-products, CO_2 emissions, and waste. The concept of material flow in the ICT industry is shown in **Fig. 1**.

The Japanese Ministry of the Environment uses MFA to obtain information about current resource circulation. Moreover, it is using MFA results to set numerical targets for resource productivity and cyclical use rate by adding to the conventional target expressed in the amount for final disposal in order to save resources and use appropriate waste treatment with the goal of establishing a sound material-cycle society [3].

3. Resource input measurement in the ICT industry

Data collection for productivity management is already under way for the purchase of raw materials, and many manufacturing companies disclose MFA

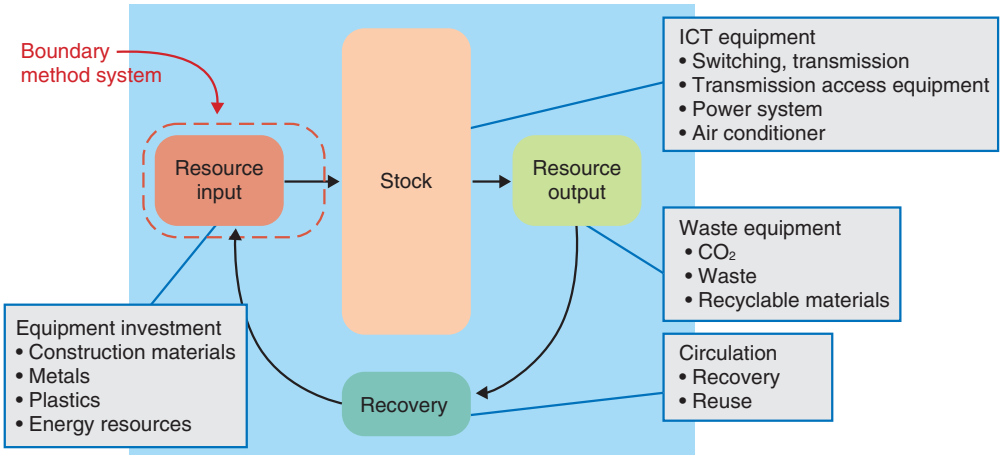


Fig. 1. Material flow in ICT industry.

results in relation to their annual activities in sustainability reports. On the other hand, the service and infrastructure industries have some difficulties in managing material input related to product purchasing and infrastructure construction. This is why there have been no case studies estimating the resource input of the ICT industry. With a view to applying MFA to the ICT industry, NTT Energy and Environment Systems Laboratories has investigated an algorithm for indirectly estimating the resource input using input-output analysis (IOA).

4. Outline of IOA

Today's economic activities, namely, the supply of goods and services, consist of production activities performed by interlinked industries. Input-output (I-O) tables provide information about production activities in the form of a matrix that shows how many goods and services are produced and distributed among the industries. IOA is an economic estimation methodology that uses I-O tables. In this study, a physical input-output table (PIOT), which is an application table focusing on materials on the basis of I-O tables and industrial statistics, was used to estimate the resource input. The formats of the basic and modified PIOTs used in this study are given in **Table 1**.

5. Resource input estimation algorithm

NTT Energy and Environment Systems Laboratories has established an algorithm based on a top-down

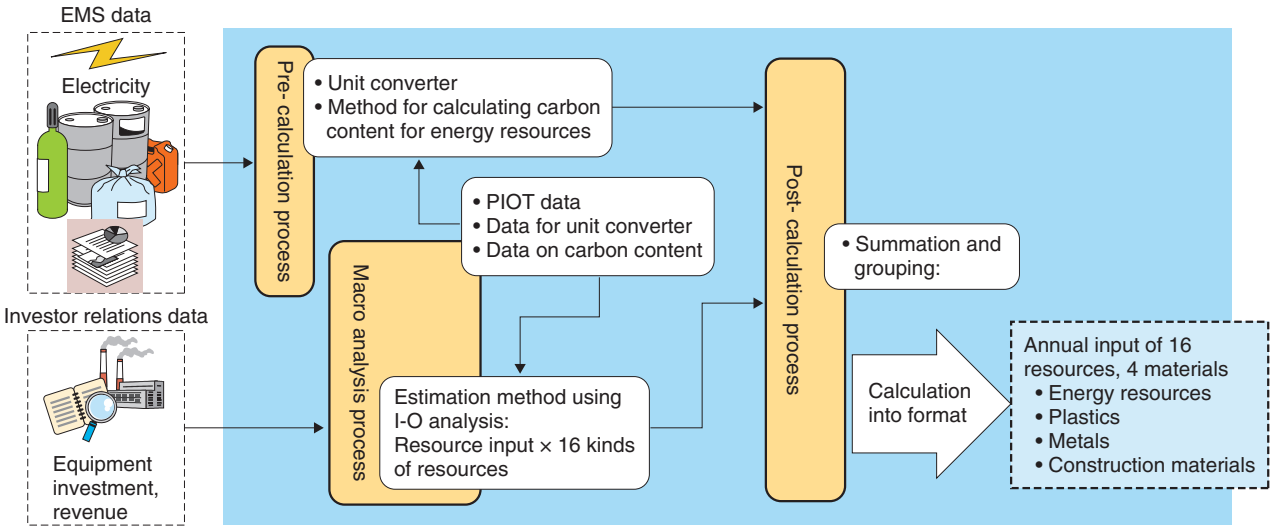
Table 1. Physical input-output tables (PIOTs).

(a) Basic PIOT

Item	Industrial category	Number	Sales (yen)
Product a	Industry A	**,***	**,***
	Industry B	**,***	**,***
	• • •	• • •	• • •
	Industry Z	**,***	**,***
Product b	Industry A	**,***	**,***
	Industry B	**,***	**,***
	• • •	• • •	• • •
	Industry Z	**,***	**,***
• • •	• • •	• • •	• • •
Product z	Industry A	**,***	**,***
	Industry B	**,***	**,***
	• • •	• • •	• • •
	Industry Z	**,***	**,***

(b) Modified PIOT

Industrial category	Input resource	Amount/sales
Industry A	Resource a	**,***
	Resource b	**,***
	• • •	• • •
	Resource z	**,***
Industry B	Resource a	**,***
	Resource b	**,***
	• • •	• • •
	Resource z	**,***
• • •	• • •	• • •
Industry Z	Resource a	**,***
	Resource b	**,***
	• • •	• • •
	Resource z	**,***



EMS: environmental management system

Fig. 2. Concept of algorithm for estimating resource input.

Table 2. Examples of input data sets in financial reports.

(a) Using equipment investment or annual purchase

Company X	Industrial category of equipment	20XX	20XX
Equipment investment (or annual purchases) (million yen)	Industry X (equipment x)	**,***	**,***
	Industry Y (equipment y)	**,***	**,***
	Industry Z (equipment z)	**,***	**,***

(b) Using revenue

Company X	Industrial category of business segment	20XX	20XX
Revenue (million yen)	Industry X (business x)	**,***	**,***
	Industry (business y)	**,***	**,***
	Industry (business z)	**,***	**,***

approach for estimating the input resources consumed to build and maintain ICT equipment effectively in the service industries. It is an estimation application of IOA using economic indices such as capital investment and annual purchases. It is important to note that the existing algorithm cannot separate the indirect input of resources consumed in supply chains from the direct input for the service industry. For this reason, its input amount results are defined differently from the input data on an aggregate basis.

As shown in **Fig. 2**, the algorithm consists of three processes: (1) pre-calculation of a set of input data related to the operation of equipment, (2) estimation of the resource input on the basis of IOA using PIOT (macro analysis), and (3) post-calculation including a summation of the pre-calculated and estimated data and allocation of the summation to material groups.

The input data for IOA should be financial data such as annual investments, equipment purchases, or revenue. The input data for equipment operation should be management data related to resource consumption (**Table 2**), such as the annual consumption

of electricity, natural gas, petroleum, and paper aggregated in an environmental management system (**Table 3**). Using the input data set, the algorithm outputs the annual input of 16 resources grouped into 5 categories (**Table 4**).

(1) Pre-calculation process

The set of input data for resources consumed for ICT operation requires the conversion of units because the consumption is expressed in various units. In this process, each consumption data set is converted into a weight unit by using an equation converter according to the units of the resources. Energy resources such as petroleum and gas are converted to carbon content to avoid inconsistency for data expressed in resource weight and CO_2 emissions in CO_2 equivalent.

(2) Estimation process

In the estimation process, the resources input for managing equipment are estimated by IOA using input financial data and PIOT data according to the industrial category for each production activity. Since the PIOT data units vary with the materials, they are converted into weight units using the abovementioned process.

(3) Post-calculation process

The input resources for operation and equipment provided by (1) and (2) are calculated in an application format that includes summation and grouping into categories.

Table 3. Example of input data for ICT operation.

ESM item	Unit	20XX	20XX
Natural gas	10,000 m^3	**,***	**,***
Heavy oil	kL	**,***	**,***
Gasoline	kL	**,***	**,***
Light oils	kL	**,***	**,***
Electricity	10,000 kWh	**,***	**,***
Virgin pulp	10,000 tons	**,***	**,***

Table 4. Output data for resources and categories.

Resource	Category
Petroleum (fuel)	Energy resources
Coal	
Natural gas	
Petroleum (plastics)	Plastics
Iron	Metals
Copper	
Lead	
Zinc	
Aluminum	
Manganese	
Chromium	
Nickel	
Crushed stone	Construction materials
Gravel and quarrying	
Limestone	
Logs	Wood

6. Application of results

NTT Group companies publish statements of resource input using the estimated data, as shown in **Fig. 3**. The provided results are also useful for creating a material flow chart (**Fig. 4**). The input flow in Fig. 4 shows the sum of the resource inputs for both operation and equipment. The output flow shows CO_2 emissions and waste, including recovered materials.

7. Conclusion

We have established a top-down-approach-based algorithm for estimating input resources in the ICT industry by using IOA. This algorithm is effective at enabling ICT companies to overview the environmental impact of their business activities. Its results include the indirect resource input in the supply chain. To divide the estimated input into direct and indirect inputs, we are developing an aggregation-based estimation model for accurate analysis of a bottom-up-approach-based algorithm. In further research, we intend to develop a method for estimating stock and output amounts as well as input resources in the ICT industry.

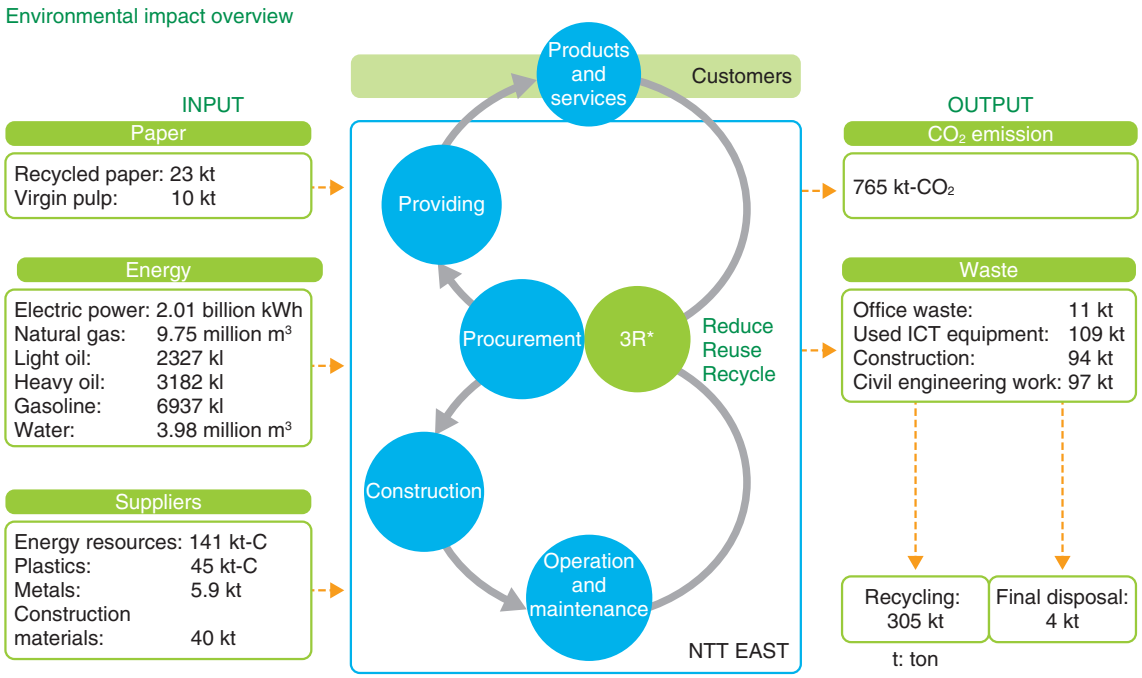


Fig. 3. Application example for NTT Group results (source: Japanese translated by the author) [4].

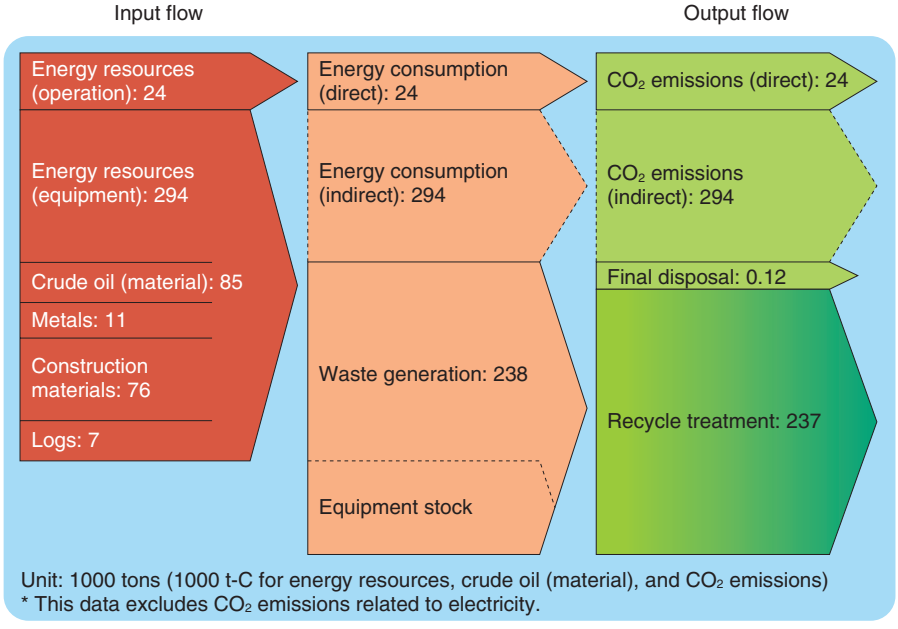


Fig. 4. Material flow chart created from results published by NTT EAST and NTT WEST.

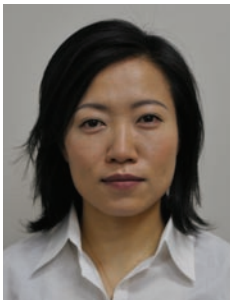
References

[1] Global Reporting Initiative, Sustainability Reporting Guidelines, G3, Amsterdam, 2006.

[2] Y. Onishi et al., "Implementing Material Flow Cost Accounting in a Pharmaceutical Company," Eco-efficiency in Industry and Science, Vol. 24, pp. 395-396, 2009.

[3] Japanese Ministry of the Environment, Annual Report on the Environment, "A Sound Material-Cycle Society and Biodiversity in Japan," pp. 229–237, 2010 (in Japanese).

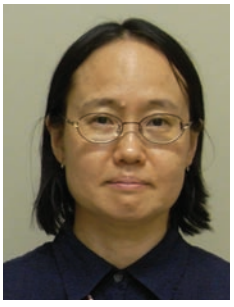
[4] NTT EAST Corporate Social Responsibility Report 2009, p. 33, 2009 (in Japanese).



Minako Hara

Research Engineer, Environmental Information System Project, NTT Energy and Environment Systems Laboratories.

She received the B.S. degree in applied chemistry from Tokyo University of Science in 1998 and the M.E. and Ph.D. degrees in applied chemistry from the University of Tokyo in 2000 and 2005, respectively. During 2004–2006, as a postdoctoral researcher at the Japan Science and Technology Agency, she developed an environmental impact assessment methodology and an eco-efficiency index. She joined NTT Energy and Environment Systems Laboratories in 2006 and studied environmental assessment, including life cycle assessment and material flow analysis. She is currently studying materials recovery technology. She is a member of the Society of Environmental Science, Japan, and the Society for Environmental Economics and Policy Studies.



Kazue I. Takahashi

Senior Research Engineer, Environmental Material Technology Group, Environmental Information Systems Project, NTT Energy and Environment Systems Laboratories.

She received the B.E. and M.E. degrees in applied chemistry from Waseda University, Tokyo, in 1986 and 1988, respectively, and the Ph.D. degree in materials engineering from the University of Tokyo in 2010. She joined NTT in 1988 and studied functional polymers, a sustainability assessment methodology, and electronic device recycling. Her primary areas of interest include evaluating the social impact of ICT services and new technology for reducing the environmental load of telecommunication networks. She is a member of the Institute of Electronics, Information and Communication Engineers of Japan, the Chemical Society of Japan, the Society of Environmental Science, Japan, and the Japanese Liquid Crystal Society.

Tatsuya Kunioka

Senior Research Engineer, Supervisor, NTT Energy and Environment Systems Laboratories.

He received the B.E. and M.E. degrees in electrical engineering from Waseda University, Tokyo, in 1985 and 1987, respectively. He joined NTT LSI Laboratories in 1987 and engaged in research on a precision mechanical system for electron beam lithography, spending most of the time developing a precision non-magnetic XY-stage using an ultrasonic linear motor for use in vacuum. He moved to the Environmental Protection Office of NTT EAST in 2001 and was responsible for the entire environmental protection management in NTT EAST. In particular, he promoted life cycle assessment of the telecommunication network in cooperation with NTT Energy and Environment Systems Laboratories. In 2004, he moved to NTT Energy and Environment Systems Laboratories and is currently studying refuse reclamation technology. He is a member of the Japan Society for Atmospheric Environment and the Society for Instrument and Control Engineers.

Jiro Nakamura

Group Leader, Environmental Information Systems Project, NTT Energy and Environment Systems Laboratories.

He received the B.E., M.E., and Ph.D. degrees in applied chemistry from Osaka University in 1987, 1989, and 1995, respectively. He joined NTT LSI Laboratories in 1989, where he worked on the development of microfabrication technology. He moved to the NTT Information Sharing Laboratory Group in 2001. Since moving to his present research department in 2004, he has been engaged in developing environmental sensing systems and analyzing the influence of ICT on the global environment. He received the Award of the MicroProcess Conference in 1997 and the Award of the Photopolymer Conference in 1998.

NTT Group Energy Efficiency Guidelines Initiative and Promotion of Green R&D

Katsuhiko Okazaki†, *Tatsumi Miyazaki, Jun Nishikido, Yoh Somemura, Yasuyuki Sugiyama, and Yuriko Tanaka*

Abstract

In April 2010, the NTT Group Energy Efficiency Guidelines were created with the goal of reducing the NTT Group's energy costs as well as its environmental load. The guidelines establish evaluation methods and set target standards for power-consumption efficiency in information and communications technology (ICT) equipment. They were accompanied by revisions to the "Detailed Guidelines for the Green Assessment of R&D Results", which is part of the NTT Group Green R&D Guidelines. This article introduces the background and current state of this series of initiatives.

1. ICT Ecology Guidelines

As services continue to diversify and traffic on the networks of telecommunications service providers increases, the power consumed by information and communications technology (ICT) equipment comprising the networks, air conditioners, power supplies, and other accompanying equipment, as well as the amount of CO_2 emitted as a result, are increasing in proportion. In response, the Ministry of Internal Affairs and Communications released a report in June 2009 entitled "Study Group on Ecological Measures in the ICT Field" [1]. This report stated that if telecommunications service providers would, at their own initiative, procure equipment designed to conserve energy and increase the visibility of their CO_2 emissions reduction initiatives, it would be effective in reducing CO_2 emissions. Accordingly, NTT and other telecommunications service providers created the ICT Ecology Guideline Council (Ecology Council [2]) in June 2009. It produced the ICT Ecology Guidelines (1st ed.) (Ecology Guidelines [3]) in February 2010 to establish procurement standards for telecommunications services providers for the purpose of evaluating the energy efficiency of ICT equipment and services. These guidelines indicate (1) assessment standards for evaluating applicable equipment, (2) assessment standards for evaluating datacenters, and (3) assessment standards for obtaining the Eco ICT Logo designation.

2. Standards for evaluating energy savings in ICT equipment

The Ecology Guidelines ver. 1.1 (revised on Dec. 27, 2010) stipulate figures of merit, normative references, and approximate dates for achieving the normative references for seven types of ICT equipment such as routers and servers[*1] (**Table 1**). The figure of merit for each type of ICT equipment was determined with due consideration for energy-saving methods, assessment standards from standards organizations, and also actual operational conditions. Furthermore, technical trends and other factors were also taken into

† NTT Research and Development Planning Department
Chiyoda-ku, Tokyo 100-8116 Japan

*1 Compact routers (without a virtual private network feature), Layer-2 switches (box-type), transport equipment, passive optical network equipment, broadband base stations, external power supplies, and server equipment.

Table 1. Normative references for equipment covered by the ICT Ecology Guidelines (ver. 1.1).

Equipment type	Category	Equipment name	Figure of merit	Normative reference	Approximate date for achieving normative reference	Notes
Broadband router (no VPN function)	A	Wired router	Power consumption (W)	4.0	FY2010 end	×2: 2.4-GHz radio output (mW/MHz) ×5: 5-GHz radio output (mW/MHz) * Figures of merit and normative references (×2, ×5, etc.) conform to assessment standards based on the Top Runner Method
	B	Wired router with VoIP		5.5		
	C	Wireless router (2.4 GHz)		$0.10\times2+3.9$		
	D	Wireless router (5 GHz)		$0.15\times5+3.9$		
	E	Wireless router (2.4 GHz + 5 GHz)		$0.10\times2+0.15\times5+5.1$		
	F	ADSL router		7.4		
	G	ADSL router with VoIP		7.4		
	H	Wireless ADSL router		8.8		
Layer-2 switch (box-type)	A	Layer-2 switch (SNMP management function, IP filter function)	Power consumption (W) ÷ max. effective Tx speed (Gbit/s)	$(\alpha_n+P_n)/T$	FY2011 end	α_n: Sum of port and fixed power consumption P_n: PoE additional power component T: Max. effective transmission rate n: Class (A, B, C, D) * Figures of merit and normative references conform to assessment standards based on the Top Runner Method
	B	Layer-2 switch (SNMP management function, no IP filter function)				
	C	Layer-2 switch (web-equiv. management function)				
	D	Layer-2 switch (no management function)				
Transport equipment	WDM	DWDM equipment	Max. throughput (Gbit/s) ÷ avg. power cons. (W)	0.32	FY2012 end	Avg. power consumption: (full wavelength power + 1 wavelength power)/2 * Figure of merit conforms to ATIS references
		CWDM equipment		0.48		
PON equipment	GE-PON	OLT (AC power source)	Average power consumption (W) ÷ total no. of lines	0.46	FY2012 end	Avg. power consumption = (P100 + P50 + P0)/3 Total no. of lines = total intermediate frequency ports x no. of PON branches
		OLT (DC power source)		0.42		
		ONU (100 Mbit/s)	Avg. power consumption (W)	3.68	FY2012 end	Avg. power consumption = (P100 + P50 + P0)/3
		ONU (1 Gbit/s)		4.45		
Broadband base station equipment	WiMAX	WiMAX base station (integrated, 10-W device (one system))		12.60	FY2012 end	P_n: Tx power on antenna terminal n (W) P_{idle}: primary input power with no load (W) P_{max}: primary input power at max Tx (W) α: daily average transmit traffic rate
		WiMAX base station (integrated, 10-W device (two systems))		9.63		
		WiMAX base station (integrated, 5-W device (one system))		5.84		
External power supply	AC adapter	AC adapter	Average conversion rate	$62.2+6.26\ln(P_{no})$	FY2011 end	Avg. conversion rate = $(\eta_{25}+\eta_{50}+\eta_{75}+\eta_{100})/4$ η_n: efficiency when load rate is n% P_{no}: nominal power (W) * Figures of merit conform to international agreements on efficiency
Server equipment	Server equipment	Server equipment	(Operating conditions evaluation index) $0.1\times\Sigma_{ssj\_ops}/\Sigma P$, where P is power consumption (W)	1000	FY2010 end	ssj_ops: processing capacity * Figure of merit conforms to SPECpower ssj®
			(Idle state evaluation index) {idle state power consumption (W)+ low-power mode conversion (W)}/2 ÷ combined theoretical performance	Under study	Under study	

ADSL: asynchronous digital subscriber line
CWDM: coarse wavelength division multiplexing
DWDM: dense wavelength division multiplexing
GE-PON: Gigabit Ethernet-passive optical network
IP: Internet protocol
OLT: optical line terminal
PoE: Power over Ethernet
PON: passive optical network
SNMP: simple network management protocol
Tx: transmitter
VOIP: voice over Internet protocol
VPN: virtual private network
WDM: wavelength division multiplexing
WiMAX: worldwide interoperability for microwave access

account when setting each normative reference and the approximate date for its achievement. Threshold values in five steps were also set to evaluate the degree to which ICT equipment achieves a given

Table 2. Assessment scales established in ICT Ecology Guidelines (ver. 1.1).

Equipment type	Five-step assessment scale threshold				
	★	★★ (normative reference)	★★★	★★★★	★★★★★
Broadband router (no VPN function)	(normative reference not achieved)	Power consumption reduction relative to normative reference: 0–10%	Power consumption reduction relative to normative reference: 10–20%	Power consumption reduction relative to normative reference: 20–30%	Power consumption reduction relative to normative reference: over 30%
Layer-2 switch (box-type)	(normative reference not achieved)	Power consumption reduction relative to normative reference*1: 0–10%	Power consumption reduction relative to normative reference*1: 10–20%	Power consumption reduction relative to normative reference*1: 20–30%	Power consumption reduction relative to normative reference*1: over 30%
Transport equipment	(normative reference not achieved)	Power consumption reduction relative to normative reference: 0–10%	Power consumption reduction relative to normative reference: 10–20%	Power consumption reduction relative to normative reference: 20–30%	Power consumption reduction relative to normative reference: over 30%
PON equipment					
Broadband base-station equipment					
Server equipment	(normative reference not achieved)	Power consumption reduction relative to normative reference*2: 0–20%	Power consumption reduction relative to normative reference*2: 20–40%	Power consumption reduction relative to normative reference*2: 40–60%	Power consumption reduction relative to normative reference*2: over 60%

*1 Power consumption reduction relative to normative reference is for comparison with equipment with equivalent maximum effective transmission speed.
*2 Power consumption reduction relative to normative reference is for comparison with equipment with equivalent processing capacity (ssj_ops value).

normative reference. For example, if the relative reduction in energy consumption exceeds the normative reference by 10–20%, it is given three stars, if it exceeds the normative reference by 20–30%, it gets four stars, and if it does not meet the normative reference, it gets only a single star (**Table 2**).

It is assumed that manufacturers will conduct these evaluations themselves and that the product-evaluation results will be published on the council's website. Telecommunications service providers will be able to refer to the results on the website when deciding their procurement standards.

3. NTT Group Energy Efficiency Guidelines

To reduce CO_2 emissions by the NTT Group, we are focusing on communications equipment and offices, which account for 90% of emissions by the group, in order to reduce power consumption. Accordingly, in April 2010, eight NTT-Group companies[*2] established the NTT Group Energy Efficiency Guidelines (1st ed.) (Energy Efficiency Guidelines [4], [5]), on the basis of the Ecology Guidelines, in order to support development and procurement of equipment with high energy-efficiency for NTT Group companies. The Energy Efficiency Guidelines ver. 1.1 (revised on Dec. 27, 2010) represent the basic approach to developing and procuring ICT equipment for the NTT Group. Some key extracts from them are shown in **Fig. 1**.

To encourage manufacturers to meet target values for equipment types as far as possible when applying these guidelines, manufacturers are required to indicate specific requirement items and show how they were evaluated in their technical specification documents. Moreover, the suitability of energy-saving-performance-guideline target values for each equipment group will be reexamined according to product trends. An overview of the operational flow for the guidelines is shown in **Fig. 2**. In the future, we will promote their application beyond the initial eight group companies.

*2 NTT, NTT EAST, NTT WEST, NTT Communications, NTT DOCOMO, NTT DATA, NTT Facilities, and NTT Comware.

Scope of application:
Applies to new development and procurement of ICT equipment by the NTT Group. Note that applicable ICT equipment is that conforming to standard values set in the “ICT Ecology Guidelines”.

Stipulated content:
(1) Basic approach for development and procurement of equipment
Development and procurement of ICT equipment by NTT Group companies will refer to normative references in the “ICT Ecology Guidelines” and equipment with the highest ranking (most stars) possible shall be developed or procured. Note that ICT equipment developed or procured shall be evaluated comprehensively, including functionality, performance, and cost, but also operating costs such as cooling and power and other environmental added values.
(2) Group target values
The group will strive to achieve the normative reference values set in the “ICT Ecology Guidelines (ver. 1.1)” in newly developed or procured equipment by the approximate dates for achieving normative references. Individual companies will also set target values for each type of equipment in each fiscal year. Note that these target values will be reviewed as appropriate according to external trends.

Fig. 1. Extracts from the NTT Group Energy Efficiency Guidelines (ver. 1.1).

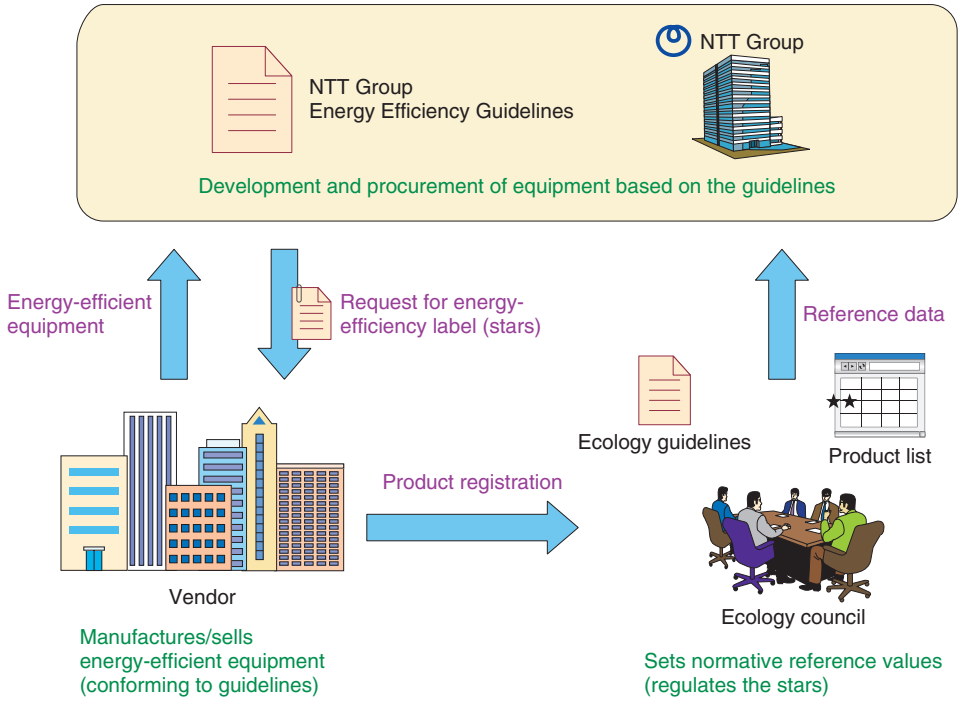


Fig. 2. Operational flow for the guidelines.

4. Eco ICT Logo

The Eco ICT Logo shows that a telecommunications service provider is taking appropriate initiatives to reduce CO_2 emissions. The Ecology Council began accepting applications for the Eco ICT Logo and publishing the names of companies receiving it in July 2010. The eight NTT companies that established the Energy Efficiency Guidelines have all received the Eco ICT Logo [6], [7].

The process for receiving the Eco ICT Logo is shown in **Fig. 3**. The Ecology Guidelines establish items that companies must check themselves regarding the state of their CO_2 emissions reduction initiatives. These items include mainly whether the company is creating equipment procurement standards,

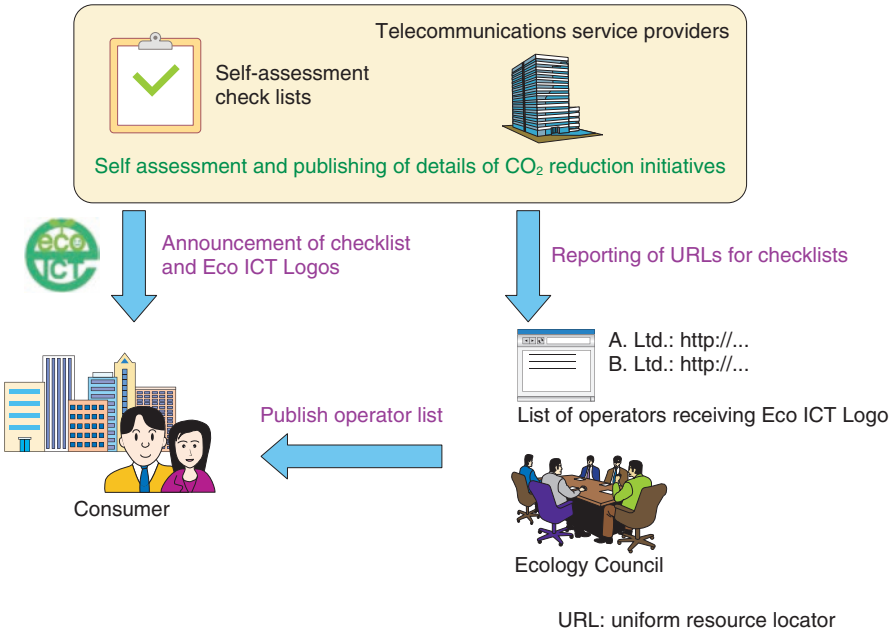


Fig. 3. Operation flow for the Eco ICT logo.

whether it is conducting procurement according to these standards, whether it has a voluntary environmental action plan describing CO_2 emission reduction target values, whether it is operating according to this plan, and whether it has any initiatives, staff announcements, or developments, besides CO_2 reduction ones, toward reducing its environmental load. The Ecology Guidelines include eight mandatory items and two optional items. Telecommunications service providers can obtain the Eco ICT Logo by fulfilling all the mandatory items and publishing the results of their self-assessment on their own websites. In the future, this Eco ICT Logo will be displayed on the websites and in corporate social responsibility reports of companies that have received it, and we will continue to widely promote NTT Group efforts to reduce CO_2 emissions.

5. NTT Group Green R&D Guidelines

In the NTT Group, we established the NTT Global Environmental Charter in 1991 and are promoting environmental protection measures throughout the company. In 2000, the NTT Group Green R&D Guidelines were established as an initiative toward research and development (R&D) taking the environment into consideration. Then, in 2004, the R&D Green Assessment Detailed Guidelines (GA Detailed Guidelines) were established and assessments based on these guidelines are instituted when R&D is started and when the results are provided to businesses, promoting ongoing efforts for environmental improvement.

In particular, from the outset, R&D must consider compatibility with issues such as the selection and compatibility of materials, restricted use of toxic substances, conservation of resources and energy, ease of disassembly and disposal, and methods for recycling and disposal. The energy efficiency of ICT devices and other R&D products are also evaluated (Green of ICT), as well as the effect of reducing the overall load of society on the environment (Green by ICT) through aspects such as improving distribution efficiency, reducing the movement of people and materials, and dematerialization. With this introduction of Energy Efficiency Guidelines, the GA Detailed Guidelines have also been revised so that in the future, in addition to previously evaluation items, conformance to the target values for each equipment group in the energy-saving guidelines will also be evaluated.

Finally, the NTT Group Green Procurement Guidelines [8] and the (Addendum) Green Procurement Guidelines [9], which establish the idea of reducing environmental load from a procurement perspective, have also been revised. The relationships among these guidelines are shown in **Fig. 4**.

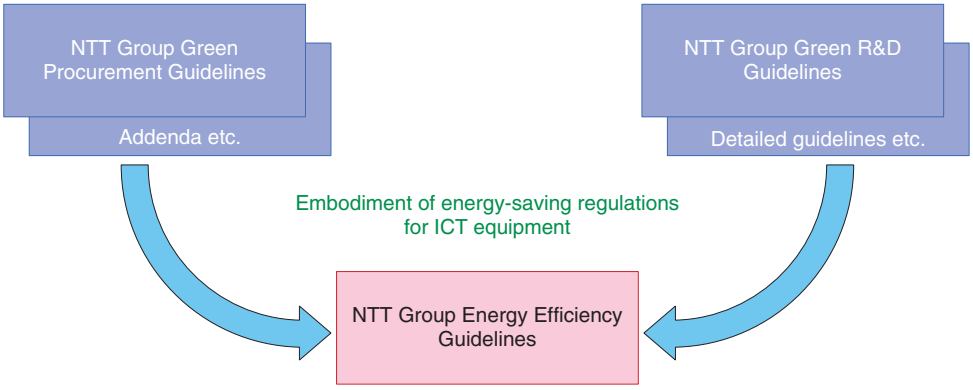


Fig. 4. Position of NTT Group Energy Efficiency Guidelines.

6. Future prospects

In the future, we will continue to revise the Energy Efficiency Guidelines in accordance with the Ecology Guidelines and technical trends for ICT equipment, promote the application of these guidelines in group companies besides the original eight companies, and further expand initiatives within NTT to reduce CO_2. The NTT Group will endeavor to create R&D results that have less environmental load (Green of ICT) and that help reduce the environmental load of society (Green by ICT) and will continue to promote policies at the R&D level that consider the environment.

References

[1] Ministry of Internal Affairs and Communications, "Study Group on Ecological Measures in the ICT Field," June 2009 (in Japanese). http://www.soumu.go.jp/main_sosiki/joho_tsusin/policyreports/chousa/ecology/index.html
[2] Telecommunications Carriers Association, "Ecological Guidelines in the ICT Field Council," (in Japanese). http://www.eco.tca.or.jp/
[3] "Ecological Guidelines in the ICT Field (1st ed.)" (in Japanese). http://www.tca.or.jp/information/pdf/ecoguideline/ictecoguideline.pdf
[4] "Introduction of Energy Efficiency Guidelines in NTT Group Companies," (in Japanese). http://www.ntt.co.jp/news2010/1004/100413a.html
[5] "NTT Group Energy Efficiency Guidelines," (in Japanese). http://www.ntt.co.jp/kankyo/guideline/index.html
[6] Press release, "Eight NTT Group Companies Obtain the Eco ICT Logo," (in Japanese). http://www.ntt.co.jp/news2010/1008/100811a.html
[7] NTT Corp. Self-Assessment Checklist (in Japanese). http://www.ntt.co.jp/kankyo/ecoict/index.html
[8] NTT Group Green Procurement Guidelines. http://www.ntt.co.jp/ontime/eg/green/pdf/green_e.pdf
[9] NTT Group Green Procurement Guidelines Supplement. http://www.ntt.co.jp/ontime/eg/green/pdf/green_esup.pdf

Katsuhiko Okazaki

Producer, Energy and Environment Produce Team, NTT Research and Development Planning Department.

He received the B.E. and M.E. degrees from the University of Electro-communications in 1993 and 1995, respectively. He joined NTT Network Service Systems Laboratories in 1995. He researched high-speed and high-density packaging technologies for ATM switching systems and QoS control technologies in broadband IP network including the NGN. Since 2008, he has been engaged in green ICT strategy in NTT Group. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.

Tatsumi Miyazaki

Chief Producer, Energy and Environment Produce Team, NTT Research and Development Planning Department.

Jun Nishikido

Senior Research Engineer, Supervisor, Second Promotion Project, NTT Network Service Systems Laboratories.

He received the B.S. degree in electrical and communication engineering from Waseda University, Tokyo, in 1986. He joined NTT in 1986. Since then, he has been engaged in research on photonic switching systems and developing NGN edge routers and aggregation switches. He received the Paper Award from IEICE in 2000. He is a member of IEEE and IEICE.

Yoh Somemura

Senior Research Engineer, Supervisor, Environmental Management & Provisioning Project, NTT Energy and Environment Systems Laboratories.

He received the B.E., M.E., and Ph.D. degrees in applied physics from Waseda University, Tokyo, in 1988, 1990, and 1995, respectively. He joined NTT LSI Laboratories in 1990 and worked on the development of microfabrication technology. Since moving to his present research department in 2006, he has been engaged in promoting environmental management in the NTT Group. He was a vice-chairman of the ITU-T Focus Group on ICTs and Climate Change until March 2009.

Yasuyuki Sugiyama

Project Manager, Environmental Management & Provisioning Project, NTT Energy and Environment Systems Laboratories.

He received the B.S., M.S., and Dr.Eng. degrees in electronic engineering from Waseda University, Tokyo, in 1985, 1987, and 1994, respectively. He joined NTT Electrical Communication Laboratories in 1987. From 1987 to 1993, he worked on optical data storage systems. He was a visiting scholar at Stanford University, USA, in 1998. Since 2002, he has been studying ICT systems for environmental protection.

Yuriko Tanaka

Senior Research Engineer, Environmental Management & Provisioning Project, NTT Energy and Environment Systems Laboratories.

She received the B.S. and M.S. degrees in physics from Keio University, Kanagawa, in 1992 and 1994, respectively. She joined NTT Interdisciplinary Research Laboratories in 1994 and worked on the development of microfabrication and sensors technologies. Since 1999, she has been studying ICT services for environmental protection. She moved to her present research department in 2009. She is currently engaged in promoting environmental management for the R&D in the NTT Group.

Quantifying Environmental Load Reduction Effect of Utilizing ICT

Toshihiro Hayashi†, *Takeshi Origuchi, Yoh Somemura, and Yasuyuki Sugiyama*

Abstract

This article describes our methodology for assessing the environmental impact of information and communications technology (ICT) and reports on international standardization activities regarding ICT and the environment.

1. ICT and its environmental impact

The recent rapid spread of information and communications technology (ICT), such as the Internet, broadband access, and mobile communications, has accelerated the paradigm shift from an industrial society to an information society. ICT has a large influence on the environmental, economic, and social aspects of our lives. However, the impact of ICT on the global environment is becoming larger, such as the increase in energy consumption due to the spread of the always-connected Internet. The environmental impact of ICT has both negative and positive aspects, as shown in **Fig. 1**.

Negative aspects result from the environmental load caused by ICT. They include energy consumption due to the electricity used by ICT devices and networks, the use of natural resources for producing ICT devices and constructing facilities, and the generation of waste from the disposal of ICT devices and dismantling of facilities.

Positive aspects are associated with the reduction in environmental load achieved by ICT services. Some examples of the positive aspects are:

- Dematerialization, which refers to the replacement of physical production and distribution of music, video, books, and software, etc. by the delivery of digital information over the network;
- Reduction of movement through the use of videoconferencing;
- Reduction of transportation through the use of intelligent transport systems;
- More efficient industry through supply chain management systems;
- More efficient lifestyles through the use of information appliances;
- Enhancement of environmental awareness and environmental education; and
- Reduction of the environmental load through the use of environmental sensors and environmental monitoring.

To construct a sustainable society from an environmental viewpoint, it is important to minimize the negative aspects of ICT and maximize the positive ones. To this end, both the positive and negative environmental aspects of ICT must be quantitatively evaluated.

2. Evaluation of ICT environmental impact

The "Guideline for Information and Communication Technology (ICT) Eco-Efficiency Evaluation" [1] (hereafter called the Guidelines) was published by the Japan Forum on Eco-Efficiency in March 2006. It is a uniform domestic standard for quantitatively evaluating the environmental impact associated with the implementation of ICT. NTT has played an active role in establishing the Guidelines for technology for evaluating the environmental impact of networks and ICT services.

† NTT Energy and Environment Systems Laboratories
Musashino-shi, 180-8585 Japan

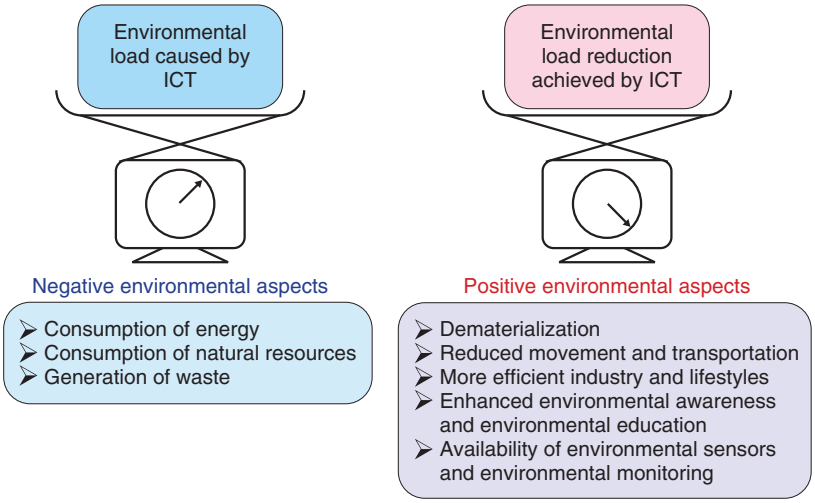


Fig. 1. Impacts of ICT on the environment.

Table 1. Activities to be evaluated for each life cycle stage of ICT.

Activity	Description
(1) Material and energy consumption	Activities that occur and are relevant to the life cycle of materials and energy input into and output from the product system, excluding activities included in (2)–(8). Material includes information printouts, information media (e.g., CDs and DVDs), toner cartridges for printers, water, and compressed air. Energy includes fuel (e.g., gasoline and fuel oil) and electricity.
(2) Utilization of ICT goods	Activities utilizing ICT goods, e.g., using personal computers and printers. ICT goods composing the assessed ICT are evaluated in each life cycle stage. In the use stage, for example, electricity consumed by using ICT goods is considered.
(3) Utilization of network infrastructures	Activities utilizing facilities composing the network infrastructure. Network infrastructure means the facilities providing ICT-related services for the assessed ICT, e.g., telephone communication, ISP (internet service provider) connection, and data services offered by datacenters.
(4) Utilization of software	Series of activities of design, development, and use of software. Software includes individual software, packages, middleware, and operating systems. Software composing the assessed ICT is evaluated in each life cycle stage. In the production stage, for example, electricity and information printouts used for design and development of software are considered.
(5) Movement of goods	Activities for shipping products, components, materials, and so on. Material (including pallets and secondary material) and energy used for transportation are considered.
(6) Movement of people	Activities related to travel by artificial means of transportation. Gasoline consumed by private cars, electricity consumed by trains, and light oil consumed by buses are included.
(7) Storage of goods	Activities for storing products, components, materials, and so on without quality deterioration. A certain amount of energy is consumed because air conditioning and lighting are generally necessary for such storage.
(8) Work processes	Activities related to work in offices or other work places. A certain amount of energy is consumed because air conditioning and lighting are generally necessary in offices.

The Guidelines state that the ICT environmental load should be assessed using life cycle assessment (LCA) conforming to the ISO 14040 series and JISQ 14040 series. The LCA technique quantitatively evaluates the environmental impact at each stage in the life cycle of goods or services, from the acquisition of raw materials to production, use, and disposal.

For each life-cycle stage, the Guidelines classify the activities to be evaluated, i.e., the activities that have an impact through the use of an ICT service, into eight categories as shown in **Table 1**. The Guidelines state that the following items should be taken into account in an evaluation of the environmental load of

the network infrastructure (Activity (3) in Table 1):

- Units of evaluation regarding the type of telecommunication system (circuit switching and packet communication);
- Evaluation period of network infrastructure consisting of many communication facilities having different lifetimes; and
- Allocation procedure for each type of facility (customer premises, access network, and core network).

The Guidelines also state the classification of software and the method of allocation when evaluating the environmental load of software (Activity (4) in Table 1). Moreover, they discuss a framework for performing a comparative evaluation of ICT services or a comparative evaluation between an ICT service and a *traditional means* on the basis of the environmental load evaluation. Here, traditional means refers to an existing means or service that does not use ICT, such as a face-to-face meeting involving a business trip, which can be evaluated in comparison with videoconferencing. In a comparative evaluation, we first determine the ICT service for comparison (target ICT service) and then set up another ICT service or traditional means as a baseline service. We evaluate the environmental load reduction effect of the ICT service by evaluating the difference between the environmental loads of the target ICT service and the baseline service.

This section has given a brief outline of the ICT environmental impact evaluation stated in the Guidelines. For more details, see reference [2].

3. Application to environmental management

The NTT Group is promoting activities for better communicating the environmental contributions of ICT services to its customers by using the environmental impact evaluation method stated in the Guidelines. Examples of activities are the development of the "Environmental Impact Assessment System for ICT Services" [3], which is a tool for quantitatively evaluating the environmental load reduction effect of ICT services from an LCA standpoint, and of the "NTT Group Solution Environmental Label System" [4], which is a means of identifying NTT Group's ICT solutions with notably low environmental impacts as eco-friendly. These activities promote the quantification of the environmental load reduction effect achieved by utilizing ICT.

4. International standardization activities

The environmental impact of ICT on climate change has drawn attention not only domestically but also globally. While the Guidelines state the domestic uniform methodology, evaluation methods have not been standardized internationally. The problems in establishing an internationally agreed methodology include securing fairness, adequacy, and transparency; being available for comparison between countries or regions considering the national or regional differences; and obtaining understanding from other sectors. These problems have led to a strong need to discuss international standardization for ICT and the environment.

Under these circumstances, the Focus Group on ICTs and Climate Change (FG-ICT&CC) was established in the International Telecommunication Union, Telecommunication Standardization Sector (ITU-T) as a result of discussions in the Telecommunication Standardization Advisory Group (TSAG) meeting of ITU-T held in Geneva in July 2008 [5]. FG-ICT&CC engaged in vigorous discussion on issues related to standardization of an internationally agreed common methodology for measuring the reduction in CO_2 emissions achieved by ICT. The FG-ICT&CC Deliverables were completed in March 2009, and the contents of the Guidelines were included in the final report of Deliverable 3 "Methodology".

The results of FG-ICT&CC Deliverables were reported at the TSAG meeting in April 2009, and the reorganization of Study Group 5 (SG5) on the environment and climate change was approved in the meeting. In response to this approval, the establishment of Working Party 3 (WP3/5) on ICT and climate change was approved in the SG5 meeting in May 2009, as shown in **Fig. 2**.

WP3/5 is composed of five questions (Qs), as shown in **Table 2**. Discussion in WP3/5 is becoming more active, as represented by the approval of the Recommendation on a universal power adapter for mobile devices in Q21/5. Moreover, Q18/5 is developing Recommendations for an ICT environmental impact assessment methodology (**Fig. 3**).

Recommendation L.1400 "Overview and general principles of methodologies for assessing the environmental impact of ICT" presents general principles for how to assess the environmental impact of ICT and outlines the different methodologies that are being developed. It states that the series of methodology Recommendations focuses on both energy consumption and greenhouse gas (GHG) emissions as

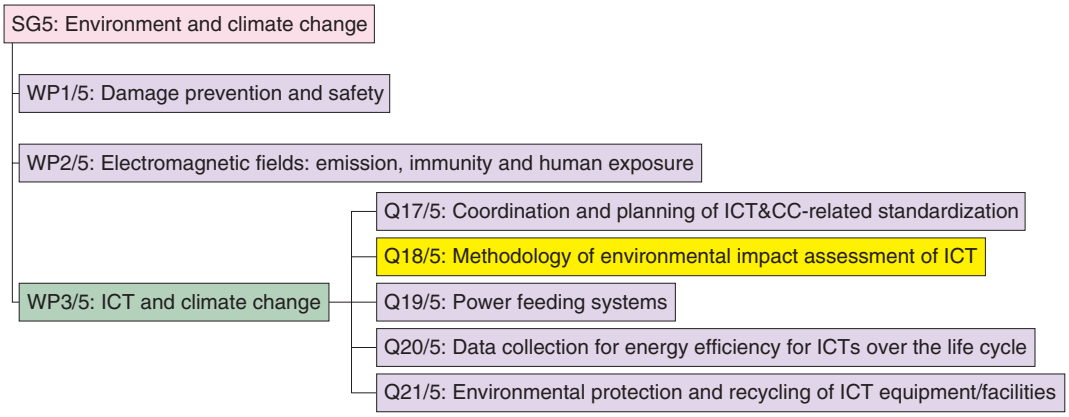


Fig. 2. Structure of ITU-T WP3/5.

Table 2. Tasks of questions in ITU-T WP3/5.

Question title	Main tasks
Q17/5: Coordination and planning of ICT&CC-related standardization	– Develop and maintain an overview of ICT&CC-related Recommendations in WP3/5. – Coordinate with other SGs and other bodies on a regular basis to improve planning of the work. – Provide and maintain an overview of key mitigation technologies (e.g., teleconferencing, teleworking, and e-learning).
Q18/5: Methodology of environmental impact assessment of ICT	– Develop Recommendations for a methodology for environmental impact assessment of ICTs considering general principles, criteria for evaluating ICT impact, system boundaries, functional units, and environmental load intensity. – Develop handbooks as necessary making reference to available databases related to common environmental load intensities. – Coordinate with other SGs and other bodies on a regular basis for effective collaboration.
Q19/5: Power feeding systems	Develop Recommendations on: – Characterizations and specifications of the power feeding system, especially for the high-voltage direct current system. – Safety for humans and equipment with regard to the power feeding system. – System configuration, architecture, and cable distribution including feeding, lightning protection, electromagnetic compatibility, earthing, and bonding of the power feeding system. – Methodologies for evaluating the performance of energy feeding and its environmental impact.
Q20/5: Data collection for energy efficiency for ICTs over the lifecycle	– Develop deliverable on the metrics for data collection on energy efficiency based on the latest deliverable appropriately identified by Q18/5. – Issue questionnaires on topics of interest to collect energy-efficiency-related data on relevant network elements. – Establish handbooks related to analysis of questionnaires and practical case studies on energy saving approaches.
Q21/5: Environmental protection and recycling of ICT equipment/facilities	– Study solutions for mitigating e-waste (e.g., universal charging device for mobile phones and related telecommunications terminals). – Determine process for analyzing the environmental effects of products (materials, hazardous materials avoidance, manufacturing processes, operational procedures and disposal) and ways to minimize them. – Assess environmental effects of recycling related to ICT equipment/facilities. – Prepare handbook of environmental sustainability in ICT equipment/facilities.

assessment targets. L.1400 received consent as the first Recommendation on methodology in October 2010.

The following five different methodologies are being developed as draft Recommendations.

(1) Recommendation L.methodology_ICT goods, networks and services: This Recommendation aims to provide a methodology for evaluating the environmental impact of ICT goods, networks, and services objectively and transparently. It is scheduled to be approved by 2011. Japan is proposing the contents of the Guidelines

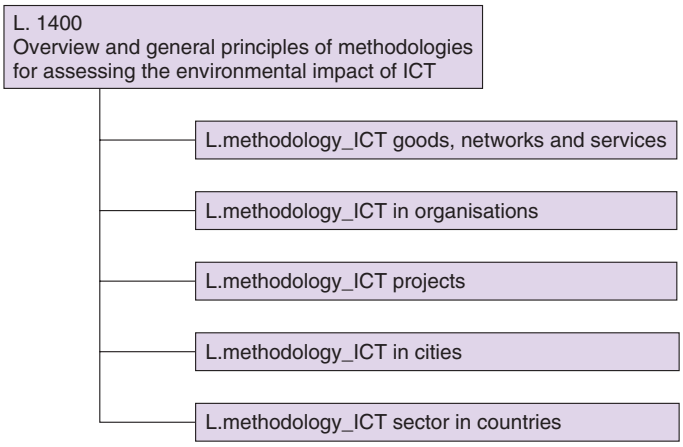


Fig. 3. ITU-T recommendations for ICT environmental impact assessment methodology.

as an LCA-based methodological framework and as a framework on comparative evaluation, which are under discussion in this Recommendation's activities.

(2) Recommendation L.methodology_ICT in organisations: This recommendation aims to provide a methodology for assessing the energy consumption and GHG emissions of ICT within organizations over a certain period of time, e.g., one year. It also aims to provide a methodology for assessing the energy consumption and GHG emissions of ICT organizations. This Recommendation is also scheduled to be approved by 2011.

(3) Recommendation L.methodology_ICT projects: An ICT project is defined as either (i) a GHG project using mainly ICT goods, networks, and services aiming at GHG emissions reductions and enhancing GHG removal or enhancements or (ii) a project using mainly ICT goods, networks, and services aiming at energy consumption savings and energy efficiency improvements.

(4) Recommendation L.methodology_ICT in cities: This recommendation aims to provide a GHG emissions reporting method that accounts for the positive and negative impacts of ICT in cities. This work item was established in October 2010.

(5) Recommendation L.methodology_ICT in countries: This recommendation aims to provide a GHG emissions reporting method that accounts for the positive and negative impacts of ICT in countries or groups of countries.

5. Further study

We will continue to work on establishing an internationally standardized assessment methodology that is objective and transparent, and we will promote activities quantifying the environmental load reduction effect achieved by ICT services provided by NTT Group.

References

[1] http://www.jemai.or.jp/JEMAI_DYNAMIC/data/current/detailobj-2687-attachment.pdf

[2] T. Origuchi, T. Sawada, and S. Nishi, "Formulation of Guidelines for ICT Eco-efficiency Evaluation at the Japan Forum on Eco-Efficiency," NTT Technical Review, Vol. 5, No. 3, pp. 18–24, 2007. https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr200703018.pdf

[3] Y. Takeshita, T. Origuchi, M. Yuito, T. Maeda, A. Ishikawa, T. Sawada, and S. Nishi, "Environmental Impact Assessment System for ICT Services—Development and Application," NTT Technical Review, Vol. 4, No. 3, pp. 17–21, 2006. https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr200603017.pdf

[4] http://www.ntt.co.jp/csr_e/2009report/ecology/activity02.html

[5] Y. Somemura, T. Origuchi, Y. Sugiyama, R. Kobayashi, S. Nishi, and T. Sawada, "Standardization Activities on ICTs and Climate Change in ITU-T," NTT Technical Review, Vol. 7, No. 9, 2009. https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr200909gls.html

Toshihiro Hayashi

Energy Optimization Technology Group, Energy System Project, NTT Energy and Environment Systems Laboratories.

He received the B.E. and M.E. degrees in geosystem engineering from the University of Tokyo in 2004 and 2006, respectively. He joined NTT Energy and Environment Systems Laboratories in 2006. His research interests are energy control technologies, optimization techniques, and environmental impact assessment of ICT services. He is a member of the Institute of Electronics, Information and Communication Engineers of Japan.

Takeshi Origuchi

Senior Research Engineer, Environmental Systems Project, NTT Energy and Environment Systems Laboratories.

He received the B.S. degree in physics from Nihon University, Tokyo, in 1995 and the M.S. degree in materials science and the Ph.D. degree in environmental impact assessment from the University of Tokyo in 1997 and 2008, respectively. He joined NTT Access Network Service Systems Laboratories in 1997 and worked on R&D of environmental protection technologies. He moved to his present Laboratories in 2002 and has been engaged in R&D of environmental impact assessments of ICT services, a macroscopic analysis of ICT society, and environmental accounting to promote environmental management and operations in NTT Group. He is a member of the Institute of Life Cycle Assessment, Japan, and has been a vice-chairman of the working party "ICT and Climate Change" of ITU-T SG5 since May 2009.

Yoh Somemura

Senior Research Engineer, Supervisor, Environmental Management & Provisioning Project, NTT Energy and Environment Systems Laboratories.

He received the B.E., M.E., and Ph.D. degrees in applied physics from Waseda University, Tokyo, in 1988, 1990, and 1995, respectively. He joined NTT LSI Laboratories in 1990 and worked on the development of microfabrication technology. Since moving to his present research department in 2006, he has been engaged in promoting environmental management in the NTT Group. He was a vice-chairman of the ITU-T Focus Group on ICTs and Climate Change until March 2009.

Yasuyuki Sugiyama

Project Manager, Environmental Management & Provisioning Project, NTT Energy and Environment Systems Laboratories.

He received the B.S., M.S., and Dr.Eng. degrees in electronic engineering from Waseda University, Tokyo, in 1985, 1987, and 1994, respectively. He joined NTT Electrical Communication Laboratories in 1987. From 1987 to 1993, he worked on optical data storage systems. He was a visiting scholar at Stanford University, USA, in 1998. Since 2002, he has been studying ICT systems for environmental protection.

Optical Control of Nanomechanical Vibration in GaAs Resonators

Hajime Okamoto†, *Koji Onomitsu, Tetsuomi Sogawa, and Hiroshi Yamaguchi*

Abstract

Vibrational control in GaAs micromechanical cantilevers through optical carrier excitation has been demonstrated. With laser irradiation to [110]-oriented cantilevers at near-band-gap wavelengths, the quality factor increased with increasing laser power, whereas shorter-wavelength irradiation decreased the quality factor. The opposite laser power dependence was observed for [-110]-oriented cantilevers (90° different). These results indicate that the control of the quality factor is due to the piezoelectric stress generated by optically excited carriers. This is a new method of controlling nanomechanical vibration in micromechanical resonators, which does not need any cavities or feedback circuits.

1. Introduction

Micromechanical and nanomechanical resonators have been extensively used for a wide variety of applications, such as sensors, actuators, and filters [1], [2]. The quality factor (Q-factor) is an important factor determining the sensitivity and performance of micromechanical resonators. It is inversely proportional to the damping; i.e., the vibration of a low-Q resonator is rapidly damped while that of a high-Q resonator lasts longer. Controlling the damping and the Q-factor is of great importance in many micromechanical device applications. One effective method is feedback control of micromechanical resonators by using electrical and optical circuits. Feedback Q-control has been applied to high-sensitivity measurements, such as atomic force microscopy and magnetic resonance force microscopy [3]–[6]. Another approach to Q-factor control involves coupling micromechanical resonators to light in optical cavities. Cavity-induced radiation pressure and photothermal pressure enable us to modify the Q-factor as well as the resonance frequency of micromechanical resonators [7]–[18]. These methods have been used in practical micromechanical devices, but they need a feedback circuit or a carefully aligned optical cavity.

Here, we describe our carrier-excitation-based Q-factor control in micromechanical resonators [19]. This method has potential as an alternative to conventional Q-control methods because the Q-factor of micromechanical resonators can be controlled by simply adjusting the wavelength and power of the incident laser light. The micromechanical resonators used in this experiment were made of GaAs, which is a direct-band-gap semiconductor exhibiting piezoelectricity [20]. These material properties are essential for this optical Q-control method.

2. Experimental

The micromechanical cantilevers were fabricated by molecular beam epitaxy crystal growth, photolithography, and etching [21]. A scanning electron micrograph of a fabricated cantilever is shown in **Fig. 1(a)**. The cantilever was 20 μm long and 14 μm wide, including two legs 10 μm long and 4 μm wide. It consisted of a 100-nm-thick Si-doped (n-type) GaAs layer and a 200-nm-thick undoped (i-type) GaAs layer, which were grown on a 4-μm-thick $Al_{0.65}Ga_{0.35}As$ sacrificial layer on a GaAs(001) substrate (**Fig. 1(b)**). The n-type layer had a temperature-independent carrier concentration of 1.5×10^{18} cm^{-3} and electron mobility of 1900 cm^2/Vs. This cantilever had

† NTT Basic Research Laboratories
Atsugi-shi, 243-0198 Japan

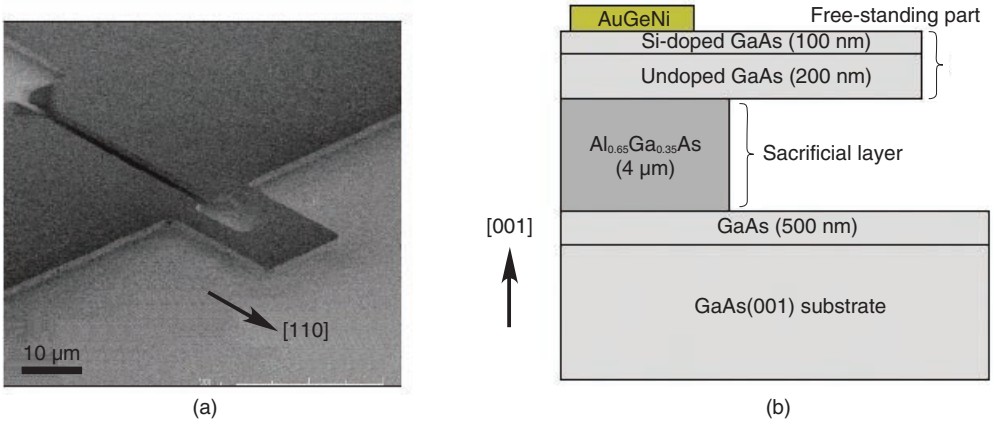


Fig. 1. (a) Scanning electron microscope image of the [110]-oriented cantilever. (b) Schematic of the cross-sectional view of the device.

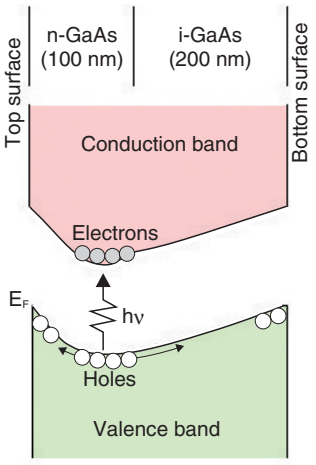


Fig. 2. Energy band diagram and illustration of the optical carrier excitation.

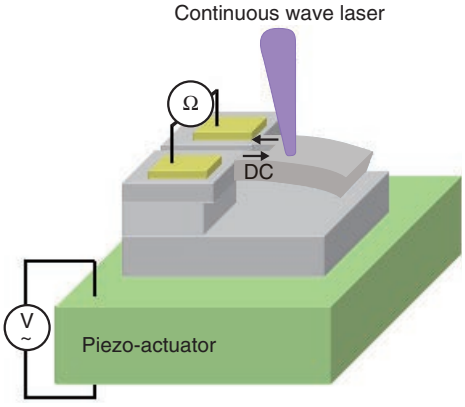


Fig. 3. Schematic of electrical detection of a cantilever's mechanical motion by the piezoresistive method.

a built-in electric field, as illustrated in **Fig. 2**, due to the impurity doping and the surface depletion. The sacrificial AlGaAs layer was selectively removed with hydrofluoric acid and then the free-standing structure was completed using supercritical drying [21]. AuGeNi electrode pads were sintered onto the supporting part to form an ohmic contact with the *n*-GaAs layer. We prepared cantilevers oriented along the [110] and [-110] directions to study the dependence of orientation on the resonance characteristics.

Fabricated cantilevers were mounted on piezo-actuators (**Fig. 3**) and set in the vacuum chamber of a ^{4}He cryostat with a small window allowing optical access to the sample. The mechanical resonance characteristics were electrically measured by the following piezoresistive method (Fig. 3): (i) Sinusoidal voltage (6 mV_{rms}) was applied to the piezo-actuators while the frequency was swept around the resonance frequency of the fundamental vibration mode. (ii) Constant current (30 μA) was applied to the cantilevers and the frequency response of the resistance change (piezoresistance) was measured by monitoring the voltage difference with a spectrum analyzer. (iii) The resonance characteristics were measured by illuminating the center of each cantilever's free-standing part with continuous-wave laser light. A He:Ne laser and a tunable Ti:Sapphire laser beam with a 4-μm spot were used to study the wavelength dependence of the damping in the range λ = 633–840

nm.

The Q-factor of the cantilevers, given by $Q = \sqrt{3}f_0/\Delta f$, where f_0 is the resonance frequency and Δf is the full width at half maximum of the resonance peak, was derived by fitting the resonance power spectrum with a Lorentzian function. **Figure 4** shows the temperature dependence of the intrinsic Q-factor (Q_i), which was measured without laser illumination. Q_i was maximum at 50 K, where the value was about 4.5 times higher than that at 300 K (Q_i (300K) ~4000). This is because the thermal expansion, which causes the thermoelastic damping effect, was minimized at 50 K [21]. Optical control of the Q-factor was demonstrated at 50 K, where the photothermal effect became negligible. At 50 K, the resonance frequency of the cantilevers was 240 kHz and the band-gap wavelength for *i*-GaAs was $\lambda_{BG}{}^{i}$ = 820 nm [20]. The *n*-GaAs layer had a conduction-band tail (Fig. 2), resulting in wavelength $\lambda_{BT}{}^{n}$, which corresponded to the energy difference between the tail edge and the top of the valence band, of 850–860 nm [20].

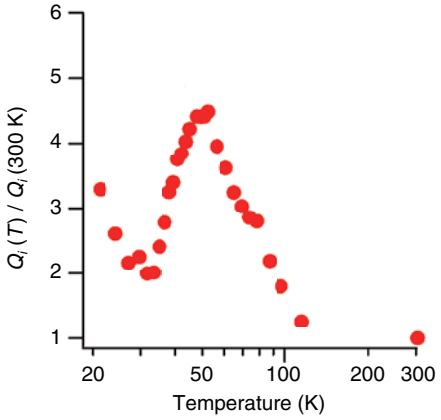


Fig. 4. Temperature dependence of the cantilever's Q-factor.

3. Results and discussion

Figure 5 shows the relation between the damping factor and laser power for several wavelengths and the mechanical resonance characteristics of the [110]-oriented cantilever measured for several laser powers at those wavelengths. The sharpness of the resonance peak depended strongly on the incident laser power. The laser power dependence of the damping is shown in detail in Fig. 5(a). The damping increased with increasing laser power for λ = 633 nm; e.g., the Q-factor was reduced by a factor of three when the intensity was increased from P = 0.04 μW (Fig. 5(c)) to 0.29 μW (Fig. 5(b)). The damping also increased with increasing laser power for λ = 780 nm, which is still shorter than $\lambda_{BG}{}^{i}$ (Fig. 5(a)). Note that, for this wavelength, the laser power dependence of the damping was much weaker than that for λ = 633 nm, as shown in Fig. 5(a). Interestingly, we found that when the incident wavelength was λ = 840 nm, which is in the range of $\lambda_{BG}{}^{i} < \lambda < \lambda_{BT}{}^{n}$, increasing the laser power decreased the vibration damping (Q^{-1}) (Fig. 5(a)). For λ = 840 nm, drastic enhancement of the Q-factor from 22,000 to 90,000 can be clearly seen in Figs. 5(d) and (e). These results demonstrate that the Q-factor can be widely altered by changing the power and wavelength of the incident laser. We did not observe any change in the Q-factor for λ = 860 nm ($\lambda > \lambda_{BT}{}^{n}$). This suggests that the change in Q-factor was caused by photogenerated electron-hole pairs in the cantilever.

To study the physical mechanism of the optical Q-factor control, we investigated its cantilever orientation dependence. The Q-factor normalized by the intrinsic Q-factor (Q_i) is plotted in **Fig. 6** as a function of laser power in [110]- and [-110]-oriented cantilevers for λ = 840 nm. In the [110]-oriented cantilever, higher laser power enhanced the Q-factor. In contrast, in the [-110]-oriented cantilever, higher laser power decreased it. This behavior suggests that the change in Q-factor is not dominated by radiation pressure or photothermal pressure [5]–[16].

Here, we focus on the piezoelectric stress due to the photovoltaic effect because the piezoelectric constant d_{31} is opposite in sign to that of d_{32}; i.e., the piezoelectric stress should work oppositely in the [110] and [-110] orientations in the zincblende structure [17]. Thus, once electric dipoles have formed in the growth direction ([001]), they induce piezoelectric stress in the longitudinal direction, where the stress is compressive or tensile depending on the cantilever orientation. Optically excited carriers generate such electric dipoles because holes in the valence band drift toward the cantilever surfaces, whereas electrons gather at the bottom of the conduction band located in the *i*-GaAs layer owing to the built-in electric field (Fig. 2). This spatial charge separation is the cause of the piezoelectric stress, which provides the bending motion that influences the mechanical vibration of the cantilever (i.e., backaction). If this backaction enhances the vibration in the [110]-oriented cantilever, it oppositely damps the vibration in the [-110]-oriented one because the direction of the

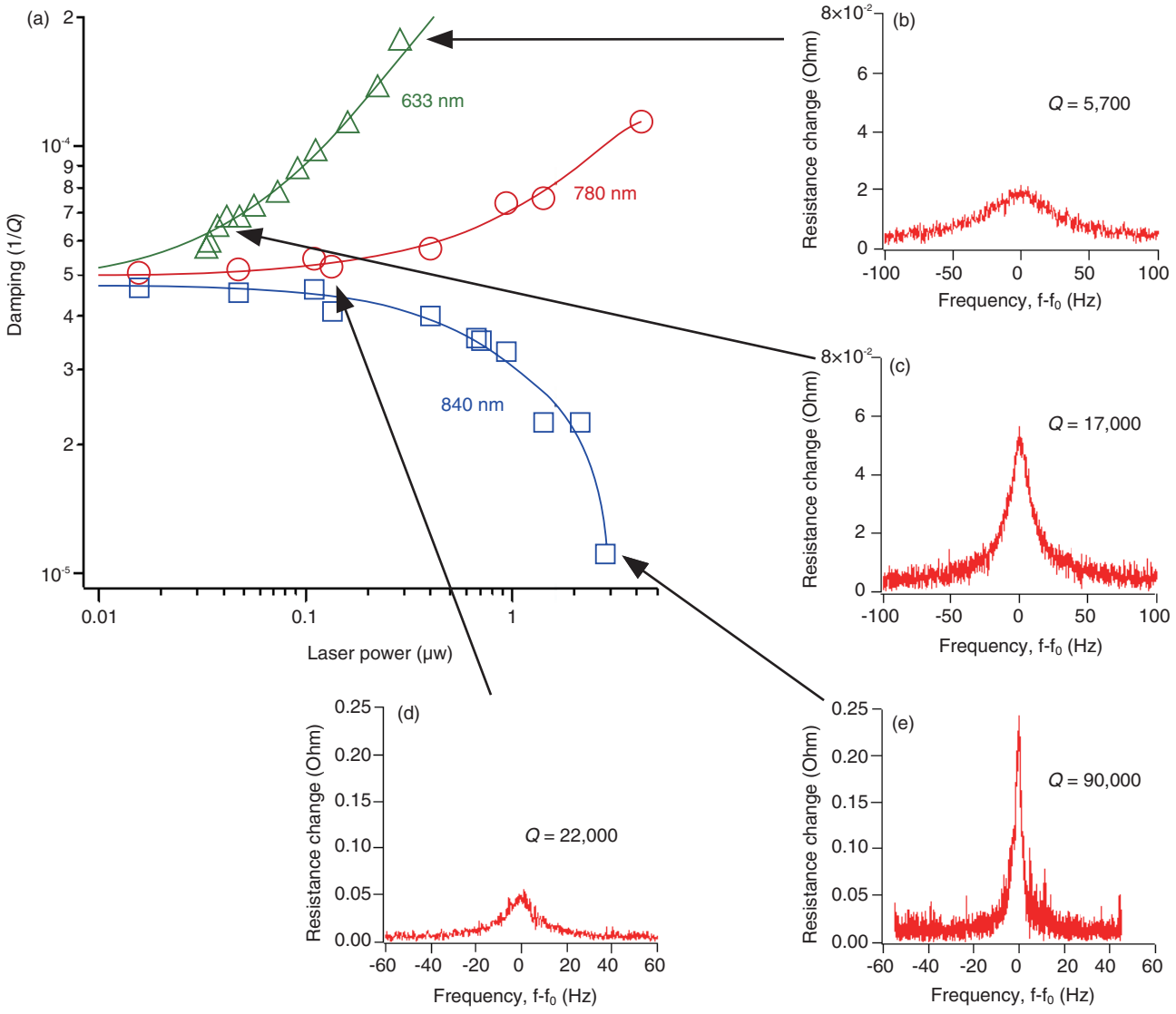


Fig. 5. (a) Relation between the damping factor (1/*Q*) and laser power for λ = 633, 780, and 840 nm. Mechanical resonance characteristics of a GaAs cantilever for λ = 633 nm with (b) *P* = 0.29 and (c) 0.04 mW and for λ = 840 nm with (d) *P* = 0.11 (d) and (e) 2.8 mW.

piezoelectric stress is opposite in the latter.

By analogy with optomechanical damping produced by Fabry-Perot cavities [17], there are two requirements for this optical *Q*-factor control: (i) The backaction force should act on the cantilever with a certain time delay with respect to the cantilever's motion and (ii) the amplitude of the backaction force should vary depending on the cantilever's displacement. The photovoltaic effect due to the optical excitation satisfies the first requirement because carrier drift and electron-hole recombination take finite lengths of time. The photovoltaic effect can also meet the second requirement if the optical absorption coefficient changes with the cantilever's deflection. The deformation potential and piezoelectric potential in GaAs can provide such a deflection-dependent optical absorption property. This deflection dependence will be pronounced when the incident laser wavelength is near the absorption-edge wavelength, while it will be weaker for shorter wavelengths because of the large absorption coefficient. Thus, we consider that the change in *Q*-factor at λ = 840 nm is due to the

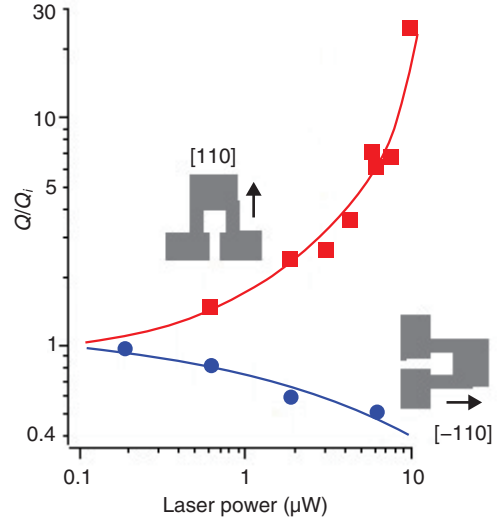


Fig. 6. Cantilever orientation dependence of the normalized *Q*-factor (Q/Q_i) with respect to the incident laser power for λ = 840 nm.

piezoelectric stress induced by carrier excitation. For shorter-wavelength excitation, some other factors may dominate the vibration damping.

4. Conclusions

We have demonstrated *Q*-factor control by carrier excitation in micromechanical cantilevers consisting of *n*- and *i*-GaAs layers. For laser irradiation to a [110]-oriented cantilever at near-absorption-edge wavelengths, the *Q*-factor increased with increasing laser power, while shorter-wavelength irradiation decreased the *Q*-factor. The opposite behavior was observed for a [-110]-oriented cantilever. This difference suggests that the *Q*-control is due to piezoelectric stress generated by optically excited carriers. This *Q*-control method is a promising alternative to the conventional methods because it does not need either external feedback loops or high-finesse cavities.

Acknowledgments

We thank Daisuke Ito (now in Sony, Japan) for help with sample fabrication and measurement. This work was partly supported by Grants-in-Aid for Scientific Research (*Kakenhi*) from the Japan Society for the Promotion of Science (20246064 and 19310067).

References

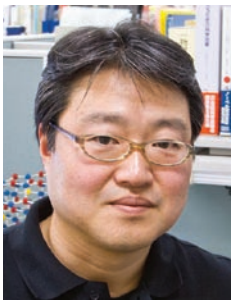
[1] S. E. Lyshevski, "MEMS and NEMS: Systems, Devices, and Structures," CRC Press, 2002.
[2] A. N. Cleland, "Foundations of Nanomechanics," Springer, 2003.
[3] J. Mertz, O. Marti, and J. Mlynek, "Regulation of a Microcantilever Response by Force Feedback," Appl. Phys. Lett., Vol. 62, No. 19, pp. 2344–2346, 1993.
[4] J. L. Garbini, K. J. Bruland, W. M. Dougherty, and J. A. Sidles, "Optimal Control of Force Microscope Cantilevers. I. Controller Design," J. Appl. Phys., Vol. 80, No. 4, pp. 1951–1958, 1996.
[5] D. M. Weld and A. Kapitulnik, "Feedback Control and Characterization of a Microcantilever Using Optical Radiation Pressure," Appl. Phys. Lett., Vol. 89, No. 16, pp. 164102–164104, 2006.
[6] M. Poggio, C. L. Degen, H. J. Mamin, and D. Rugar, "Feedback Cooling of a Cantilever's Fundamental Mode Below 5 mK," Phys. Rev. Lett., Vol. 99, No. 1, p. 017201, 2007.
[7] P. F. Cohadon, A. Heidmann, and M. Pinard, "Cooling of a Mirror by Radiation Pressure," Phys. Rev. Lett., Vol. 83, No. 16, pp. 3174–3177, 1999.
[8] S. Gigan, H. R. Böhm, M. Paternostro, F. Blaser, G. Langer, J. B. Hertzberg, K. C. Schwab, D. Bäuerle, M. Aspelmeyer, and A. Zeilinger, "Self-cooling of a Micromirror by Radiation Pressure," Nature, Vol. 444, No. 7115, pp. 67–70, 2006.
[9] O. Arcizet, P. F. Cohadon, T. Briant, M. Pinard, and A. Heidmann, "Radiation-pressure Cooling and Optomechanical Instability of a Micromirror," Nature, Vol. 444, No. 7115, pp. 71–74, 2006.
[10] D. Kleckner and D. Bouwmeester, "Sub-Kelvin Optical Cooling of a Micromechanical Resonator," Nature, Vol. 444, No. 7115, pp. 75–78, 2006.
[11] O. Arcizet, P. F. Cohadon, T. Briant, M. Pinard, A. Heidmann, J. M. Mackowski, C. Michel, L. Pinard, O. Français, and L. Rousseau, "High-sensitivity Optical Monitoring of a Micromechanical Resonator with a Quantum-limited Optomechanical Sensor," Phys. Rev. Lett., Vol. 97, No. 13, p. 133601, 2006.
[12] O. Arcizet, T. Briant, A. Heidmann, and M. Pinard, "Beating Quantum Limits in an Optomechanical Sensor by Cavity Detuning," Phys. Rev. A, Vol. 73, No. 3, p. 033819, 2006.
[13] A. Schliesser, P. Del'Haye, N. Nooshi, K. J. Vahala, and T. J. Kippenberg, "Radiation Pressure Cooling of a Micromechanical Oscillator Using Dynamical Backaction," Phys. Rev. Lett., Vol. 97, No. 24, p. 243905, 2006.
[14] T. J. Kippenberg and K. J. Vahala, "Cavity opto-mechanics," Opt. Exp., Vol. 15, No. 25, pp. 17172–17205, 2007.
[15] A. Schliesser, R. Rivière, G. Anetsberger, O. Arcizet, and T. J. Kippenberg, "Resolved-sideband Cooling of a Micromechanical Oscillator," Nat. Phys., Vol. 4, No. 5, pp. 415–419, 2008.
[16] M. Vogel, C. Mooser, K. Karrai, and R. J. Warburton, "Optically Tunable Mechanics of Microlevers," Appl. Phys. Lett., Vol. 83. No. 7, pp. 1337–1339, 2003.
[17] C. H. Metzger and K. Karrai, "Cavity Cooling of a Microlever," Nature, Vol. 432, No. 7020, pp. 1002–1005, 2004.
[18] I. Favero, C. Metzger, S. Camerer, D. König, H. Lorenz, J. P. Kotthaus, and K. Karrai, "Optical Cooling of a Micromirror of Wavelength Size," Appl. Phys. Lett., Vol. 90, No. 10, p. 104101, 2007.
[19] H. Okamoto, D. Ito, K. Onomitsu, T. Sogawa, and H. Yamaguchi, "Controlling Quality Factor in Micromechanical Resonators by Carrier Excitation," Appl. Phys. Exp., Vol. 2, p. 035001, 2009.
[20] S. Adachi, "GaAs and Related Materials," World Scientific, 1994.
[21] H. Okamoto, D. Ito, K. Onomitsu, and H. Yamaguchi, "Thermoelastic Damping in GaAs Micromechanical Resonators," Phys. Stat. Sol. (c), Vol. 5, No. 9, pp. 2920–2922, 2008.

Hajime Okamoto
Research Scientist, Nanostructure Technology Research Group, Physical Science Laboratory, NTT Basic Research Laboratories.

He received the B.E., M.E., and Ph.D. degrees in materials science and engineering from Waseda University, Tokyo, in 1998, 2000, and 2004, respectively. He joined NTT Basic Research Laboratories in 2004 and studied compound semiconductor nanomechanical systems. He received the Japan Society of Applied Physics (JSAP) Paper Award and the International Conference on Solid State Devices and Materials Paper Award in 2010. His current interests are opto-mechanical coupling, nonlinear dynamics, and coupled vibration in nanomechanical systems. He is a member of JSAP.

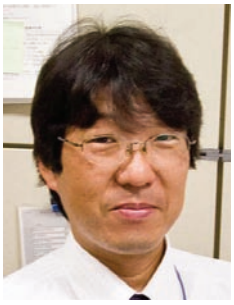
Koji Onomitsu
Research Scientist, Nanostructure Technology Research Group, Physical Science Laboratory, NTT Basic Research Laboratories.

He received the B.E. and M.E. degrees in electrical engineering from Aoyama Gakuin University, Tokyo, in 1998 and 2000, respectively, and the Ph.D. degree in electrical engineering from Waseda University, Tokyo, in 2004. He joined NTT Basic Research Laboratories in 2006. His current interests are crystal growth of modulation-doped structures for high-mobility two-dimensional electron systems using MBE, mechanical devices incorporating GaMnAs, and on-chip amplifiers of mechanical vibration signals using HEMTs. He is a member of JSAP.



Tetsuomi Sogawa
Executive Manager of the Research Planning Section, Group Leader of the Quantum Optical Physics Research Group, NTT Basic Research Laboratories.

He received the B.S., M.S., and Ph.D. degrees in electrical engineering from the University of Tokyo in 1986, 1988, and 1991, respectively. He joined NTT Basic Research Laboratories in 1991. From 2004 to 2006, he worked for the Council for Science and Technology Policy, Cabinet Office, Japan, as a deputy director for policy planning. His current research interests include (i) fabrication technology of low-dimensional nanostructures, (ii) optical properties of quantum dots/wires and photonic crystals, (iii) spin-related phenomena, and (vi) surface acoustic wave applications on nanostructures. He is a member of JSAP.



Hiroshi Yamaguchi
Executive Manager of the Physical Science Laboratory and Group Leader of the Nanostructure Technology Research Group, NTT Basic Research Laboratories.

He received the B.E. and M.S. degrees in physics and the Ph.D. degree in engineering from Osaka University in 1984, 1986, and 1993, respectively. He joined NTT Basic Research Laboratories in 1986. His current interests are micro/nanomechanical devices using semiconductor heterostructures. He has been a guest professor at Tohoku University since 2006. He is a member of JSAP, the Physical Society of Japan, and IEEE.

Ray-tracing-based Technique for Reducing Computational Complexity of MIMO Propagation Channel Estimation

Wataru Yamada†, Naoki Kita, and Takatoshi Sugiyama

Abstract

When radio areas or systems in wideband wireless communication systems are being planned, a multiple-input multiple-output (MIMO) propagation channel must be considered. This article introduces a technique based on ray tracing that reduces the computational complexity for estimating the MIMO propagation channel. This technique can estimate the MIMO propagation channel without any increase in the computational complexity when the number of antenna elements is increased.

1. Introduction

In wireless communication systems, wireless signals from a transmitter are transmitted to a receiver via multiple propagation paths. As shown in **Fig. 1**, the ground and buildings cause reflection, diffraction, or penetration in these paths. As a result, radio waves taking different propagation paths arrive at the receiver at different times and each propagation path has a different phase condition since it has a different path length. Therefore, at the receiver, different received power levels are observed for each frequency. This frequency selective fading, as it is called, has a tremendous impact on the communication quality of wideband wireless communication systems. Therefore, propagation characteristics including frequency selective fading must be considered when service areas or systems in wideband wireless communication systems are being planned. There are various methods for estimating propagation characteristics. The ray-tracing method [1] is one of the most well known and most effective methods for estimating the propagation characteristics in multiple-input multiple-output (MIMO) systems. However, MIMO propagation channel estimation by ray tracing requires an enormous amount of calculation resources. In this article, we introduce a ray-tracing technique for overcoming the computational complexity, which is a major problem in MIMO propagation channel estimation.

† NTT Access Network Service Systems Laboratories
Yokosuka-shi, 239-0847 Japan

2. Ray-tracing method and its issues

2.1 Ray-tracing method

Algorithms for the ray-tracing method are classified into two general types: the imaging method and ray-launching method. The imaging method derives a propagation path by using geometric optics from a combination of the transmission position, receiving position, and reflecting surfaces. On the other hand, the ray-launching method derives the propagation path using rays discretely launched at given regular intervals and searching for the rays that arrive at the received position.

Estimating the propagation characteristics using the ray-tracing method requires three parameters: the propagation distance, incident angle to the reflecting surface, and complex permittivity of the reflecting surface. The propagation distance and the incident

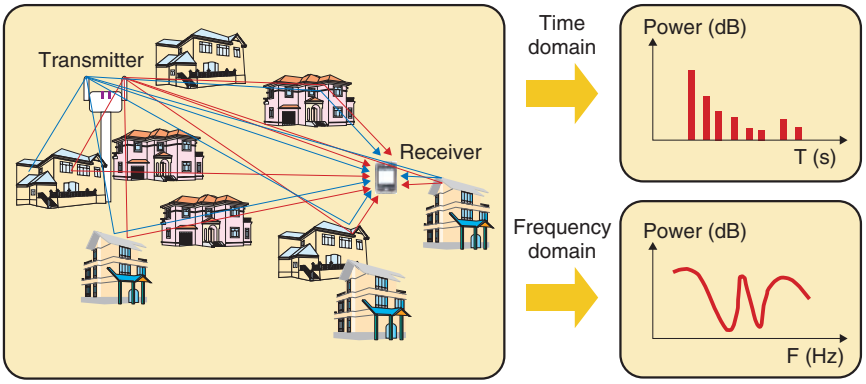


Fig. 1. Propagation characteristics in wireless communication systems.

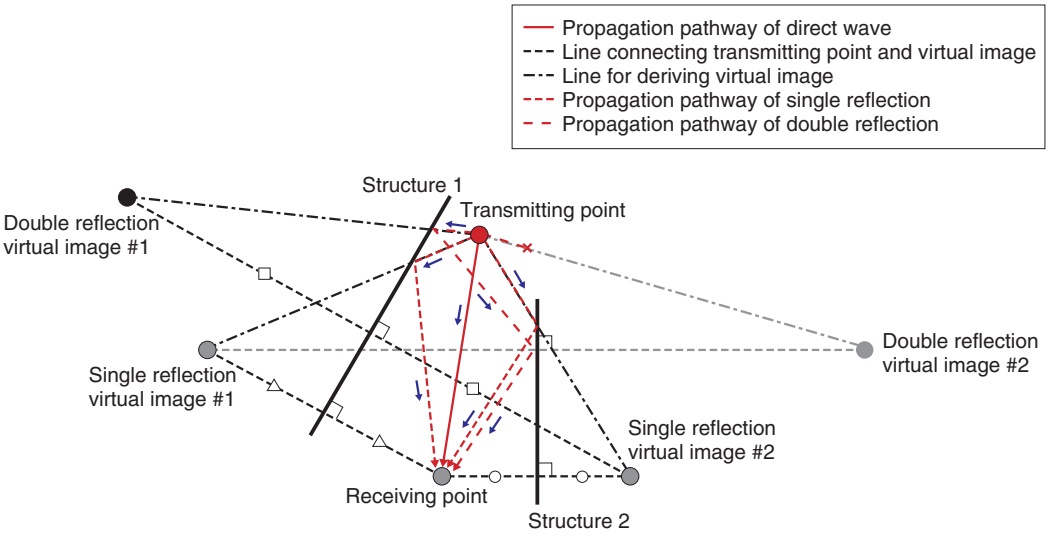


Fig. 2. Propagation path search process using imaging method.

angle to the reflecting surface are derived from ray-tracing estimation results. The complex permittivity of the reflecting surface is a predetermined static parameter.

2.2 Issues facing ray tracing

As shown in **Fig. 2**, the ray-tracing method derives the propagation path including reflection, diffraction, and penetration from the transmitter to receiver using geometric optics. The estimation accuracy can be improved by increasing the number of reflections, diffractions, or penetrations in the case of the imaging method or by increasing the number of rays launched from the transmitter in the case of the ray-launching method. However, the receiving area must be configured for propagation channel calculation by the ray-launching method since there is a very low probability that rays launched from the transmitter will arrive at the receiving point. Moreover, it is quite complicated to decide the receiving area. Therefore, in this article, we focus on the imaging method in order to introduce our new technique.

In the imaging method, it is necessary to search for the propagation path for the combination of all allocated building walls. Thus, in the case of single-input single-output systems, one must judge whether a reflection point exists on the wall a total of A^B times when the number of building walls is set to A and the number of reflections is set to B. For instance, as shown in Fig. 2, a single reflection requires two

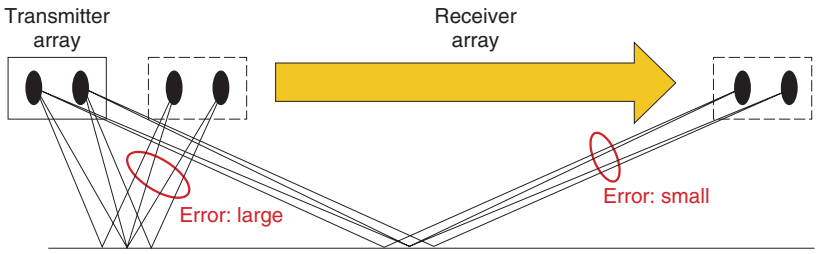


Fig. 3. Features of MIMO propagation channel.

judgments and a double reflection requires four. The computational complexity increases with the square of the number of walls, reflections, diffractions, and penetrations. Therefore, many computational complexity reduction techniques have been studied.

2.3 Special problem in applying ray tracing to MIMO systems

MIMO technology, which uses multiple antennas at the transmitter and at the receiver to improve the transmission rate, has recently been widely studied. IEEE 802.11n (IEEE: Institute of Electrical and Electronics Engineers) and WiMAX (worldwide interoperability for microwave access), which are recently standardized wireless schemes, both use MIMO technology. MIMO propagation channel evaluations that use the ray-tracing method have been reported. However, whether a reflection point exists on a wall must be judged a total of $m \times n \times A^B$ times when an $m \times n$ MIMO system is treated. Thus, there is the additional problem that the computational complexity increases in proportion to the number of antenna combinations when the ray-tracing method is applied to MIMO systems.

3. New technique for reducing calculation complexity for MIMO propagation channel estimation

3.1 Special characteristics of MIMO propagation channel

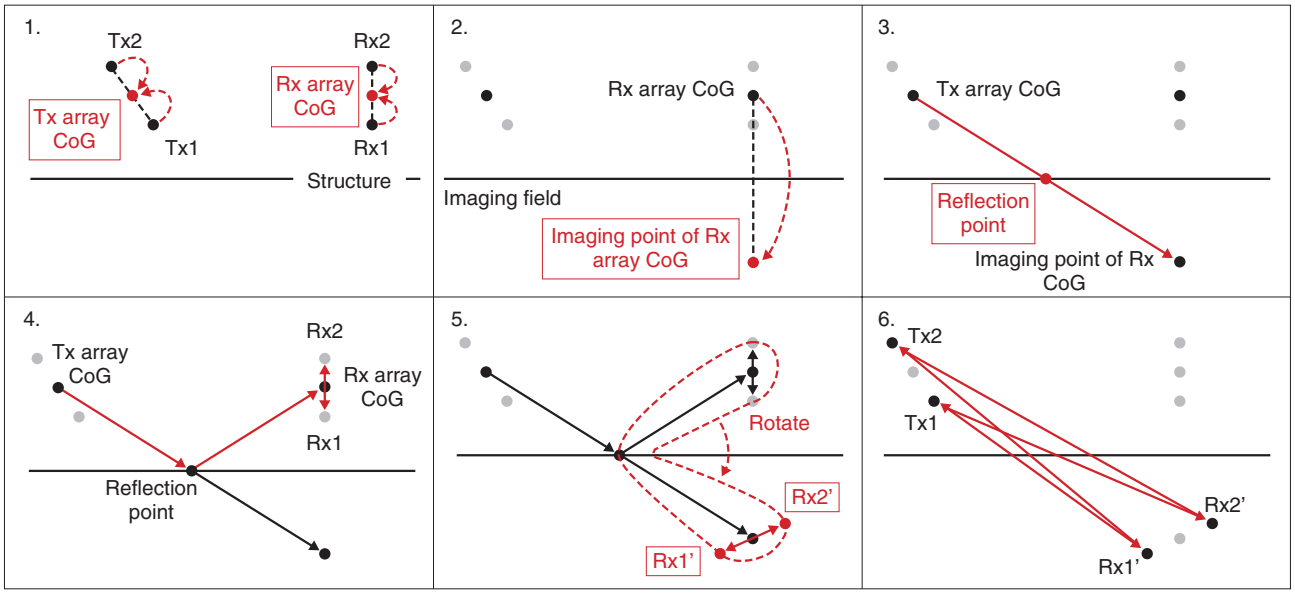
In general, a MIMO propagation channel simulation is performed under the condition that the physical sizes of the transmitter and receiver array antennas are much smaller than the distance between the transmitter and receiver antennas. Under such a condition, as shown in **Fig. 3**, the propagation paths between all the transmitter and receiver antenna elements are often extremely similar. Thus, to decrease the computational complexity, it is generally thought that a MIMO propagation path can be simulated by using the propagation path between a particular combination of antennas instead of those for all the transmitter and receiver antenna combinations.

3.2 New technique

Our new technique uses the abovementioned MIMO propagation channel characteristic to simulate a MIMO propagation channel for the propagation path between a particular combination of transmitter and receiver antennas instead of those for all antenna combinations. The procedure for deriving the propagation distance using this technique for a single-reflection wave in a 2×2 MIMO system is shown in **Fig. 4**.

The procedure is as follows.

1. Calculate the center of gravity (CoG) of the transmitter and that of the receiver.
2. Derive the virtual image of the receiver CoG.
3. Derive the vector from the transmitter CoG to the virtual image of the receiver CoG, and derive the reflection point on the basis of the intersection of the vector and the reflecting wall.
4. Derive the vector from the transmitter CoG to the reflection point, the vector from the reflection point to the receiver CoG, and the vectors from the receiver CoG to all of the receiver antenna array components.
5. Calculate the positions of all the receiving antenna array components by rotating the vectors from the reflection point to the receiver CoG until they overlap the vectors derived in Step 3 while retaining the positional relationship between the vector from the reflection point to the receiver CoG and the vectors from the receiver CoG to all of the receiver antenna array components (Rx1' and Rx2' in Fig. 4).



Rx: receiver
Tx: transmitter

Fig. 4. Procedure of our MIMO propagation channel estimation.

6. Calculate the propagation distances from all the transmitter antenna positions and receiver antenna positions and then derive the MIMO propagation channel.

In our technique, a shorter distance between a particular antenna position and another antenna position is better considering the estimation error. Thus, desirable antenna positions for a particular combination are the CoGs of the transmitter and the receiver array.

Our technique attempts to decrease the propagation distance estimation error by using information about the positional relationship between the array CoG and each array element. The reflection and diffraction angles in our technique are defined as the same angles as derived by ray tracing between the transmitter and receiver COGs. This is because the propagation paths between all transmitter and receiver antenna elements are often extremely similar to the results of ray tracing between the transmitter and receiver CoGs.

3.3 Special features of our technique

Because our technique focuses on decreasing the computational complexity of the path search, it can be applied to not only the imaging algorithm but also the ray-launching algorithm. Moreover, it further decreases the computational complexity by combining previously proposed ray-tracing acceleration algorithms because they are mainly focused on efficient path searching.

4. Verification based on simulation model

4.1 Simulation model and parameters

The propagation channel calculated using the ray-tracing method is derived using the propagation distance, reflection or diffraction angle, and electrical properties of the wall. The wall's electrical properties are represented by a fixed parameter. On the other hand, since the propagation distances and reflection or diffraction angles calculated using our technique are approximated parameters, there is some mismatch between the values of these parameters calculated by our technique and by conventional ray tracing. Therefore, the MIMO propagation channel estimation error was evaluated from the difference between the eigenvalue calculated using the imaging algorithm and that using our technique because the parameter provides a good representation of the effect of the phase difference of each element.

A MIMO propagation channel simulated using the outdoor simulation model is shown in **Fig. 5**. A four-element transmitter antenna array and a four-element

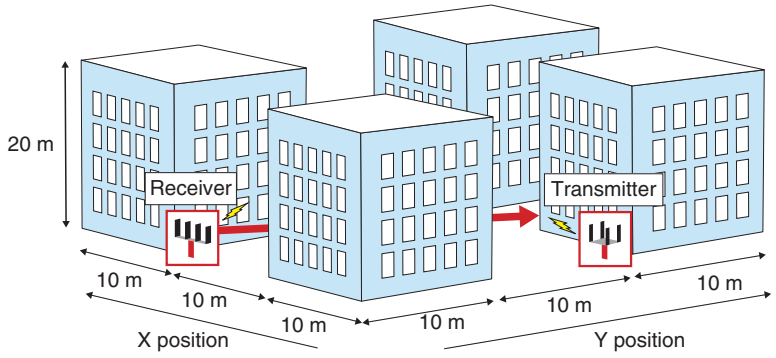
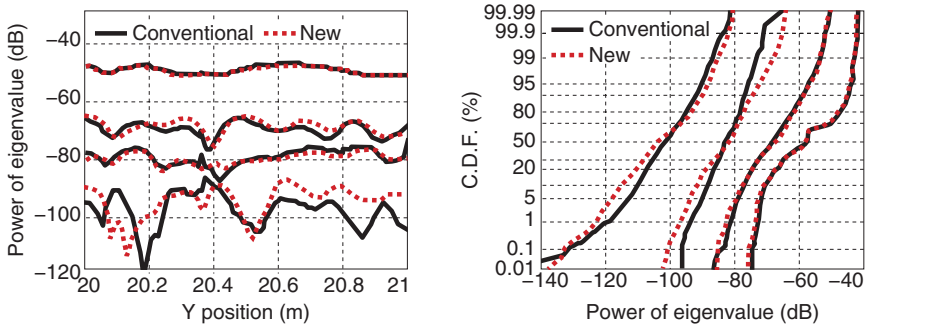


Fig. 5. Simulation model.



(a) Distance characteristics of eigenvalue (b) Cumulative provability distribution of eigenvalue

Fig. 6. Calculation example of simulation results.

receiver antenna array were used. As shown in Fig. 5, a 4 × 4 MIMO propagation channel was calculated using the imaging algorithm and our technique at positions ranging from Y= 0 m to 30 m at intervals of 1 cm. The calculated frequency was 2.45 GHz. The maximum number of reflections was set to three, and the number of diffractions was set to one for the ray-tracing calculation. Only the reflected wave and the diffracted wave were treated in the simulation model for verifying our technique. When propagation characteristics are simulated using the ray-tracing method, a penetration wave may need to be considered. However, our technique is effective even when the existence of a penetration wave is taken into consideration.

4.2 Simulation results

An example of the variability of the eigenvalue characteristics obtained using the imaging algorithm and our technique for positions from Y=20 m to 21 m in the simulation model is shown in **Fig. 6(a)**. The value of each eigenvalue calculated using the imaging algorithm could be reproduced by our technique. The cumulative probability of each eigenvalue in the whole simulation section calculated using the imaging algorithm and our technique is shown in **Fig. 6(b)**, which shows that the distribution was almost the same for all eigenvalues compared with those for the imaging algorithm and our technique. Therefore, these results show that a statistical evaluation of the MIMO propagation characteristics calculated using the imaging algorithm can be reproduced using our technique.

With our technique, as the number of antennas is increased, the benefit of the reduced computational complexity increases. This is because the path search process accounts for the majority of the computational complexity in the conventional ray-tracing method. In general, when the number of antenna elements is increased, our technique can estimate the

MIMO propagation channel without any increase in computational complexity. For instance, when 4 × 4 MIMO is assumed, the number of antenna combinations is 16. Therefore, the computational complexity for our technique is approximately 1/16 (6.25%) of that for the conventional ray-tracing method. For the simulation model and conditions, it is 6.30% [4].

5. Conclusion

MIMO technology is essential to current wireless communication systems. In this article, we described a technique for overcoming the computational complexity, which is a major problem in MIMO propagation channel estimation using ray tracing. Our technique can estimate the MIMO propagation channel without any increase in computational complexity when the number of antenna elements is increased.

In the future, we will continue to evaluate propagation characteristics with our technique and improve it for practical use so that it can handle various wireless communication systems.

References

[1] Y. Hosoya ed., "Radio Propagation Handbook," REALIZE Inc., 1999 (in Japanese).

[2] F. Agelet, A. Formella, J. Rabanos, F. Vicente, and F. Fontan, "Efficient Ray-tracing Acceleration Techniques for Radio Propagation Modeling," IEEE Trans. Veh. Tech., Vol. 49, No. 6, pp. 2089–2104, 2000.

[3] T. Imai, "Novel Ray-tracing Acceleration Technique Employing Genetic Algorithm for Radio Propagation Prediction," IEICE Trans. (B), Vol. J89-B, No. 4, pp. 560–575, Apr. 2006 (in Japanese).

[4] W. Yamada, N. Kita, T. Sugiyama, and T. Nojima, "Plane-wave and Vector-rotation Approximation Technique for Reducing Computational Complexity to Simulate MIMO Propagation Channel Using Ray-tracing," IEICE Trans. on Commun., Vol. E92-B, No. 12, pp. 3850–3860, 2009.

Wataru Yamada

Research Engineer, Wireless Access Systems Project, NTT Access Network Service Systems Laboratories.

He received the B.E., M.E., and Ph.D. degrees in electrical engineering from Hokkaido University in 2000, 2002, and 2010, respectively. Since joining NTT in 2002, he has been engaged in research on propagation characteristics for short-range wideband access systems. He received the Young Researcher's Award from the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan in 2006. He is a member of IEEE and IEICE.

Naoki Kita

Senior Research Engineer, NTT Access Network Service Systems Laboratories.

He received the B.E. degree from Tokyo Metropolitan Institute of Technology, Japan, in 1994 and the M.E. and Ph.D. degrees from Tokyo Institute of Technology, Japan, in 1996 and 2007, respectively. After joining NTT in 1996, he engaged in research on propagation characteristics for short-range broadband wireless access systems. He was a visiting scholar at the Department of Electrical Engineering, Stanford University, U.S.A., from 2009 to 2010. He is currently conducting research on radio propagation modeling for future wireless communication systems. He received the Young Researcher's Award from IEICE in 2002. He is a member of IEEE and IEICE.

Takatoshi Sugiyama

Senior Research Engineer, Supervisor, Group Leader in NTT Access Network Service Systems Laboratories

He received the B.E., M.E. and Ph.D. degrees from Keio University, Kanagawa, in 1987, 1989, and 1998, respectively. After joining NTT in 1989, he engaged in R&D of forward error correction, interference compensation, CDMA, modulation-demodulation, and MIMO-OFDM technologies for wireless communication systems such as satellite and mobile systems. From 1988 to 2001, he was in charge of business planning for international satellite communication services in NTT Communications Corporation. From 2004 to 2007, he was with the Wireless Laboratories of NTT DoCoMo, Inc., where he worked on R&D of wireless resource management schemes, plug-and-play base stations and wireless mesh networks. He is currently responsible for R&D of intelligent interference compensation technologies and radio propagation modeling for future wireless communication systems. He received the Young Engineers Award from IEICE in 1996. He is a member of IEEE and IEICE.

TeleManagement Forum Standardization Trends at Management World 2010

Haiying Jiang†

Abstract

This article reports the most recent standardization trends in the TeleManagement Forum (TM Forum), such as the Frameworx integrated business architecture and the user-led cloud study group Cloud Service Initiative (CSI) as well as the latest trends seen at Management World 2010 in May.

1. Overview of TM Forum

The TeleManagement Forum (TM Forum) [1] is a non-profit industrial organization established to study industrial standards and promote their widespread adoption and application to actual products. The objective is information and communication system network management that enables interoperability. Since its founding in 1988, membership has increased continuously. As of September 2010, there were over 700 member corporations from 195 countries. They include NTT, AT&T, BT and other carriers that are top-ranked in sales and Ericsson, Huawei, Nokia Siemens, and other major communication equipment vendors.

TM Forum standardization activities have been moving forward, with studies centered on New Generation Operation Systems and Software (NGOSS) [2]. Enterprise members have been promoting standards that are better aligned with reality by developing an operation management system based on the industrial standards that are being studied and providing feedback on problems. The value of the eTOM (enhanced Telecom Operations Map) framework for comprehensive organization of service provider business processes, a part of NGOSS, has also been recognized in ITU-T (International Telecommunication Union, Telecommunication Standardization Sector), and ITU-T's M.3050 series Recommendations have adopted the eTOM document.

Each year in May, the TM Forum hosts an event called Management World. It includes conferences and exhibitions related to business and technology trends in the telecommunications industry.

2. Standardization trends

2.1 Frameworx

A new undertaking in recent TM Forum standardization is the study of Frameworx [3], which is positioned as the successor to the existing NGOSS. Frameworx provides a service-oriented integrated business architecture that subsumes the NGOSS frameworks. This is considered to be an important factor in a market that requires rapid provisioning of new services, given the severe competition in which service providers operate. Frameworx basically appropriates the NGOSS components listed below.

- Business Process Framework (eTOM): a standard process architecture for business functions
- Information Framework (SID: Shared Information and Data Model): a common reference model for defining managed information
- Application Framework (TAM: Telecom Application Map): a common language for system functions for communication between service providers and suppliers
- Integration Framework: an integration of the functions of multiple frameworks by means of a

† NTT Comware Corporation
Minato-ku, 108-8019 Japan

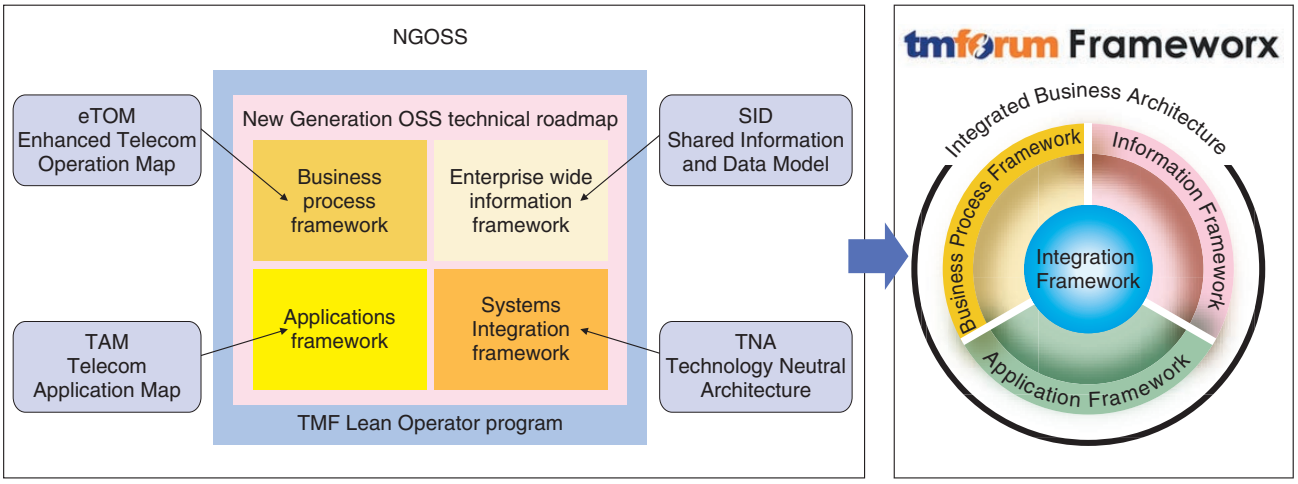


Fig. 1. NGOSS and Frameworx architecture [3].

Table 1. Standards organizations for cloud services.

Standards organizations	Main participants	Main targets
OGF (Open Grid Forum)	Microsoft, Oracle, HP, IBM, Intel, Fujitsu, Hitachi, Dell, NEC, AT&T	Application programming interface (API) for management of cloud infrastructure platform resources (IaaS)
DMTF (Distributed Management Task Force)	IBM, Intel, Dell, Novell, Oracle, BT, Telefonica, VMware, SAP	API for management of cloud infrastructure platform resources (IaaS)
SNIA (Storage Networking Industry Association)	Microsoft, Dell, Intel, Symantech, EMC2, HP, Vmware, IBM	API for management of cloud data storage

standard interface and support tools

As shown in **Fig. 1**, the Technology Neutral Architecture (TNA), which is the system integration framework in NGOSS, is used. However, when TNA was established, it was not based on service orientation, so some people think that it will not provide sufficient speed and flexibility in service construction. Therefore, the Frameworx Integration Framework focuses on the construction of a service-oriented architecture and emphasizes flexible interworking among business processes, information and applications, and the rapid development of business service categories.

To promote the development of Frameworx-compliant solutions, the TM Forum also plans to perform implementation support, solution product compliance certification, certification training, TM Forum certification partnership programs, and other such activities for service providers.

2.2 Cloud services

In existing standardization activities related to cloud services, the main target of most standards organizations is maintaining the interconnectability of the cloud infrastructure through infrastructure as a service (IaaS). Thus, a major feature is that the establishment of standards is led by vendors (**Table 1**). On the other hand, the TMF cloud study group, Cloud Service Initiative (CSI), considers that cooperation between users and vendors, particularly to clarify service requirements on the user side, is essential for widespread use of cloud services. Therefore, CSI has established the Enterprise Cloud Leadership Council (ECLC) [4] to strengthen the cooperative relationship between users and vendors and begin studies on cloud standards that focus on users' requirements, including benchmarking, i.e., performance testing (**Fig. 2**).

The participants in ECLC include enterprise users such as Deutsche Bank in addition to vendors (Alcatel-Lucent, CA, Cisco, EMC, HP, IBM, Microsoft, Nokia Siemens Networks, etc.) and carriers (AT&T, BT, Telecom Italia, etc.). ECLC's approach includes

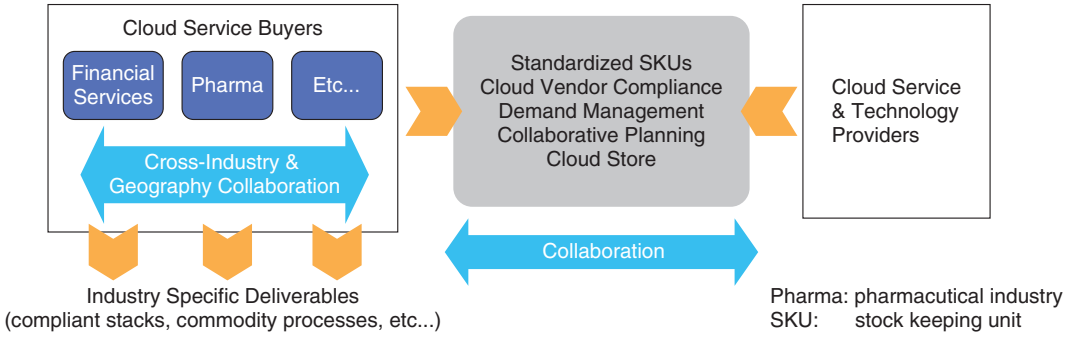


Fig. 2. ECLC activities [4].

fostering a worldwide market for an effective and efficient cloud infrastructure, accelerating standardization of cloud services to define the best common processes for providing the best services, and achieving transparency in costs and service level by means of an ecosystem.

ECLC plans to release two white papers by the end of 2010: Database as a Service White Paper and Private Cloud Reference Architecture White Paper. Other projects include setting up a Private Cloud Catalyst working group, setting vendor benchmark criteria, and defining a category for interfacing with vendors. Particular effort is going into the Private Cloud Reference Architecture White Paper, with the study proceeding on the premises listed below.

- There is an optimized reference architecture for hosting applications in a cloud environment.
- All software and hardware structural elements are fully interchangeability without any vendor dependencies in any elements of construction, operation, or charging.
- Expansion is possible from an internal cloud to an external cloud and then to an open cloud.
- The architecture can be implemented using existing technologies

In May 2010, Sean Kelley from the Deutsche Bank Platform Services Group was appointed to chair ECLC, which strengthens ECLC's ability to deal with user requirements in the field of banking.

3. Latest trends at Management World 2010

Management World 2010[*1] [5] was held on May 18–20, 2010 in France and was attended by 3000 participants from 81 countries. The main topic was "Clouds on the Horizon?" There were six keynote speech topics, six conference summit topics, and seven Forumville demonstration topics.

3.1 Keynote speeches

The six keynote speeches fell into two styles: there were four panel discussions and two presentations.

(1) Operation of an all-IP network
(2) Managed services
(3) The customer experience
(4) Mobile commerce
(5) Cloud
(6) Cost reduction

The presentation "Cloud: the new business model for tomorrow's world" attracted great interest. It was conducted in a panel discussion style and focused on how cloud users and providers can work together on cloud business model construction and popularization in a cloud era. In the discussion, the importance of rapid flexible service customization and introduction by the cloud provider from the standpoint of user benefits was emphasized. The transparency and migratability of services and the standardization of security were also discussed as prerequisites for future widespread adoption of cloud services. Furthermore, the speakers all expressed their expectation that future TM Forum cloud standardization activities will expand the application area of cloud services that can be used without anxiety by further strengthening the cooperative relationship between users and vendors and by clarifying the user-side requirements.

3.2 Conference summits

The conference was divided into six summits, and the cloud summit was further divided into six sessions

*1 In addition to the worldwide Management World conference, regional Management World conferences for the Americas, Asia, Africa, and the Middle East are also held once a year.

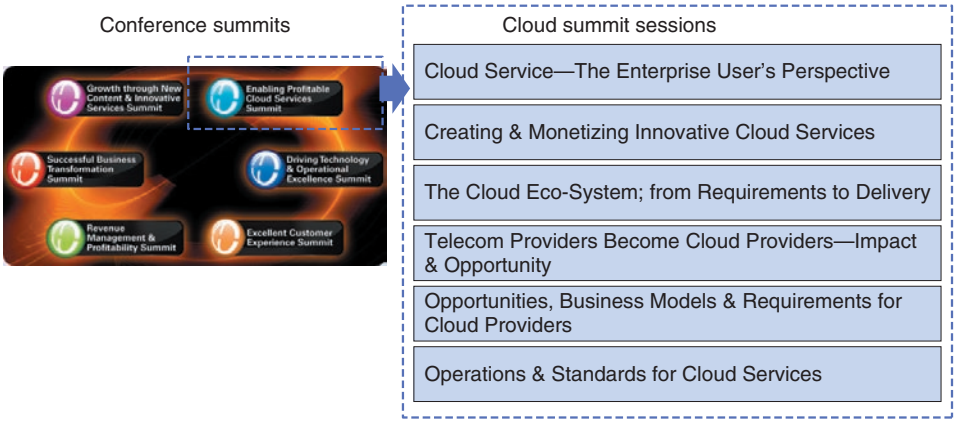


Fig. 3. Conference summits and the cloud summit sessions.

(**Fig. 3**). Of the cloud sessions, two in particular attracted great interest from the participants. They included presentations from major enterprises that represent cloud service users and providers (Deutsche Bank, IBM, etc.) on the topics of users' requirements and earnings model & introduction. The contents of these two sessions are summarized below.

(1) Cloud Service—The Enterprise User's Perspective

Deutsche Bank presented "Cloud as a Business Game Changer", which explained cloud requirements from the enterprise user's viewpoint. The cloud services needed by banks must satisfy mission-critical-grade requirements, including security, reliability, control, self service, economy, abstraction, and standardization. It was emphasized that standardization is particularly important to the user and essential for eliminating concern about vendor lock-in and allowing service selection and use.

(2) Creating & Monetizing Innovative Cloud Services

The IBM presentation on "Moving Your Cloud-Based Services Business from Concept to Reality" explained cloud business modeling and construction. The cloud market is divided into the three submarkets: business services, infrastructure services, and component supply. The market scale is expected to reach US$126 billion by 2012 according to surveys by consulting companies. Many enterprises are currently attempting to utilize their assets in order to become cloud providers, but SWOT analysis[*2] and clarification of the emerging market are needed. Furthermore, it was advised that a company should conduct in-house trials to develop expertise on construction and operation before offering the service to others.

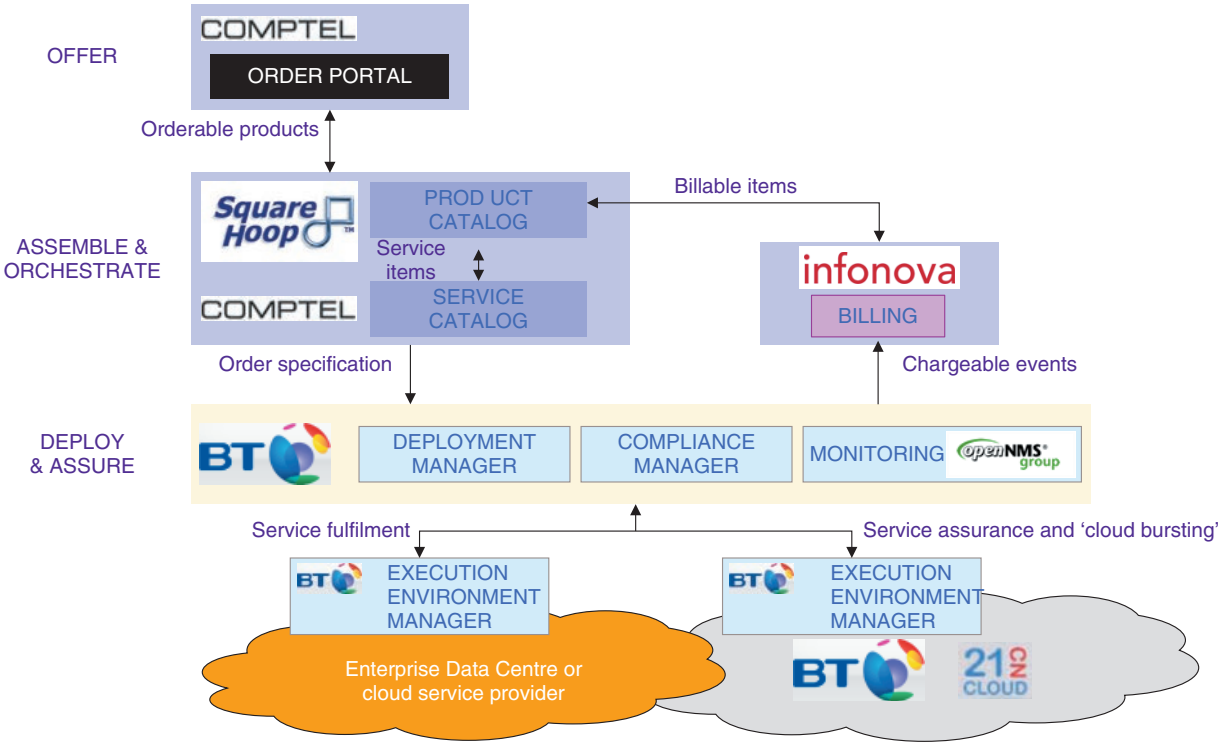
3.3 Forumville

Forumville provides a place for exhibiting experimental products that feature the standards promoted by the TM Forum. It was set up to demonstrate the utility of the standards and encourage adoption. The Forumville of Management World 2010 involved exhibits on seven subjects, including cloud services.

(1) Cloud services
(2) Business transformation
(3) Revenue management and mobile commerce
(4) Customer experience and business intelligence
(5) Digital media
(6) Technology and operations
(7) Defense

Of those, the Cloud Service Broker [6] demonstration, developed at the request of BT, drew great attention as an example of cloud service development by a carrier. The Cloud Service Broker is a tool that provides a management interface between the enterprise user and the cloud service environment (**Fig. 4**). It enables enterprise users to control cloud services according to their own governance policies and to visualize service performance, security, cost management, and other such aspects of operations.

*2 SWOT analysis: a strategic planning tool for evaluating strengths, weaknesses, opportunities, and threats in the projects and venture businesses of organizations and individuals that require decision-making for goal achievement.



*The corporation names, product names, and service names that appear in this article are trademarks or registered trademarks.

Fig. 4. Cloud Service Broker [6].

4. Conclusion

Cloud services were a major part of Management World 2010. This article reported on the presentations and demonstrations related to cloud services and on ECLC standardization activities. The cloud market is expected to continue to expand in the future, following the evolution of standardization activities.

NTT Comware is paying close attention to the studies of Frameworx and cloud services that were actively discussed at Management World, continuously keeping up with telecommunications industry trends in various countries and, as a member of the NTT Group, moving forward with activities that promise to raise the presence of Japanese enterprise in the TM Forum.

References

[1] http://www.tmforum.org/
[2] K. Sasaki, "Standardization Trends in the TeleManagement Forum (TM Forum)," NTT Technical Review, Vol. 7, No. 10, 2009. https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr200910gls.html
[3] http://www.tmforum.org/TMForumFrameworx/1911/home.html
[4] http://www.tmforum.org/EnterpriseCloudLeadership/8009/home.html
[5] http://www.tmforum.org/ManagementWorld2010/7867/home.html
[6] http://www.tmforum.org/CloudServiceBroker/8437/home.html

Haiying Jiang
Research and Development Department, Core Technology and Program Management Division, NTT Comware.
He received the M.E. degree from the Graduate School of Informatics, Kyoto University in 2004. He joined NTT Comware in 2004 and engaged in research on and verification of Carrier Grade Linux and Service Availability Forum activities in the OSS Promotion Department, Core Technology and Program Management Division. Since 2008, he has been engaged in research and review of MPLS-TP and TM Forum research.

Troubleshooting User Systems in IP Services and Case Studies

Abstract

This article describes a method for troubleshooting user systems in Internet protocol (IP) services and presents case studies demonstrating its application. It is the third in a bimonthly series on the theme of practical field information about telecommunication technologies. This month's contribution is from the Network Interface Engineering Group, Technical Assistance and Support Center, Maintenance and Service Operations Department, Network Business Headquarters.

1. Introduction

Internet protocol (IP) services such as IP-phone and IP-TV have been growing rapidly. Although problems that occur because of faults in home devices or local area network (LAN) cables can be resolved by replacing them, problems caused by other factors have been increasing. This situation has generated a need to investigate the flow of packets exchanged in actual IP communications and examine the data in those packets. This article introduces a method for analyzing faults by capturing and analyzing packets and presents case studies demonstrating its application.

2. Packet capture method

A typical packet capture method is to insert a switching hub having a mirror port between network devices from which the target packets enter and leave and to connect the mirror port to a personal computer (PC) running packet capture software such as Wireshark (formerly known as Ethereal) in order to copy and grab the packets (**Fig. 1**). If a repeater hub is used for packet capture, one must keep in mind that packet loss can occur as a result of collisions since communication here is performed in half-duplex mode (**Fig. 2**).

Here, we describe the basic functions of packet

† NTT EAST
Ota-ku, 144-0053 Japan

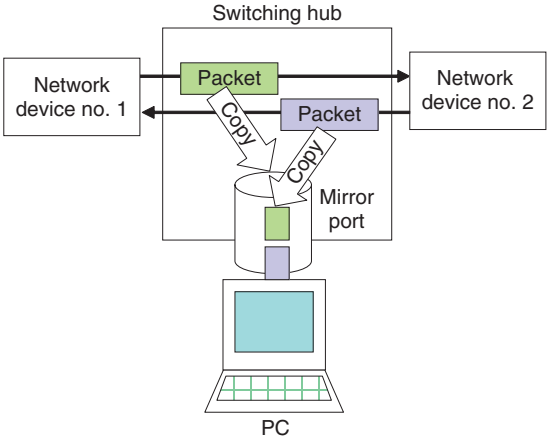


Fig. 1. Packet capture method.

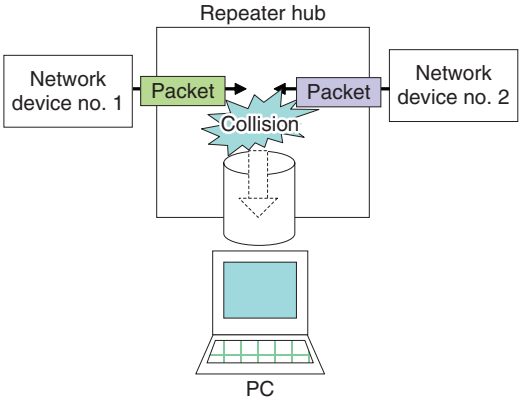


Fig. 2. Packet capture when using a repeater hub.

capture software using Wireshark (ver. 1.2.3), which has found widespread use as free software that can run on a variety of operating systems including Windows and UNIX (**Fig. 3**).

Items marked (1)–(6) on the operation screen of the packet capture software shown in Fig. 3 correspond to items (1)–(6) described below.

(1) Packet capture start/stop

The receive mode in performing packet capture is set to promiscuous mode in order to capture not only packets addressed to oneself but also those addressed to others.

(2) Packet List pane

This pane displays the receive time, transfer direction (source/destination addresses), type of protocol used, additional information, etc. about captured packets in the order in which they are collected.

(3) Packet Details pane

This pane expands parameters and displays details of the packet selected in (2) for each protocol layer.

(4) Packet Bytes pane

This pane displays the content of the packet selected in (2) as a hexadecimal dump and ASCII (text) display. For the parameter selected in (3), it displays the corresponding data in highlighted form. It also shows the address of this data within the packet (its byte from the front).

(5) Packet Filter

Since the packet capture process grabs all packets, the pane in (2) displays all of those packets including unneeded packets, which can be inconvenient in actual problem analysis. To alleviate this problem, the software enables only those packets of interest in problem analysis to be displayed by setting filtering conditions such as IP address or port number (display filter). For example, a filtering formula like "IP.addr==192.168.1.1" can be defined and applied by using the Display Filter function from the pull-down menu or by entering it in the Filter toolbar on the operation screen ((5)' in Fig. 3).

(6) Packet statistics

Packet statistics can be displayed to aid in understanding the traffic conditions in the communications environment being monitored. These include the number of sent/received packets, number of bytes, and bit rate, and so on for each protocol layer, each endpoint, and each set of endpoints. These statistics can also be displayed versus time in graph form.

3. Data analysis method

In this section, we describe a method for analyzing captured data by referring to a case study. Packet capture can be performed between a router and client PCs to analyze the cause of delays that suddenly occur in network communications (**Fig. 4**).

Specifically, to determine whether traffic is concentrating in a specific server or router, traffic statistics can be investigated from captured data in units of IP addresses. This is done by selecting Endpoints from the Statistics menu on the menu bar of the Wireshark operation screen to launch the Endpoints viewing screen. Then, by selecting the IPv4 tab on that screen ((1) in **Fig. 5**) and clicking on the Tx/Rx Packets (or Bytes) column ((2) in **Fig. 5**), one can obtain traffic

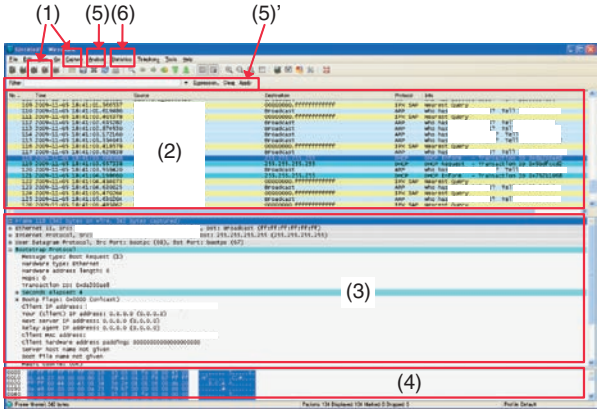


Fig. 3. Operation screen of packet capture software (using Wireshark as an example).

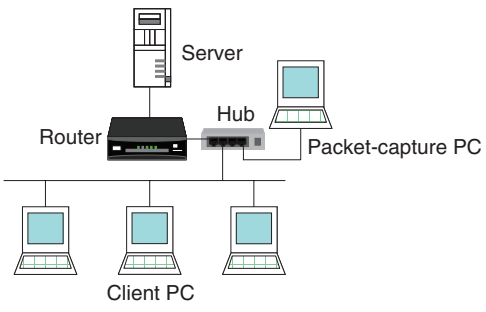


Fig. 4. Device configuration and capture location.

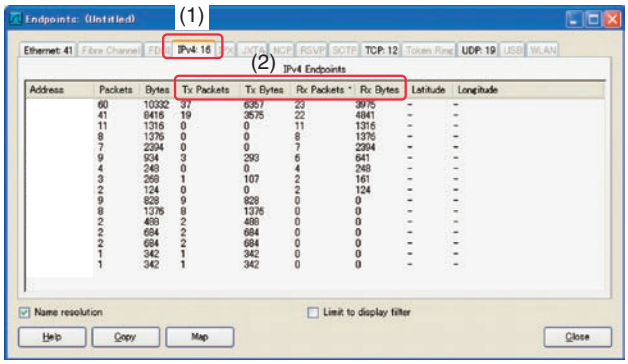


Fig. 5. Traffic statistics by network device.

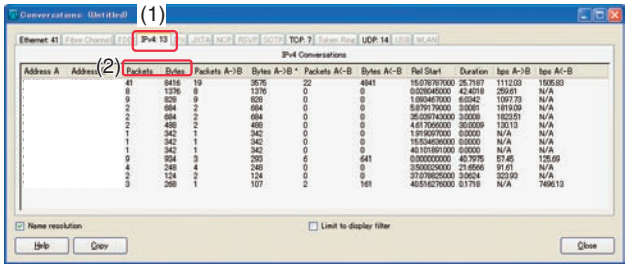


Fig. 6. Traffic statistics for communications between endpoints.

statistics for each IP address ranked in order of highest traffic volume (Tx: transmitted, Rx: received).

The ranking described above enables the user to determine whether traffic is concentrating in a specific server or router.

Next, to determine whether any of the endpoints from among those communicating with one of the above servers or routers has a particularly large traffic volume, one can investigate traffic statistics from captured data in units of communications between end points. With Wireshark, for example, this is done by selecting Conversations from the Statistics menu on the operation screen to launch the Conversations viewing screen. Then, by selecting the IPv4 tab ((1) in **Fig. 6**) and clicking on the Packets (or Bytes) column ((2) in **Fig. 6**), one can get traffic statistics for pairs of endpoints in order of highest traffic volume.

In this way, one can assess which pairs of network devices have a large traffic volume and whether they are monopolizing network bandwidth. At this time, the TCP (transmission control protocol) or UDP (user

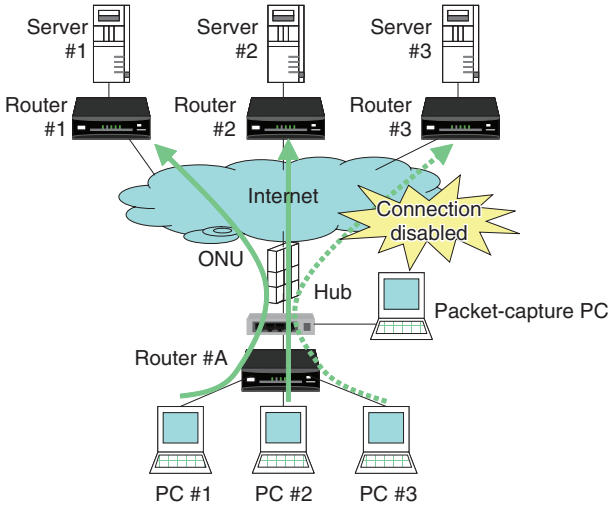


Fig. 7. Case of disabled Internet connection.

datagram protocol) tab can be selected and Packets (or Bytes) clicked to obtain traffic statistics for each port. This lets one investigate which ports are experiencing high traffic, and if the port number in question has a value of "0–49,151" (where 0–1023 are Well Known Ports and 1024–49,151 are Registered Ports) to identify the application being used by referring, for example, to the Internet Assigned Numbers Authority (IANA) site.

So far, we have described cases in which the cause of problems is traffic concentration between specific parties communicating between specific network devices. We now describe an analysis method that probes as far as packet content to determine whether an anomaly has occurred in packets or communication sequences in IP-packet communications between a server and client PCs.

We take as an example the inability to make an Internet connection (assuming that DNS (domain name system) name resolution is operating normally). In **Fig. 7**, a connection cannot be made from PC #3. Therefore, to check whether HTTP (hypertext transfer protocol) communication (port number = 80) is being performed normally from this and the other PCs as well, a hub is inserted between the optical network unit (ONU) and router #A in the figure and a packet-capture PC is connected. Then, after the packet data collected by Wireshark has been expanded, only that corresponding to HTTP communications is displayed by selecting Filter = "TCP or UDP port is 80 (http)" prepared as a default in Display Filters of the Analyze menu or by directly entering

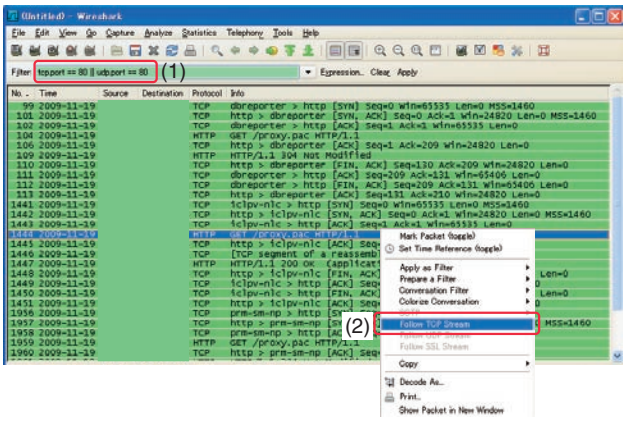


Fig. 8. Extraction of all HTTP communications by display filtering.

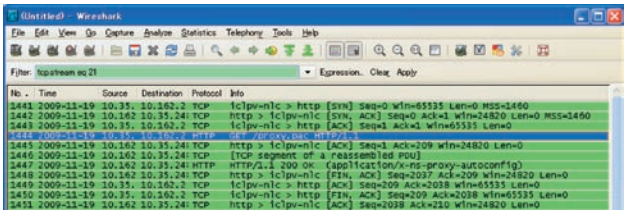


Fig. 9. Extraction of particular HTTP communications.

Fig. 10. Content of HTTP communications (command requests and replies).

"tcp.port= = 80|| udp.port==80" into the Filter toolbar on the operation screen ((1) in **Fig. 8**). This procedure lets one assess whether all HTTP communications have failed or only those of a particular site.

If it is now assessed in the above way that anomalies have occurred in only HTTP communications between PC #3 and server #3 in Fig. 7, then displaying only that TCP session will facilitate the analysis process. This is done by making any packet within that TCP session into an active display and then right-clicking and selecting Follow TCP Stream ((2) in **Fig. 8**), which causes all packets in that session to be automatically extracted and displayed (**Fig. 9**) simultaneously with the content of HTTP communications from GET requests to success replies (200 OK) (**Fig. 10**). Analysis can therefore proceed in an efficient manner while the communication sequence and packet contents of a particular communications session are being checked. This procedure also makes it possible to check the TCP session for segment loss on the server side or problems in HTTP communications on upper-level web servers.

4. Case study reflecting a typical problem

In recent years, there has been a dramatic increase in the popularity of peer-to-peer (P2P) file sharing software and online games. In the former case, a large number of users download and upload large quantities of files from and to each other over the Internet, and in the latter case, many users compete with each other over the Internet. This flourishing of applications that exploit the inherent convenience of the Internet to the limit is being accompanied by performance demands on routers and other devices on the customer's premises that could not be envisioned in normal use. As a result, problems caused by processing capacity limits and resource depletion have begun to appear. Here, we present a case study obtained from consultations made with the Technical Assistance and Support Center.

A customer who uses online games occasionally experienced the phenomenon in which the console's screen suddenly froze and the Internet connection was lost. The same customer also uses P2P file

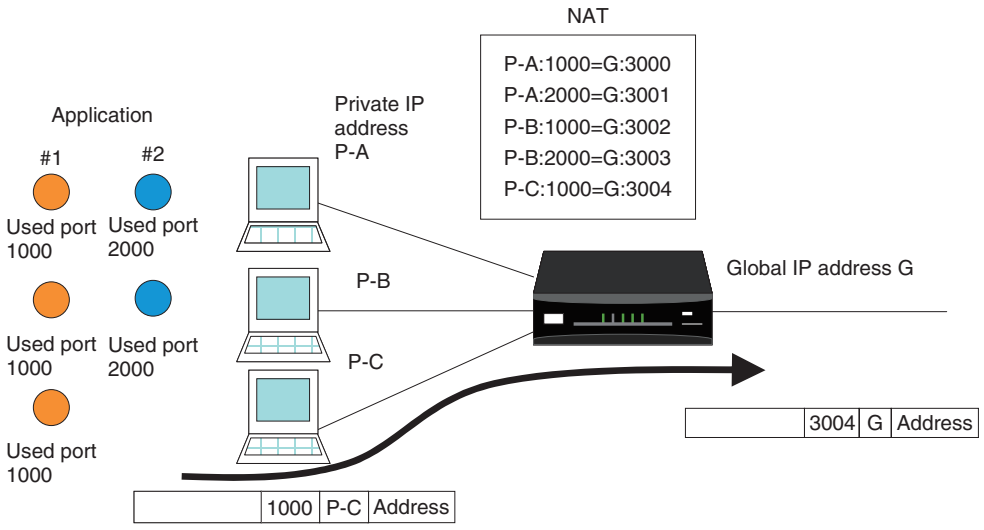


Fig. 11. NAT mechanism.

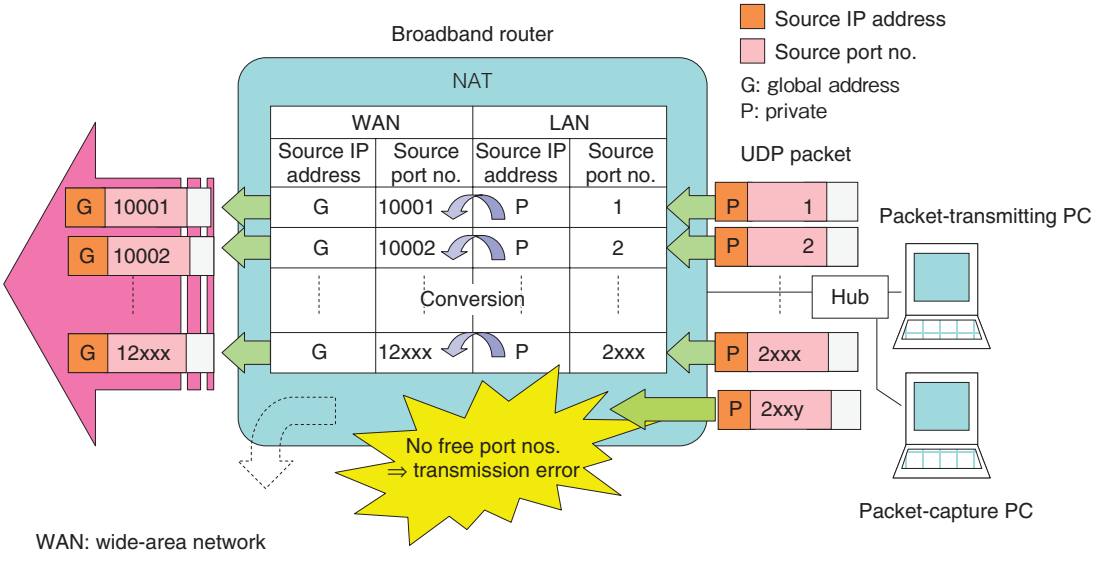


Fig. 12. Problem reproduction test.

sharing software. When the communications log of the broadband router was checked, it was found that a transmission error occurred in conjunction with the network address table (NAT) in the time period during which the problem occurred. The NAT dynamically converts IP addresses and port numbers so that multiple applications can run simultaneously on multiple PC terminals using a single global address (**Fig. 11**). The details of this error indicated that the number of entries registered in the NAT exceeded the table's capacity, which suggested that the address/port conversion pattern could not be registered in the NAT. To test this hypothesis, we connected a PC to that broadband router, and using a packet-transmission program that we created, we transmitted IP packets continuously while incrementing the destination port number by one for each packet. In this way, we could check whether the same kind of transmission error would occur in the broadband router (**Fig. 12**). At this time, we also set up one more PC between the

packet-transmitting PC and broadband router to perform packet capture.

We found from the communications log that a transmission error occurred at the NAT after the destination port number on the LAN side entered the 2000 series. Thus, to determine the maximum number of entries that could be registered in the NAT, we divided captured data into port number ranges in the manner of port no. = 1–2750, 1–2500, 1–2250, etc. and using a PC packet-generator tool, we transmitted that data in sequence to the broadband router and checked for a transmission error. We found that a transmission error did indeed occur upon exceeding port no. = 2XXX and that the maximum number of entries for the NAT was therefore 2XXX.

On the basis of this case study, we could infer that performing large-volume TCP/UDP communications simultaneously by online games and P2P-type file sharing software caused the number of NAT registration entries to reach 2XXX so that subsequent communications failed owing to insufficient NAT capacity. We could also infer that this problem could be solved by replacing the broadband router with another model having a larger NAT capacity or by changing the settings of the customer's P2P file sharing software.

5. Conclusion

In this article, we introduced a troubleshooting method targeting user systems in IP services and presented case studies of its use. We hope that readers found this article useful and interesting.

Papers Published in Technical Journals and Conference Proceedings

Complex Mode Analysis of Strong Motion Accelerograms

F. Ishiyama

Proc. of Japan Geoscience Union Meeting 2010, Makuhari, Chiba, Japan, May 2010.

We report the results of our analysis of strong motion accelerograms using our proprietary time series analysis method. Our method is a kind of mode analysis: we fit the given time series locally with a linear Green's function and calculate the function's poles. We can obtain sufficient frequency information even from data for a fraction of a cycle. For example, when we analyze fraction-of-a-cycle data for 20 samples, we can obtain a frequency resolution 2500 times higher than with Fourier analysis. We analyzed some accelerograms of the Iwate Engan Hokubu earthquake. We found that the main frequencies of the surface acceleration signals of the P-wave and S-wave were both 5 Hz. The decay rate of the P-wave was about 5/s (the rate is comparable to its frequency) and that of the S-wave was almost 0/s. This means that the P-wave was made up of repetitive impulsive waves and the S-wave was almost sinusoidal.

Detection of Anger Emotion in Dialog Speech Using Prosody Feature and Temporal Relation of Utterances

N. Nomoto, H. Masataki, O. Yoshioka, and S. Takahashi

Proc. of INTERSPEECH 2010, ISCA, Vol. 1, No. 1, pp. 494–497, Makuhari, Chiba, Japan, Sept. 2010.

This paper proposes a novel feature for detecting anger in dialog speech. Anger is classified into two types: loud HotAnger and calm ColdAnger. Prosody can reliably detect the former but not the latter. We analyzed both types of anger dialog in the two-party setting and discovered that they exhibited some differences in the temporal relation of utterances from neutral dialog. We created a dialog feature that reflects these differences and investigated its effectiveness in detecting both types of anger. Tests show that the proposed feature combination improves the F-measure of ColdAnger and HotAnger by 24.4 and 8.8 points, respectively, against a baseline technique that uses only prosody.

Efficient Data Selection for Speech Recognition Based on Prior Confidence Estimation Using Speech and Context Independent Models

S. Kobashikawa, T. Asami, Y. Yamaguchi, H. Masataki, and S. Takahashi

Proc. of INTERSPEECH 2010, ISCA, Vol. 1, No. 1, pp. 238–241, Makuhari, Chiba, Japan, Sept. 2010.

This paper proposes an efficient data selection technique to identify well recognized texts in massive volumes of speech data. Conventional confidence measure techniques can be used to obtain this accurate data, but they require speech recognition results to estimate confidence. Without a significant level of confidence, considerable computer resources are wasted since inaccurate recognition results are generated only to be rejected later. Our technique rapidly estimates the prior confidence based on just an acoustic likelihood calculation by using speech and context-independent models before speech recognition processing; it then recognizes data with high confidence selectively. Simulations show that it matches the data selection performance of the conventional posterior confidence measure with less than 2% of the computation time.

Body-biased Steep-subthreshold-swing MOS (BS-MOS) with Small Hysteresis, Off Current, and Drain Voltage

K. Nishiguchi and A. Fujiwara

Proc. of the 2010 International Conference on Solid State Devices and Materials (SSDM 2010), Vol. 1, No. 1, pp. 1261–1262, Tokyo, Japan.

We demonstrate a 30-nm-gate-length nanowire MOSFET with a steep subthreshold swing. A parasitic bipolar transistor formed in a fully depleted SOI MOSFET applies body bias to the MOSFET's channel and thus reduces the steep subthreshold swing to below 60 mV/dec at room temperature. Additionally, triple-gate operation allows current characteristics with small hysteresis, a high on/off ratio, and low drain voltage. These features promise SOI MOSFETs for low power consumption.

Strong Stark effect of electroluminescence in thin SOI MOSFETs

J. Noborisaka, K. Nishiguchi, Y. Ono, H. Kageshima, and A. Fujiwara

Proc. of the 2010 International Conference on Solid State Devices and Materials (SSDM 2010), Vol. 1, No. 1, pp. 796–797, Tokyo, Japan.

We report the electroluminescence from thin SOI MOSFETs when electrons are injected into a thin SOI layer by tunneling. We observed a large Stark shift of up to approximately 50 meV by applying an electric field normal to the thin SOI layer. The observed strong Stark effect indicates that strong quantum confinement in the Si/SiO_2 system plays an important role in light emission.

Character Recognition

Edited by M. Mori

Sciyo, Hard cover, 188 pages, 2010.

Character recognition is one of the pattern recognition technologies most widely used in practical applications. This book presents recent advances relevant to character recognition from technical topics such as image processing, feature extraction, or classification to new applications including human-computer interfaces. The goal of this book is to provide a reference source for academic research and for professionals working in the character recognition field.

Adaptive Feature Extraction Method for Degraded Character Recognition

M. Mori, M. Sawaki, and J. Yamato

Character Recognition, Sciyo, Vol. 380, No. 1, pp. 43–58, 2010.

In this chapter, we propose a category dependent method that achieves robustness against both deformation and image degradation. Our method estimates the degree of deformation and degradation of the input pattern on the basis of specific information about each category. Exploiting the category information enables us to extract the

variation in the aspect ratio and that in the run-length used for computing feature values. The fluctuations in shape and feature values are then offset by the estimated compensation coefficients. To evaluate our method, we applied it to the recognition of video text degraded by background noise and blurring and deformed by aspect ratio fluctuations.

One-by-one Trap Activation in Silicon Nanowire Transistors

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

Nature Communications, Vol. 1, Article No. 92, DOI: doi:10.1038/ncomms1092

Flicker or 1/*f* noise in metal-oxide-semiconductor field-effect transistors (MOSFETs) has been identified as the main source of noise at low frequency. It often originates from an ensemble of a huge number of charges becoming trapped and de-trapped. However, as a deviation from the well-known model of 1/*f* noise is observed for nanoscale MOSFETs, a new model is required. Here, we report the observation of one-by-one trap activation controlled by the gate voltage in a nanowire MOSFET and propose a new low-frequency-noise theory for nanoscale FETs. We show that the Coulomb repulsion between electronically charged trap sites prevents the activation of several traps simultaneously. This effect induces a noise reduction of more than one order of magnitude. It decreases when the electron density in the channel is increased owing to the electrical screening of traps. These findings are technologically useful for any FET with a short narrow channel.

Rapid change in Articulatory Lip Movement Induced by Preceding Auditory Feedback during Production of Bilabial Plosives

T. Mochida, H. Gomi, and M. Kashino

PLoS ONE, Public Library of Science, Vol. 5, No. 11, p. e13866, 2010.

Background: There has been plentiful evidence of kinesthetically induced rapid compensation for unanticipated perturbation in speech articulatory movements. However, the role of auditory information in stabilizing articulation has been little studied except for the control of voice fundamental frequency, voice amplitude, and vowel formant frequencies. Although the influence of auditory information on the articulatory control process is evident in unintended speech errors caused by delayed auditory feedback, the direct and immediate effect of auditory alteration on the movements of articulators has not been clarified.

Methodology/principal findings: This work examined whether temporal changes in the auditory feedback of bilabial plosives immediately affect the subsequent lip movement. We conducted experiments with an auditory feedback alteration system that enabled us to replace or block speech sounds in real time. Participants were asked to produce the syllable /pa/ repeatedly at a constant rate. During the repetition, normal auditory feedback was interrupted, and one of three pre-recorded syllables, /pa/, /Φa/, or /pi/, spoken by the same participant, was presented once at a different timing from the anticipated production onset, while no feedback was presented for subsequent repetitions. Comparisons of the labial distance trajectories under altered and normal feedback conditions indicated that the movement quickened during the short period immediately after the alteration onset, when /pa/ was presented 50 ms before the expected timing. Such a change was not significant under other feedback conditions that we tested.

Conclusions/significance: The earlier articulation rapidly induced by the progressive auditory input suggests that a compensatory mechanism helps to maintain a constant speech rate by detecting errors between the internally predicted and actually provided auditory information associated with self movement. The timing- and context-dependent effects of feedback alteration suggest that the sensory error detection works in a temporally asymmetric window where acoustic features of the syllable to be produced may be coded.

Orienting Kinesthetically: A Haptic Handheld Wayfinder for People with Visual Impairments

T. Amemiya and H. Sugiyama

ACM. Trans. Accessible Computing, Vol. 3, No. 2, pp. 1–23, 2010.

Orientation and position information are vital for people with visual impairments if they are to avoid obstacles and hazards while walking around. We are developing and evaluating a haptic direction indicator that delivers directional information in real time through kinesthetic cues. The indicator uses a novel kinesthetic perception method called the pseudo-attraction force technique, which utilizes the nonlinear relationship between perceived and physical acceleration to generate a force sensation. In an experiment, we found that the indicator allowed people with visual impairments to walk safely along a predefined route at their usual walking pace without any previous training, independent of the existence of auditory information. The findings indicate that the haptic direction indicator is effective at delivering simple navigational information and is a suitable substitute for and/or enhancement to conventional wayfinding methods.

Optical Flow Estimation and Counting Method of Moving Objects from a Real Environment Scene Enveloped by an Infinite Number of Particle-like Patterns

H. Sakaino

The Institute of Image Information and Television Engineers, Vol. 64, No. 11, pp. 1731–1743, 2010 (in Japanese).

In real environments, the detection and motion of an interesting moving object against a complex background in computer vision are very important. However, scenes contain many undesirable factors that can prevent stable detection such as occlusion, lighting changes, and a jittery background. In addition to these, an infinite number of randomly moving particle-like patterns can make moving objects more difficult to detect. These particles have ambiguous edges and no definite shape. In a more complicated scene, we assume that such particles cannot be smoothed out by simple preprocessing such as low-pass filtering. Thus, they can distribute the optical flow of moving objects in time and space. To deal with these issues for matching between frames, we first assumed that particle-like patterns and moving objects have properties of fluidity and rigidity, respectively. The image brightness change and motion smoothness between frames can constrain the estimated optical flow of a moving object. However, a local large brightness change caused by the above factors violates such constraints. Thus, on the basis of a statistical approach, we have developed a robust optical flow estimation method by adding a locally parallel flow constraint. Estimated flow is used to count the number of multiple moving objects by a clustering method, which is applied starting with a large number of centroids. Centroids are iteratively merged within a certain distance until converged. Experimental results show that our method outperforms previous methods, thus

validating our method.

Archiving and Preservation of Media Content Using MPEG-A

N. Harada, Y. Kamamoto, T. Moriya, Hendry, H. Sabirin, and M. Kim

IEEE Multimedia, Vol. 17, No. 4, pp. 94–99, 2010.

This article describes a standardized packaging format for digital media files. Archiving is accomplished through a hierarchical file structure and rich contextual information, while preservation is realized by enabling portability in the structure and file attributes. Advanced functionality, such as usage governance, is supported by the packaging format.

Fast Sensing Using Single-electron Stochastic Resonance in Si Nano-wire Transistors

K. Nishiguchi and A. Fujiwara

Proc of the 23rd International Microprocesses and Nanotechnology Conference (MNC 2010), Kokura, Kyushu, Japan, 2010.

We demonstrated single-electron-based stochastic resonance (SR) using nanoscale MOSFETs. The physical nature of shot noise allows fast SR demonstration, which leads to time-division SR operation with one unit instead of multiple network units. This is very useful for high integrability of sensors and for single-shot sensing of quickly moving targets.