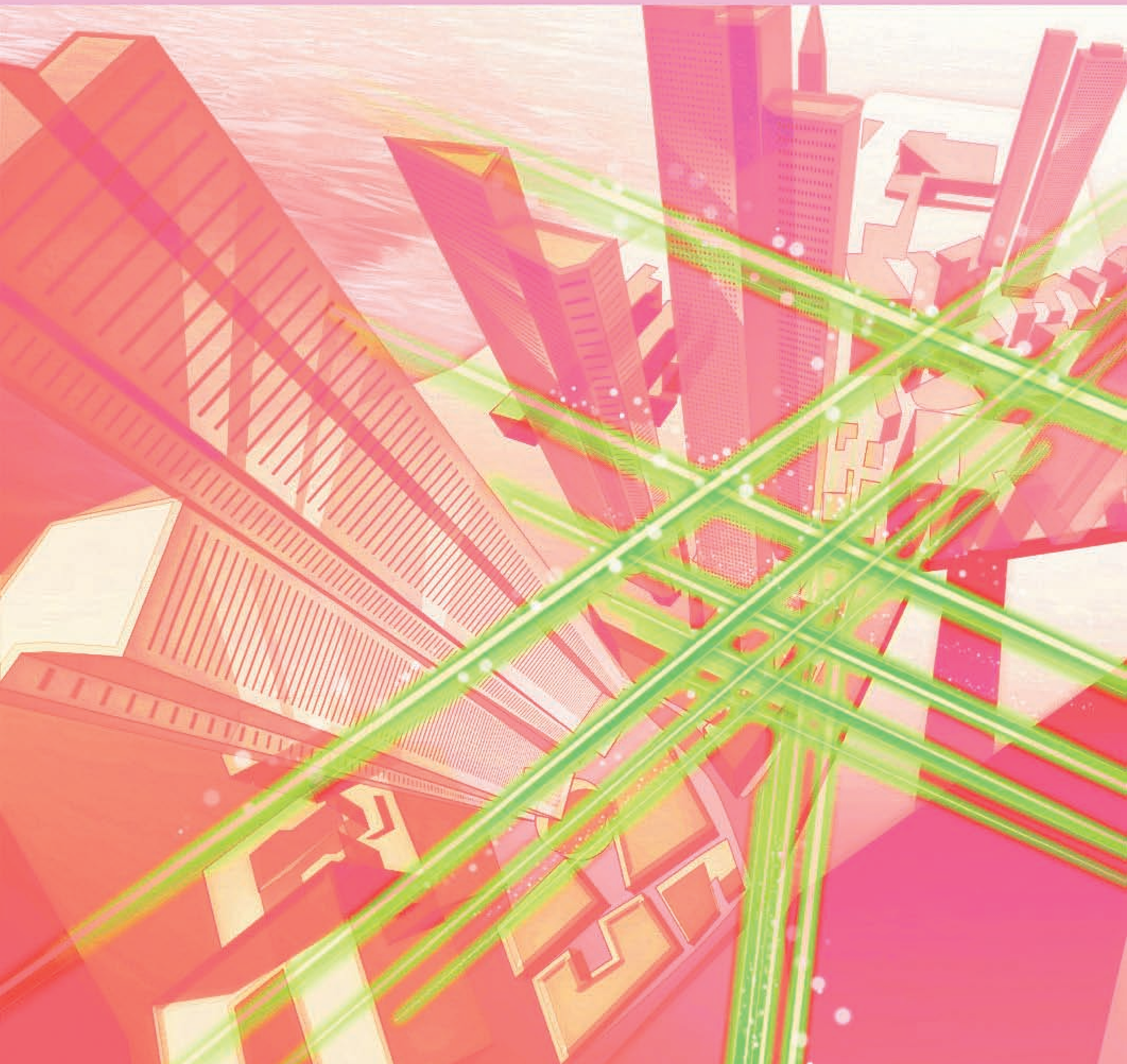
# NTT Technical Review

3
2013



March 2013 Vol. 11 No. 3

# NTT Technical Review

March 2013 Vol. 11 No. 3

# Listen Carefully to the Voice of Stakeholders and Produce Results that Exceed their Requests
## —Sustainable, Open, Agile, and Global R&D as Keywords

***Hiromichi Shinohara***
***Director and Executive Vice President, Director of Research and Development Planning Department, NTT***

**Overview**
NTT's pioneering research and development (R&D) division continues to pursue innovation in the face of great change in the industry. We asked Hiromichi Shinohara, NTT Executive Vice President and Director of the Research and Development Planning Department, to tell us how he plans to manage this effort with a strategy based on four motivating keywords.

### Facing change with the right attitude based on four keywords

*—Mr. Shinohara, you have been involved in research and development (R&D) management and planning for quite some time. Looking back at the path taken to date, how do you think the NTT Group should posture itself going forward?*

In the past, most R&D at NTT was undertaken by creating five- and ten-year visions as in a planned economy and working accordingly to meet the objectives set therein. Today, however, it goes without saying that world trends are changing at an increasingly rapid pace.

In contrast to the previous era in which new technologies brought great change to society, today it is customer needs that are becoming a major factor driving the world we live in. At the same time, intense competition and other factors in the external environment are having a big impact on the market.

Under these conditions, I don't think we will be able to survive unless we combine three different approaches. The first is pursuing R&D with a long-term vision, the second is pursuing R&D that anticipates customer needs and creates new trends, and the third is cultivating a development mindset that allows us to quickly identify and respond to new social trends over the short term. This calls for a new management style.

I can describe my management policy as "sustainable, open, agile, and global." I would like to explain the meaning of these four keywords.

### Technology development that blossoms over many years of effort—adopting a *sustainable* approach to research

As the word implies, "sustainable" means the ability to continue on. This is a keyword directed toward our researchers. It's easy to terminate a certain line of research but nearly impossible to resume it. When research is being done on a certain topic, it may happen that a totally unexpected discovery comes along that puts that research on a path different from the original objective. In any case, research must be continued in order to bear fruit.

For example, R&D of optical fiber technology began about two years before I entered NTT and has continued ever since to produce the amazing results that we see today. The concept of "scrap and build" may sound appealing, but when it comes to research and development, being resolute in purpose is a must. So to all our fine researchers, I say, "Let's pursue research and development in a sustainable manner."

### Adopting an *open* attitude: "raising our hand" to reveal ourselves

At present, the areas covered by information communications are extensive—much more so than in the telephone era—and the supporting technologies are broad as well. It should be obvious that it is becoming impossible for us to cover all of these areas by ourselves especially if we are to face the changes around us with a sense of urgency. Researchers, however, are apt to want to research a certain topic all the way from start to finish; they crave that feeling of individual accomplishment. This is why I am firmly committed to a theme of open innovation and collaboration and am accelerating its adoption. And here, I'm not just talking about tie-ups with outside companies. I believe it's important that we work with parties within the NTT Group and the NTT R&D Laboratories Group, too. Furthermore, I don't mean collaboration just in the complementary sense in which we ask others to provide the technological expertise we don't possess. It is also important that we search out cooperative methods in which we can make "1+1 = 3" by synergistically joining forces.

Let me give an example of how collaboration within NTT R&D produced an effective result.

There was a need at one time to install optical fiber into older condominium buildings, but the existing conduits had little extra space to accept new wiring. The group researching and developing optical fiber and the group researching cable materials consequently joined forces in a joint project to tackle this problem. In the end, they succeeded in developing thin and low-friction indoor optical cables that could be smoothly slipped into tight places, thereby resolving the problem. This was the first cable of this type in the world, and try as they might, other companies around the world could not duplicate it. I think it's fair to say that such a result could be achieved precisely because research and development at NTT R&D is so broad-based.

I can also give an example of how collaboration between NTT R&D and a party outside NTT is producing good results. I'm referring specifically to Jubatus, which is a distributed processing framework for deep analysis of big data in real time, which we jointly developed with some young developers of a Japanese venture company. Up until now, our development style had been for the most part to place orders with manufacturers for products that we decided to develop based on our technology. Now, however, we are changing this style and adopting an approach in which we try to produce something in a joint manner.

In addition, our R&D efforts are producing results that can be used and applied for purposes other than communications. One example is Revtrina, a reverberation control system that received a Japan Audio Society prize in December 2012. It was originally developed as a technology for improving the sound quality of phone calls, but we encountered opportunities to provide this technology to companies in fields outside of communications for adoption in audio equipment and other devices. Incidentally, as a technology that can control reverberation without having to reprocess the original sound, it has been highly praised by music distribution companies that own the publication rights to the music of rock bands such as Queen and the Rolling Stones, and it has even been adopted by movie theaters for use in screening movies. In short, Revtrina has gained a good reputation among professionals in various fields.

Moreover, as announced in a recent press release, we have successfully fabricated a conductive composite material that is mild on the skin by coating fiber with a conductive polymer. This product demonstrates the potential to continuously monitor a person's heartbeat and to perform electrocardiogram tests via a piece of clothing the person is wearing, and it holds the promise of tie-ups with companies in the medical field and other industries. Looking forward, I would like to see more of our R&D results be put to such positive use.

Although the NTT name is and has always been known for communications, a diverse array of byproducts has been coming out of the R&D process for communications. For example, the laser was developed for use in communications, but it has also come to be particularly useful in identifying the district where rice was produced. This is done by lasing a grain of rice to determine its water content. While I don't think such applications will make a name for NTT as strongly as communications has, I think it is important that we have many technologies that can make a viable contribution to society by simply looking at them in a slightly different way. I also believe that we should use our technologies to develop business in new fields to provide the firm with new sources of revenue in addition to those from voice-related operations. In short, we should apply and develop the technological assets that we as a company possess.

In this way, I think it will become possible for us to contribute to new fields and create value by collaborating with other industries with which we have had no points of contact in the past. To this end, I would like to see us take on a mindset such that when determining whether the technologies that we are researching and developing can be put to good use, we consider not just our own ideas but also the ideas of other companies and groups that wish to collaborate. Likewise, I would like to see us become accustomed to creating opportunities for others to get to know our technologies.

We also need to reflect on a few things in relation to NTT's customary approach of taking the initiative in searching out a partner for collaboration purposes. To begin with, ideas in this regard have so far only reflected the viewpoint of NTT. This creates a narrow perspective with the result that a hunt for a partner takes more time. However, making this a bidirectional process can shorten the time involved as well as broaden our perspective. In addition, each prospective partner has its own practices, dynamics, and needs. Analyzing such characteristics takes time in itself. If, on the other hand, we make an effort to reveal ourselves and "raise our hand" to attract attention to the technologies that we possess, it should be possible to promptly get the partner we need to perform the selection process for us and become a valued partner.

## Responding to customer needs with a sense of urgency: *agile*, on-sight development

Our past approach to research and development was to provide NTT's business companies with sound, complete products, or, to put it another way, products "scoring a full 100 points." However, considering that even "80-point" products should be acceptable to customers, I think we should make a change to a "beta version" approach in which we provide such products as promptly as possible to meet customer needs. Then, once these products are in the customers' hands, we can make on-site visits to the business companies and refine these products as needed while listening to what customers have to say.

NTT DOCOMO's voice-activated concierge

service called “Shabette Concier” is one example of this approach. The original technology used here for answering user questions on a mobile phone was developed by NTT DOCOMO itself. The service evolved, however, when NTT researchers visited NTT DOCOMO and worked with their staff to further research and develop the technology. This collaborative process resulted in the introduction of Japanese-language processing and a more enjoyable conversational experience.

We have begun to apply our technologies to other fields as well. For example, with the aim of improving customer satisfaction and creating even better services, we have brought voice-recognition, emotion-estimation, and other technologies from NTT R&D to NTT contact centers where comments and claims are received so that customer input can be analyzed in a more accurate manner.

*—Has this 80-point concept been well received?*

First of all, establishing specific criteria for achieving “80 points” in a product is difficult. Although we may know when a certain product has a “passing” grade, we may be totally in the dark as to what customer needs must be satisfied to achieve a 100-point, complete product. I think that the portion of product development that must be performed to reach a perfect score requires a great deal of effort since it requires that we first determine what it is that customers really need and then accurately reflect their demands in the product. It’s exactly because we live in an era of diverse customer needs that deciding on what makes a 100-point product is so difficult. This is why it is necessary to complete a product at sites close to the market.

## Becoming a *global* leader in new world markets and fields

NTT R&D has expanded its activities to include standardization and tie-ups with overseas universities as well as the global provision of R&D results.

Last year, we succeeded in selling more than 10 billion yen worth of optical devices and encryption technology for delivering video of the Olympic Games, the World Cup, and other events. Furthermore, in addition to tie-ups with venture companies and cooperative activities with the open source community, we are also expanding our proposals for new open source software on a global basis.

At the same time, the international expansion of

NTT business is accelerating rapidly. In this regard, I would like to actively provide technologies that we have researched and developed to overseas group companies that have been increasing in number through merger and acquisition activities. I also think that we need to create an environment conducive to creating new products as a global business strategy. In the United States, open innovation thrives, markets are active, regulations are relatively easy to satisfy, and venture companies are abundant. I want R&D to support NTT’s global strategy announced in last year’s Medium-Term Management Strategy by setting up a new R&D base in North America that is blessed with this open environment, and using this base as a means of providing the services that are researched and developed in North America throughout the world.

*—Please tell us more about this R&D base in North America and other activities tied to NTT’s Medium-Term Management Strategy.*

Preparations are now in place to open this North America R&D base in April 2013. The plan is to locate the base on the west coast and to begin with the R&D of security- and cloud-related technologies and services. I would like to start off with 30–40 employees and expand the staff gradually over time. We plan to build a vigorous team composed of both locally hired personnel and staff members drawn from group companies, and with this team, we intend to promote open innovation without delay from North America while listening closely to market demands. The current name planned for this R&D base is NTT Innovation Institute, Inc. (provisional), or NTT $I^3$ for short. As opposed to creating a perfect organization for this base from the very start, we intend to make adjustments as needed as the institute grows.

Furthermore, with an eye to the next stage of R&D,

we will need to achieve a simple, friendly, and personalized UI/UX (user interface/user experience). Let's take the smartphone as an example; it has been called a very convenient device, but is it really that convenient for all users? Some people think smartphones have too many functions that actually make them less convenient than they thought. I would like to combine smartphone technology with fundamental technologies like voice recognition and image processing from NTT R&D so that we can provide user-friendly products for all types of people that can be customized with customer input instead of products having a uniform set of specifications.

## Becoming sustainable and open by working with conviction and listening to stakeholders

*—Mr. Shinohara, please leave us with a few words for NTT researchers.*

First of all, I would like to see our researchers approach their work in a multifaceted way: not just on a theme-driven basis but also in a sustainable and open manner. Additionally, instead of simply taking the development requests received from NTT's business companies in a literal fashion, I would ask researchers to reflect on and search out the real, substantial meaning of those requirements. That is to say, I would like our researchers to listen carefully to what the business companies—NTT stakeholders—have to say, and to then combine their requests with their own knowledge of technology trends with the aim of providing technologies and services that even exceed those requests.

Finally, I would like our researchers to believe in themselves and work with conviction. To each and every researcher I say: "Please carry out your duties with purpose while absorbing all the stimuli you need from the outside." This is what I look forward to seeing NTT researchers do.

**Interviewee profile**

■ Career highlights

Hiromichi Shinohara joined Nippon Telegraph and Telephone Public Corporation (now NTT) in 1978. He took up the post of Project Manager in NTT Access Network Systems Laboratories in 1998, General Manager of the Access Network Service Systems Laboratories of the Information Sharing Laboratory Group in 2003, and Director of the Information Sharing Laboratory Group in 2007. He became Senior Vice President and Director of the Research and Development Planning Department of NTT in 2009 and took up his present position in June 2012.

# Current Status, Issues, and Future Perspective of Wireless Home Networks

*Yasushi Takatori, Masato Mizoguchi, Kazuhiro Uehara, Shuichi Yoshino, Mitsuru Harada, and Kazuyasu Okada*

**Abstract**

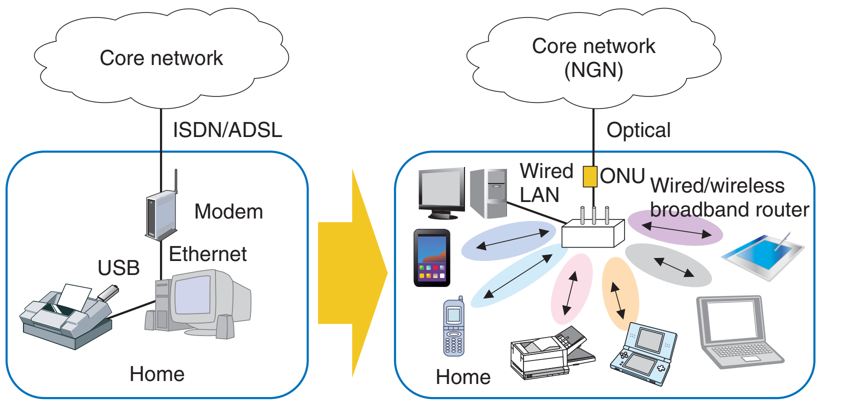
Wireless access is now widely available in home networks. This allows network access from anywhere in the home. When wireless home networks become more secure and reliable and can be deployed more easily, more people will be able to use home network services. This article explains the current status and issues of home networks. It also introduces the concept of a user-centric wireless home network that is under development at NTT Network Innovation Laboratories.

## 1. Introduction

More and more people have started using wireless access at home in recent years. The changes in the way home networking is used are the backdrop of this trend. As shown in **Fig. 1**, at the beginning of the Internet era in the early 1990s, the only networked device was the desktop personal computer (PC), and few people were using the Internet at home. In contrast, optical broadband network access has now penetrated the entire country, and various network devices, e.g., smart phones, tablets, gaming machines, and PC peripheral devices, are now used at home. In addition, people are using home networks in various ways, e.g., data communication using the Internet, sound communication using a wireless headset and wireless microphone, and communication with sensing devices. This change has been possible because of the introduction of various wireless systems as shown in **Fig. 2**. There are three major wireless access systems: (1) wireless local area networks (LANs), used for Internet access [1], (2) Bluetooth, used for wireless headsets and healthcare appliances, and (3) ZigBee, used for communication with sensing devices for network services such as visualizing the power consumption of home appliances.

Most smartphones and tablets now use wireless LANs. In home networks, they are mainly used for data communications. The current wireless LAN standards are IEEE 802.11b/g for the 2.4-GHz band, IEEE 802.11a for the 5-GHz band, and IEEE 802.11n for the 2.4/5-GHz band. The next standards, i.e., IEEE 802.11ac and IEEE 802.11ad, are currently under development and will apply to gigabit throughput. Draft documents have already been issued, and procedures are being developed to complete the standard. Wireless LANs based on the IEEE 802.11ac draft are expected to be available by April or May of 2013. Wireless broadband access will undoubtedly become more common after the launch of the IEEE 802.11ac standard.

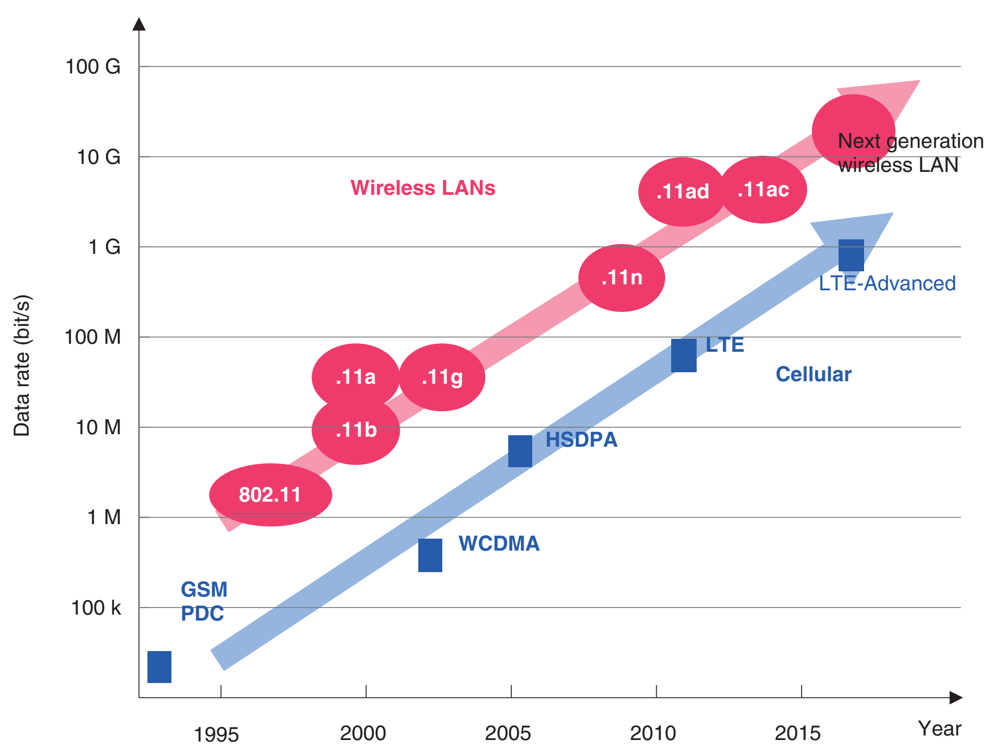
Bluetooth has also become a popular wireless system. It uses the 2.4-GHz band and is based on the IEEE 802.15.1 standard, which targets wireless personal area networks (PANs) whose service area is smaller than that of a wireless LAN. In 2009, Bluetooth 4.0 was developed with reduced power consumption, and various mobile devices started deploying Bluetooth. It is mainly used for voice communications or music appliances such as wireless headsets and wireless mikes. It is expected to be applied to various appliances in the near future, and larger numbers of Bluetooth-enabled products are predicted to be shipped.




ADSL: asymmetric digital subscriber line
ISDN: integrated services digital network
LAN: local area network

NGN: Next Generation Network
ONU: optical network unit

Fig. 1. Changes in home network usage.




HSDPA: high-speed downlink packet access
GSM: global system for mobile communications

LTE: Long Term Evolution
PDC: personal digital cellular

Fig. 2. Acceleration in use of wireless LAN.

A machine-to-machine (M2M) network is also considered to be an affordable wireless system that can connect not only high-end smart devices but also anything in the home to the network. ZigBee, which is a sensor network system based on the IEEE 802.15.4 standard, is available for use in home network services. IEEE 802.11ah is also under development to support M2M communication in the 920-MHz band.

However, some issues have arisen in the aforementioned evolution of wireless networks that must be addressed to further evolve wireless home networks. These issues are described in detail in the next section.

## 2. Issues in wireless home networks

There are three key issues regarding home networks: (1) providing support for a wider variety of wireless systems, (2) preventing interference and improving actual throughput, and (3) simplifying the setting and certification procedure. These issues are explained below.

(1) Providing support for a wider variety of wireless systems:

Each wireless standard has been optimized for a specific purpose. These standards have been amended in order to enhance performance by incorporating the latest technologies. Although this has expanded the application area of wireless systems, there are still too many wireless standards, and it is difficult for users to select the most appropriate wireless system. It is necessary to develop a wireless home network platform that supports various standards. This will allow users to buy what they want without worrying about connectivity to their own home network.

(2) Preventing interference and improving actual throughput:

Wireless systems in home networks use unlicensed frequency bands where multiple wireless systems may coexist. The possibility of the coexistence of other wireless systems was low just a few years ago because of the low deployment rate. However, the recent proliferation of wireless systems has increased the possibility of coexistence, which will increase the rate of interference within the same system and between different systems. Interference degrades the actual system throughput, especially in high population zones such as train stations or urban areas. The use of the 5-GHz band is an effective solution to mitigate the influence of interference because most current wireless systems use the 2.4-GHz band. However, it is insufficient to handle the predicted increase in mobile traffic. Improving the spectral efficiency will be necessary to maintain high system throughput in high-density wireless system areas.

(3) Simplifying the setting and certification procedure:

When people start using a home network to communicate with things such as sensing devices, the number of wireless devices will drastically increase. The setting procedures may be very complex for users because they differ according to the wireless system. It is necessary to create a mechanism that does not require the user to implement any setting procedures. Thus, both the settings and the certification procedure will need to be simplified in future wireless access systems.

When the above issues are resolved, users can deploy and extend their wireless home network without concerns for the security and reliability of the wireless network. The next section reviews the research and development (R&D) of the wireless home network underway at NTT Network Innovation Laboratories.

## 3. R&D of user-centric wireless home network

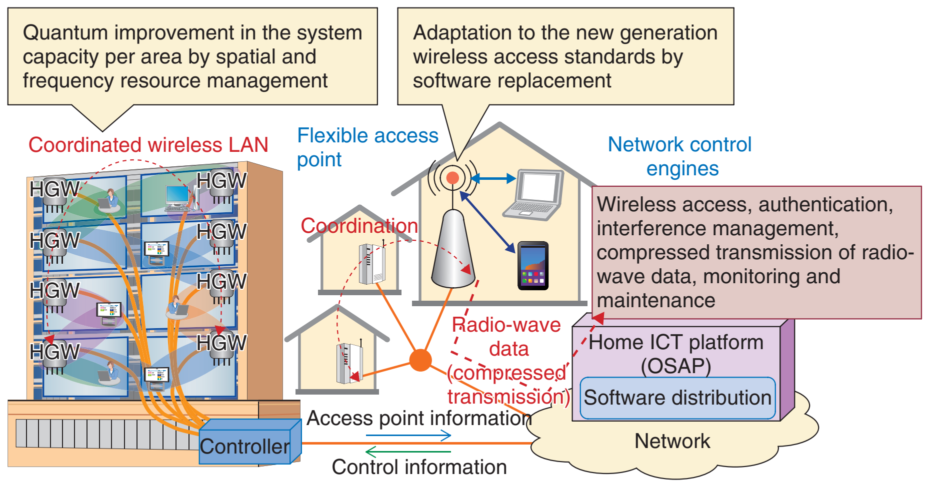
To address the issues described in the previous section, NTT Network Innovation Laboratories is developing a user-centric wireless home network. Its key concepts are detailed below.

The user-centric wireless home network allows people to use any applications and devices without concern for wireless connectivity. It enables users to: (1) select wireless devices without worrying about connectivity to their home network, (2) operate devices without having to set them first to avoid interference, and (3) carry out certification procedures with reduced complexity. These benefits are described in more detail as follows:

(1) Wireless device selection without worrying about connectivity to their own home network:

The user-centric wireless home network provides a platform that enables users to deploy arbitrary wireless systems for various purposes, e.g., the Internet for data communication, a wireless headset and mike for sound communication, and sensing devices for monitoring home equipment, without worrying about connectivity to their own home network. These features are enabled by the use of software technology for processing radio signals and by a flexible access point (AP), which supports a wide variety of wireless systems. Since the flexible AP can be used for new standards by updating the radio signal processing software at the network server, users do not need to buy new access points for new wireless devices. Thus, users can select their wireless devices without ever worrying about the connectivity.

(2) No need to input settings or operations in




HGW: home gateway
ICT: information and communications technology
OSAP: OSGi Service Aggregation Platform

Fig. 3. User-centric wireless home networks.

devices to avoid interference

Interference within the same system as well as between different systems can be suppressed by employing the wireless access platform where beam patterns and channels at multiple APs are coordinated and controlled over the network. Moreover, by adaptively changing beam patterns and channels according to the environment changes, spectrum resources can be effectively shared by multiple wireless systems. This increases the capacity per area even when multiple wireless systems coexist in the same area. Therefore, users need not worry about interference from other systems.

(3) Simplified certification

The certification procedure in the user-centric wireless home network is triggered by the network, whereas it is triggered by the network terminals in current general wireless systems. This new procedure reduces the complexity of certification, especially in M2M networks, where users do not directly operate the devices, and in short-range wireless access systems with very high throughput using millimeter-wave bands.

The key technology to realize the user-centric wireless home network is the control of APs over the network with secure and reliable access. R&D is being conducted to implement the architecture of AP network control as shown in **Fig. 3**, where remotely controlled functions such as the certification and interference avoidance are handled by network control. The functions at the network control engine utilize the OSGi (Open Services Gateway initiative) technology of the next-generation home network platform [2].

The Feature Article in this issue entitled "Public Wi-Fi Services at NTT DOCOMO," [3] introduces the current services and development activities underway at NTT DOCOMO to improve the user experience for mobile users. The next three Articles introduce technologies that support the user-centric wireless home network. "High-speed Wireless LAN for Broadband Wireless Home Networks" [4] describes technology to manage interference while coordinating multiple APs. "Flexible Wireless System for User-centric Wireless Home Network" [5] describes technology that makes it possible to avoid having to use individual APs for various wireless systems. "Scalable M2M Wireless Access System" [6] describes technology that enables access to/from anything.

## References

[1] K. Nagata, Y. Kojima, T. Hiraguri, and Y. Takatori, "Wireless Local Area Network Standardization of IEEE 802.11 and the Wi-Fi Alliance," NTT Technical Review, Vol. 8, No. 4, 2010.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201004gls.html

[2] T. Yamazaki, A. Kawanobe, T. Nunobiki, K. Obana, T. Yahara, K. Mizuno, K. Nakamura, Y. Koike, Y. Mihara, and T. Orisaka, "Home ICT Framework Technology that Provides Easy, Safe, Reliable, and Convenient Home ICT Services," NTT Technical Journal, Vol. 22, No.

5, pp. 23–27, 2010 (in Japanese).

[3] T. Ninagawa and K. Hirama, "Public Wi-Fi Initiatives at NTT DOCOMO," NTT Technical Review, Vol. 11, No. 3, 2013.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201303fa2.html

[4] T. Ichikawa, K. Ishihara, T. Murakami, B. A. Hirantha Sithira Abeysekera, Y.Asai, Y.Takatori, and M.Mizoguchi, "High-speed Wireless LAN for Broadband Wireless Home Networks," NTT Technical Review, Vol. 11, No. 3, 2013.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201303fa3.html

[5] S. Yoshino, T.Kaho, H.Shiba, H.Toshinaga, T. Yamada, M. Kobayashi, and Y.Shirato, "Flexible Wireless System for User-centric Wireless Home Network,"NTT Technical Review, Vol. 11, No. 3, 2013.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201303fa4.html

[6] M. Harada, T.Kumagai, Y. Shimizu, K. Suzuki, N. Mochizuki, Y.Fujino, and A.Yamagishi, "Scalable M2M Wireless Access System,"NTT Technical Review, Vol. 11, No. 3, 2013.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201303fa5.html

**Yasushi Takatori**

Senior Research Engineer, Supervisor, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. degree in electrical and communication engineering and the M.E. degree in system information engineering from Tohoku University, Miyagi, in 1993 and 1995, respectively, and the Ph.D. degree in wireless communication engineering from Aalborg University, Denmark, in 2005. He joined NTT in 1995. He served as a co-chair of COEX Adhoc in IEEE TGac from 2009 to 2010. He was a visiting researcher at the Center for TeleInFrastruktur, Aalborg University, from 2004 to 2005. He received the Young Engineer's Award from the Institute of Electronics, Information and Communication Engineers (IEICE) in 2000, and the Best Paper Award of IEICE in 2011. He is a senior member of IEICE and a member of IEEE.

**Masato Mizoguchi**

Senior Manager, R&D Produce Group, NTT Department III (R&D Strategy Department).

He received the B.E. and M.E. degrees in electrical engineering from Tokyo University of Science in 1989 and 1991, respectively. Since joining NTT in 1991, he has mainly been engaged in R&D of the personal handy-phone system (PHS) and high data rate wireless LANs such as those covered by IEEE 802.11a. Since 2004, he has been working in the R&D Planning Team for comprehensive commercialization functions. He received the Young Researcher's Award and the Best Paper Award from IEICE in 1998 and 2000, respectively. He is a member of IEICE and IEEE.

**Kazuhiro Uehara**

Senior Research Engineer, Supervisor, Group Leader, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E., M.E., and Ph.D. degrees from Tohoku University, Miyagi, in 1987, 1989, and 1992, respectively. In 1992, he joined NTT and engaged in research on array antennas, active antennas, and indoor propagation in the millimeter-wave and microwave frequency bands. From 1997 to 1998, he was a Visiting Associate at the Department of Electrical Engineering, California Institute of Technology, USA. From 2003 to 2010, he was a part-time lecturer at the Department of Electrical Engineering, Tohoku University. His current interests include R&D of software defined radio and cognitive radio systems and millimeter-wave multi-gigabit wireless systems. He is currently serving as Chair of the Technical Committee on Software Radio, IEICE Communication Society. He served as a General Co-Chair of the 6th International Conference on Cognitive Radio Oriented Wireless Networks and Communications, CrownCom, in May 2011. He was a Guest Editor-in-Chief of the Special Section on Wireless Distributed Networks, IEICE Transactions on Communications, December 2010. He received the Young Engineer's Award and Excellent Paper Award from IEICE in 1995 and 1997, respectively, the 1st YRP (Yokosuka Research Park) Award in 2002, and the 18th Telecom System Technology Award from the Telecommunications Advancement Foundation in 2003, respectively. He is a senior member of IEEE and IEICE.

**Shuichi Yoshino**

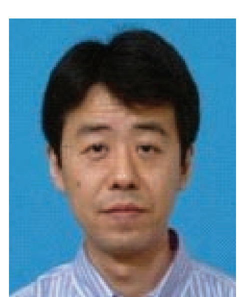
Senior Research Engineer, Supervisor, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees in mechanical engineering from Kanazawa University, Ishikawa, in 1990 and 1992, respectively. He joined NTT in 1992 and worked on satellite Internet system and wireless networking technology development. He is currently engaged in R&D on wireless technology for ubiquitous services.

**Mitsuru Harada**

Senior Research Engineer, Supervisor, Group Leader of Wireless Communication Circuits Research Group, Smart Devices Laboratory, NTT Microsystem Integration Laboratories.

He received the B.S. and M.S. degrees in physics from Tsukuba University, Ibaraki, in 1985 and 1987, and the Ph.D. degree in electronic engineering from Tohoku University, Miyagi, in 2003. In 1990, he joined NTT Atsugi Electrical Communication Laboratories, where he engaged in research on thin-film SOI devices. Since 1997, he has been researching high-speed/low-power CMOS circuits for wireless terminals.



**Kazuyasu Okada**

Director, Vice President, Wireless System Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. degree from Hokkaido University in 1983. Since joining Nippon Telegraph and Telephone Public Corporation (now NTT) in 1983, he has been engaged in R&D of satellite transponder and satellite communication systems. He moved to NTT Communications in 2001 and served as a project manager on a high-speed satellite access service for ships. He moved to NTT Network Innovation Laboratories and took up his current position in April 2008. He received the Young Engineer's Award from IEICE in 1991.

# Public Wi-Fi Initiatives at NTT DOCOMO

*Tetsuya Ninagawa and Kosuke Hirama*

**Abstract**

Smartphone use and data traffic have increased dramatically, and to cope with this, NTT DOCOMO is placing increasing importance on Wi-Fi services with the aim of raising customer satisfaction and accelerating data offloading to reduce network load. This article outlines NTT DOCOMO's public Wi-Fi service and introduces *expanded coverage, free-access campaign,* and *enhanced convenience* as specific examples of how NTT DOCOMO is promoting Wi-Fi use among its customers.

## 1. Overview of Wi-Fi environment

The recent spread of smartphones in society has led to an increasing number of customers using devices equipped with Wi-Fi functions. In response to this trend, NTT DOCOMO is paying increasing attention to Wi-Fi with the aim of providing a comfortable communications environment and raising customer satisfaction.

At the same time, mobile data traffic has been increasing year on year in parallel with this proliferation of smartphones. At NTT DOCOMO, traffic is slated to increase by about 12 times by fiscal year 2015 compared to 2011 levels [1]. To respond effectively to this dramatic increase in traffic, NTT DOCOMO's plan is to provide high-quality communications by expanding capacity through a migration to Xi (crossy) LTE (Long Term Evolution) services, adopting smaller zones, controlling the transmission speeds of heavy users, and reducing network load through use of Wi-Fi (data offloading).

## 2. Features of docomo Wi-Fi

NTT DOCOMO launched its Mzone public Wi-Fi service in 2002. It was initially assumed that this service would be used for data communications via personal computers. Positioned as a complement to FOMA 3G (third generation) circuits, Mzone marked the start of the provision of a high-speed communication service, although the locations providing Mzone were initially limited. Then, with the aim of enhancing convenience and increasing usage, NTT DOCOMO launched domestic roaming for Mzone in 2003, international roaming and the establishment of Wi-Fi locations within subway stations in 2004, and use within railway cars in 2006. In addition, the service name was changed to docomo Wi-Fi in 2012.

To provide service in more locations, docomo Wi-Fi makes frequent use of shared access points installed by NTT Broadband Platform Incorporated (NTT BP) for more efficient operations. Given that NTT DOCOMO and other Wi-Fi providers are expanding their Wi-Fi coverage, the renting and sharing of NTT BP's access points in this way prevents the inefficient construction of facilities by multiple providers at the same location while also avoiding the radio interference that would result from the operation of multiple access points.

## 3. Promotion of docomo Wi-Fi

As described above, NTT DOCOMO is placing increasing importance on Wi-Fi with the aim of raising customer satisfaction and accelerating data offloading. Specifically, the company is undertaking a variety of initiatives to get even more customers to use and enjoy Wi-Fi under even more scenarios.

### 3.1 Expanded coverage

As of the end of March 2012, docomo Wi-Fi use was available at around 8400 access points

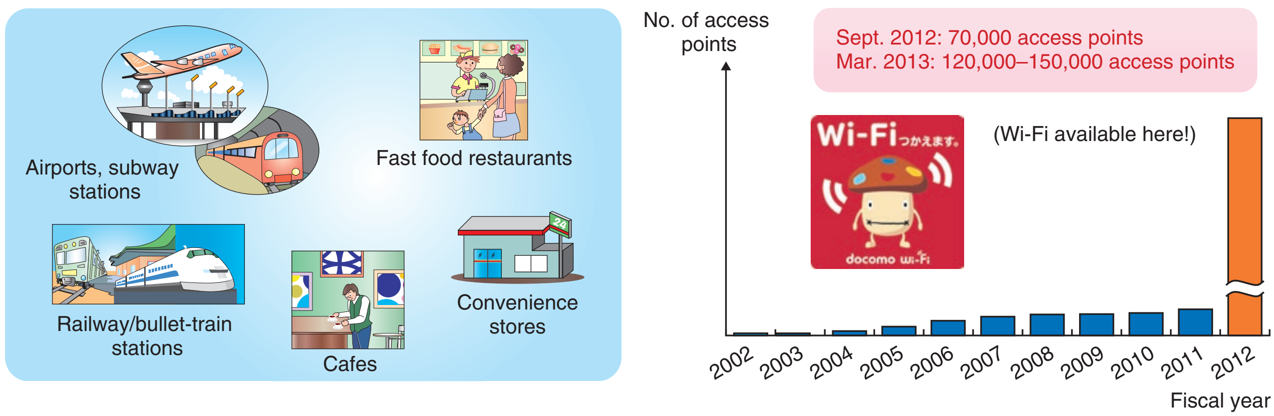



Fig. 1. docomo Wi-Fi locations and number of access points.

throughout Japan mainly in train stations, airports, cafes, fast food restaurants, and convenience stores. Since then, NTT DOCOMO has been working to expand Wi-Fi locations to commercial facilities and small eating and drinking establishments and has rapidly increased the number of access points to 70,400 as of the end of September 2012. The plan is to continue with this expansion of Wi-Fi coverage (**Fig. 1**). In this expansion, NTT DOCOMO selects the optimum method of installing an access point at a certain location in collaboration with NTT BP from the viewpoints of quality and prompt deployment. For example, either an optical circuit or Xi circuit can be used as a backhaul line depending on the volume of Wi-Fi traffic estimated for the location in question. In short, optical circuits can ensure sufficient bandwidth for high traffic locations, while using Xi circuits for small eating and drinking establishments can facilitate the prompt expansion of Wi-Fi locations.

### 3.2 Free-access campaign

For NTT DOCOMO customers, the docomo Wi-Fi service is mainly provided as an optional ISP service such as sp-mode and mopera at a monthly fee of 315 yen (tax included). Customers can apply for docomo Wi-Fi at docomo shops or by telephone, personal computer, sp-mode, etc. Individuals not having an NTT DOCOMO circuit or ISP contract can use docomo Wi-Fi for a monthly fee of 1575 yen (tax included).

To further promote the use of docomo Wi-Fi, NTT DOCOMO is conducting a *free-access forever* campaign from September 1, 2012 to March 31, 2014 in which the monthly fee of 315 yen will be waived for customers subscribing to a designated packet flat-rate service, an ISP service, and an ISP optional service. These customers will continue to receive free access even after the campaign period ends provided that they continue to satisfy applicable conditions.

### 3.3 Enhanced convenience

Since most docomo Wi-Fi users access the service not from personal computers but from smartphones and tablets, we started providing an app called *docomo Wi-Fi simple connect* for Android smartphones and tablets in January 2012. With this app, there is no need for customers to make service set identification (SSID) or security settings on their own at the startup of service, and ID/password settings for connecting to docomo Wi-Fi are greatly simplified. The app enables a customer at a docomo Wi-Fi location to connect to the service by simply tapping a docomo Wi-Fi widget on the screen. This app has significantly improved the ease of using docomo Wi-Fi (**Fig. 2**).

## 4. Future activities

Wi-Fi is becoming all the more important for making the communications environment even more comfortable and enjoyable for users. At the time of the Great East Japan Earthquake in March 2011, the NTT Group made Wi-Fi access points available free of charge in the stricken area. In the same way, NTT DOCOMO is working to make docomo Wi-Fi available at the time of a disaster as a network that complements FOMA and Xi. In addition, docomo Wi-Fi already provides a filtering function that restricts access to potentially harmful sites, and in the future, NTT DOCOMO plans to expand its efforts in

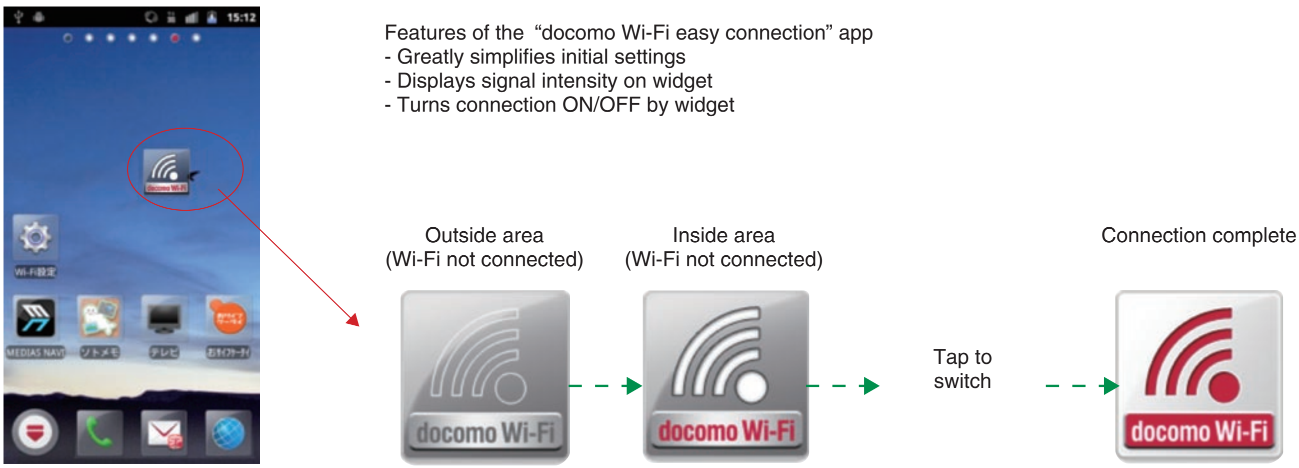



Fig. 2. Features of the *docomo Wi-Fi simple connect* app.

attracting even more customers to docomo Wi-Fi by setting up an environment in which Wi-Fi can be used in a safe and secure manner and improving its affinity with FOMA and Xi services.

## Reference

[1] NTT DOCOMO Medium Term Vision 2015 Report. http://www.nttdocomo.com/about/core_foundation/core_foundation.pdf

**Tetsuya Ninagawa**
Director, Ubiquitous Services Department, NTT DOCOMO.
He joined NTT Mobile Communications Network (now NTT DOCOMO) in 1993 and worked on network planning and corporate strategies. He is currently engaged in planning of public and in-house Wi-Fi services.

**Kosuke Hirama**
Manager, Ubiquitous Services Department, NTT DOCOMO.
He joined NTT DOCOMO in 2000 and worked on development of 2G and 3G packet communication core networks. He is currently engaged in planning of the public Wi-Fi service.

# High-speed Wireless LAN for Broadband Wireless Home Networks

*Takeo Ichikawa, Koichi Ishihara, Tomoki Murakami, B. A. Hirantha Sithira Abeysekera, Yusuke Asai, Yasushi Takatori, and Masato Mizoguchi*

**Abstract**

This article introduces cooperative transmission techniques for wireless local area networks (WLANs) to mitigate interference between neighboring wireless home networks by establishing the cooperation of multiple WLAN access points (APs) on the next-generation home ICT (information and communications technology) platform. The cooperative transmission techniques achieve stable transmission of video data (such as for high-definition televisions (TVs)) and data traffic offloading of mobile devices such as smartphones from cellular networks to fixed broadband networks.

## 1. Introduction

The number of digital network-capable devices used in homes has rapidly been increasing in recent years due to the digitization of consumer electronics appliances such as televisions (TVs), video recorders, cameras, and music players. Furthermore, new digital devices such as digital photo frames, tablet personal computers (PCs), and smartphones are becoming more and more popular. This trend is expected to increase further in the near future with the introduction of various kinds of sensor terminals. Wireless local area networks (WLANs) can be used to connect these various devices to broadband networks without the need for cables. This convenience has led to the rapid increase in the use of WLANs in homes as well as in offices.

However, the rapid growth in the use of smartphones is causing congestion in cellular networks. One solution is traffic offloading to WLANs. Cellular operators are expanding the areas where public WLANs are available by introducing WLAN access points (APs) that are capable of not only 2.4-GHz-band but also 5-GHz-band transmission, and are distributing APs to their users.

This article first describes the evolution and challenges of WLAN and then introduces the cooperative transmission techniques that NTT Network Innovation Laboratories is developing for the next-generation WLAN.

## 2. Evolution and challenges of wireless LAN

The first international WLAN standard was introduced in 1997 in Institute of Electrical and Electronics Engineers (IEEE) 802.11, which covered the use of the 2.4-GHz band. This band is called the ISM (industrial, scientific, and medical) band and is used for medical and industrial equipment such as microwave ovens (even those used in the home). In this band, a radio license is not required worldwide if the radio transmission power is less than the regulation value. The 5-GHz band is addressed in new wireless LAN standards IEEE 802.11a and IEEE 802.11n. In the 5-GHz band, no interference occurs from microwave ovens in the home.

In the latest WLAN standard, IEEE 802.11n, the channel width for wireless data transmission is 20 or 40 MHz; this means that there are 3 channels or 1 channel in the 2.4-GHz band and 19 or 9 channels in the 5-GHz band. Because the number of installed APs has increased, the number of channels has become insufficient in the 2.4-GHz band. Therefore, the use of the 5-GHz band is increasing. Mobile devices such

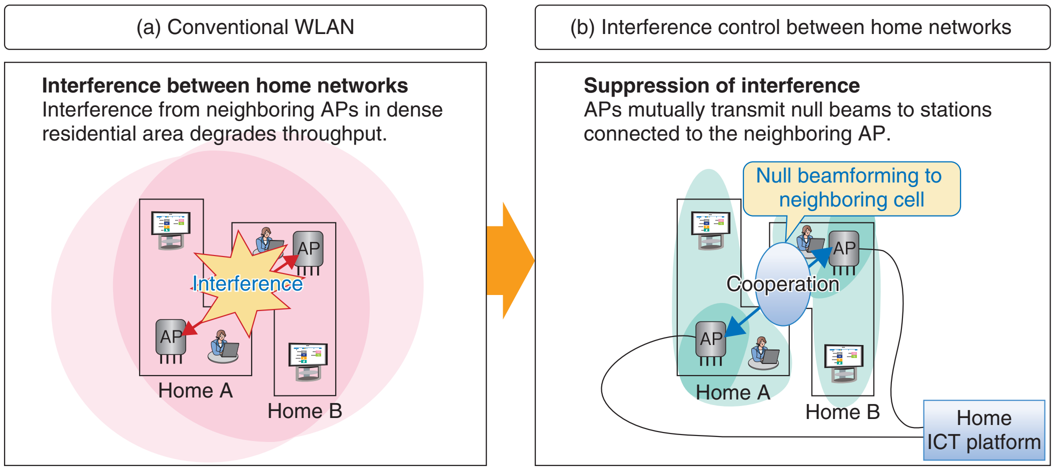



Fig. 1. Interference control between home networks.

as smartphones are now being developed that have multi-band capability (5-GHz band and 2.4-GHz band).

However, the next generation WLAN standard, IEEE 802.11ac, which targets system throughputs above 1 Gbit/s and uses the 5-GHz band, is currently being drafted by the IEEE 802.11 working group. In IEEE 802.11ac, the channel width will be 80 or 160 MHz in order to achieve higher throughput. For this reason, the number of channels in the 5-GHz band is being reduced to 2 or 4, and consequently, the number of channels in this band is expected to be insufficient in the near future, just as in the 2.4-GHz band.

## 3. Cooperative transmission techniques for wireless LAN

To accommodate the ever-increasing traffic, it is necessary to further improve the frequency utilization efficiency. We are developing cooperative transmission techniques for WLAN to improve frequency utilization efficiency and achieve stable wireless data transmission through the cooperation of multiple APs using the next-generation home ICT (information and communications technology) platform. In this section, we introduce cooperative transmission techniques for WLAN that consist of interference control between home networks, multi-user multi-channel control, and network control.

### 3.1 Interference control between home networks

Problems caused by interference between home networks due to the spread of WLAN is becoming apparent in public areas such as train stations and in dense residential areas such as areas with many apartments, where neighboring APs use the same channel because of the paucity of channels. In the IEEE 802.11ac specifications, as mentioned above, the number of channels will be reduced to 2 or 4 because the channel width is 80 MHz (mandatory) or 160 MHz (optional), which means that interference between home networks is likely to occur in the 5-GHz band in the near future. Given that two APs using the same channel are adjoining, each home network will have only half the average throughput of conventional WLAN because the channel is shared by time division multiple access based on the carrier sense multiple access with collision avoidance (CSMA/CA) protocol (**Fig. 1**).

We are developing an interference control technique as one solution to the interference problem. This technique links multiple APs by network transmission signals to achieve the cooperation of the APs via the beamforming technology of multi-user multiple-input multiple-output (MU-MIMO) transmission.

MU-MIMO, which is a new technology for wireless broadband communication, is expected to be adopted in IEEE 802.11ac as an option (**Fig. 2**) [1]. It achieves high frequency-utilization efficiency by sending data to multiple stations (STAs) over a single channel at the same time by controlling the directional characteristics of the radio signals by using beamforming control technology so the signals do not interfere with each other. We developed a wireless

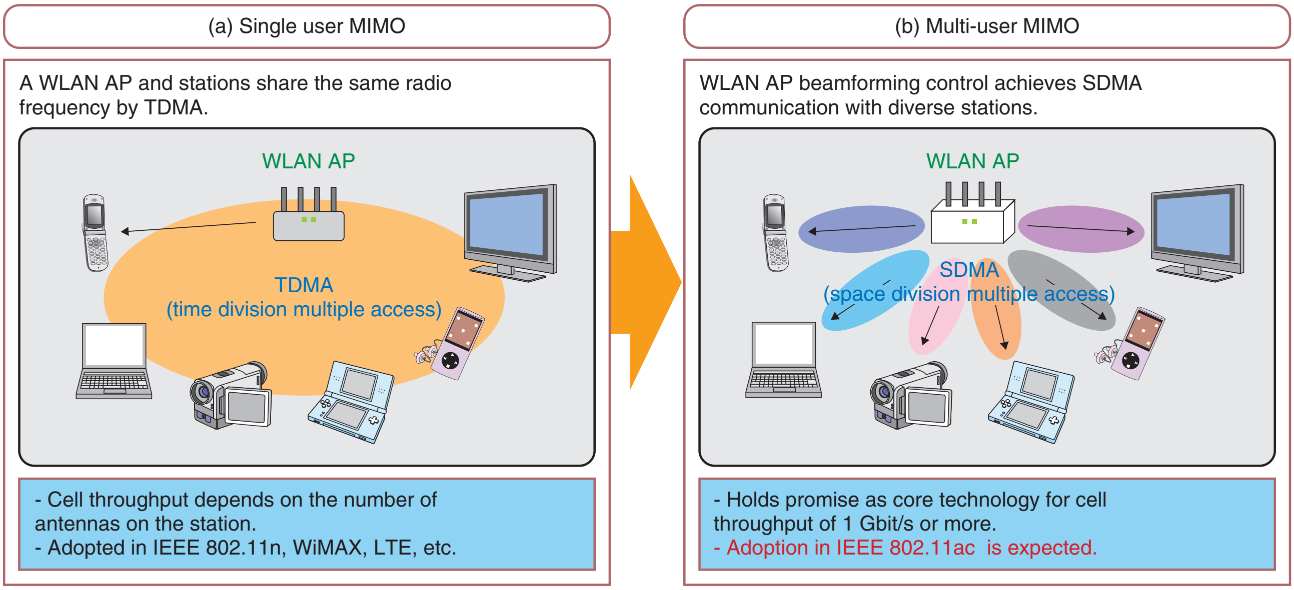
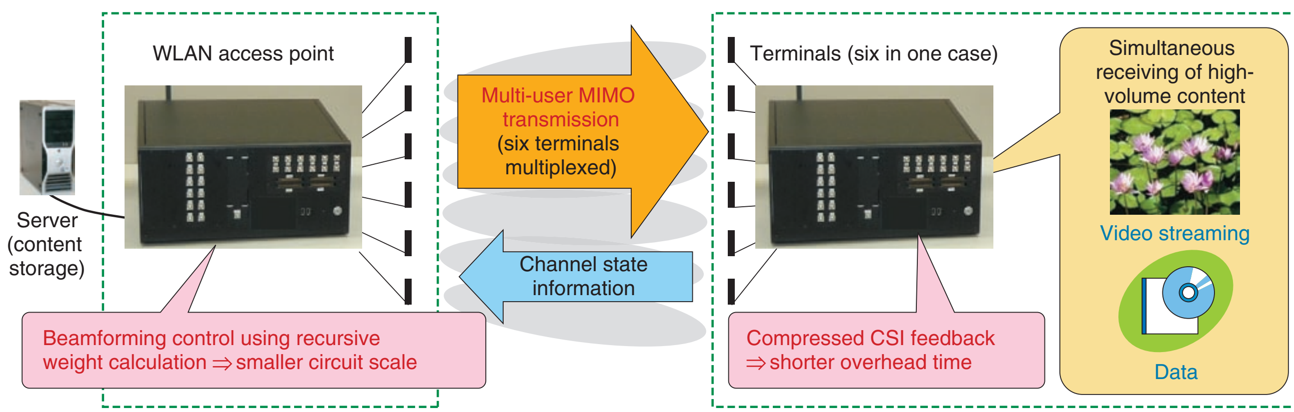



Fig. 2. Multi-user MIMO technique.




| | |
|---|---|
| Stations | Up to 6 |
| Transmission streams | Up to 6 |
| Bandwidth | Up to 80 MHz |
| Per-stream data rate (physical layer) | Up to 270 Mbit/s |
| Total data rate (physical layer) | Up to 1.62 Gbit/s |
| Data transmission rate | Up to 1.37 Gbit/s |

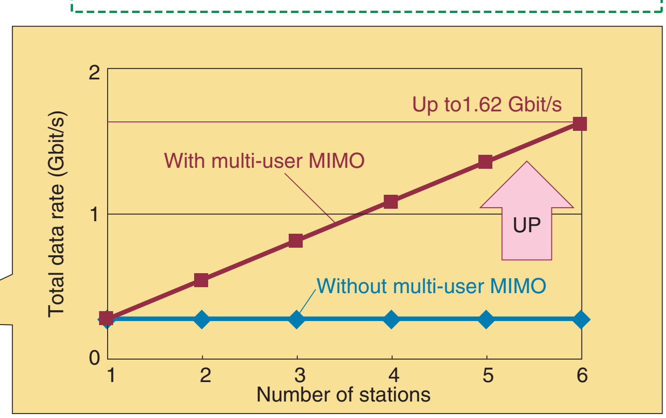
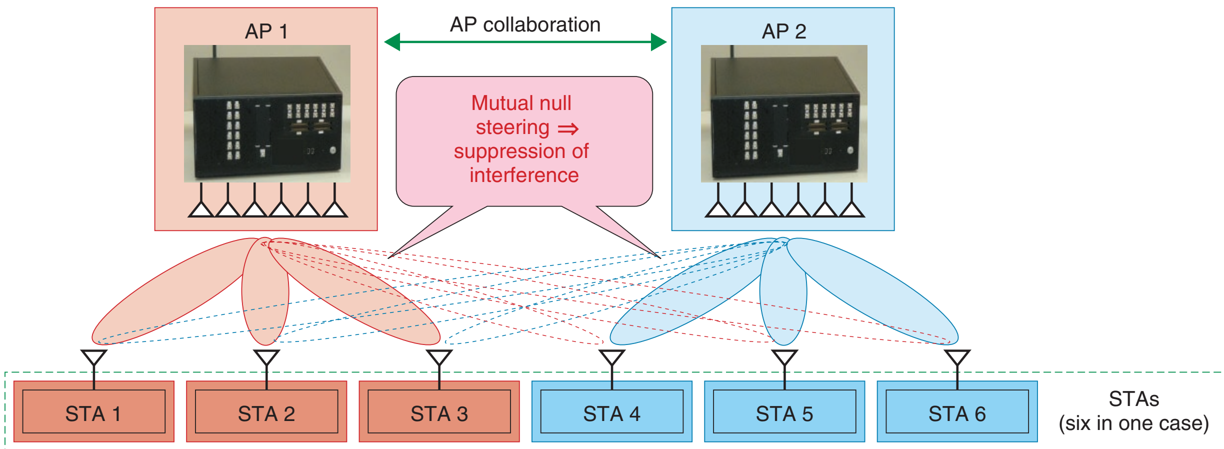



Fig. 3. Multi-user MIMO transmission prototype.




| Bandwidth | 80 MHz |
|---|---|
| Number of APs | 2 |
| Number of AP antennas | 6 |
| Number of STAs associated with AP | 3 |
| Number of STA antennas | 1 |

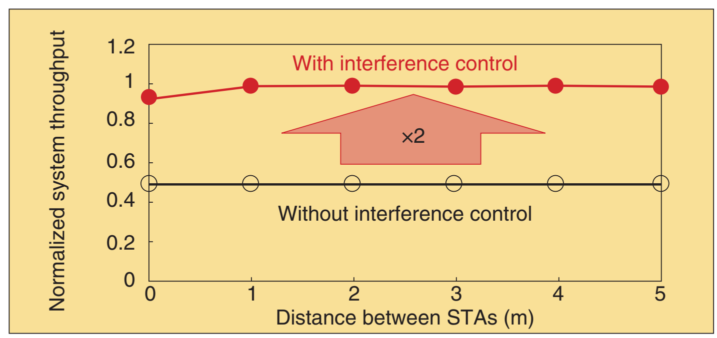



Fig. 4. Prototype of interference control system between home networks.

transmission prototype that employs MU-MIMO transmission, and succeeded in transmitting data in real time to six STAs at more than 1 Gbit/s for the first time in the world (**Fig. 3**) [2]–[4].

The interference control between home networks is an extension of the beamforming technology of MU-MIMO. An AP sends data to multiple STAs in its home network without letting signals interfere with the neighboring home network by controlling the directional characteristics of the radio signals, so that two APs in each home network can send data to their STAs over the same channel at the same time without interference. As a result, the throughput is approximately double that of the conventional CSMA/CA method (**Fig. 4**) [5].

### 3.2 Multi-user multi-channel control

APs specified in IEEE 802.11ac can perform high-speed communication using the 160-MHz-bandwidth channel as an option. In addition, to ensure compatibility with the conventional IEEE 802.11a and 802.11n protocols, the APs communicate with IEEE 802.11a-specified STAs using 20-MHz-bandwidth channels and with IEEE 802.11n STAs using channels up to the 40-MHz-bandwidth channel. Therefore, when an IEEE 802.11ac-specified AP uses a 20-MHz-bandwidth channel to transmit data to an IEEE 802.11a STA, the frequency utilization efficiency degrades because the 140-MHz band is unused.

As one solution, we are developing a multi-user multi-channel control technique in which the AP allocates a communication channel to each STA using 20-MHz-bandwidth units and transmits data to each STA simultaneously by frequency division multiplexing (**Fig. 5**). This new technique achieves efficient use of frequency resources by transmitting data to each STA using 20-MHz- and 120-MHz-bandwidth channels at the same time. If there is only one active STA in a home network, the AP may use just the 20-MHz-bandwidth channel to communicate with the STA. In this case, by synchronizing the timing of data transmission with the neighboring AP, the AP and the neighboring AP can transmit data via the 20-MHz- and 120-MHz-bandwidth channels at the same time.

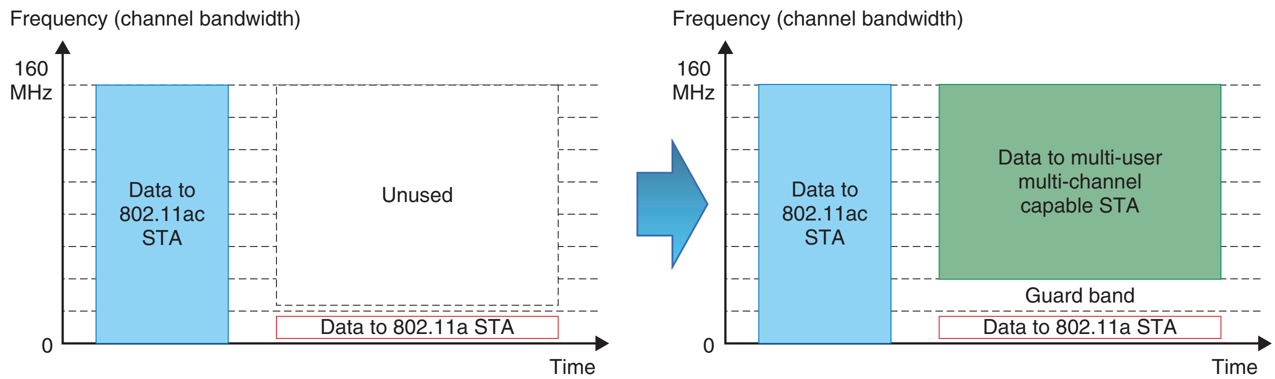



Fig. 5. Multi-user multi-channel control.

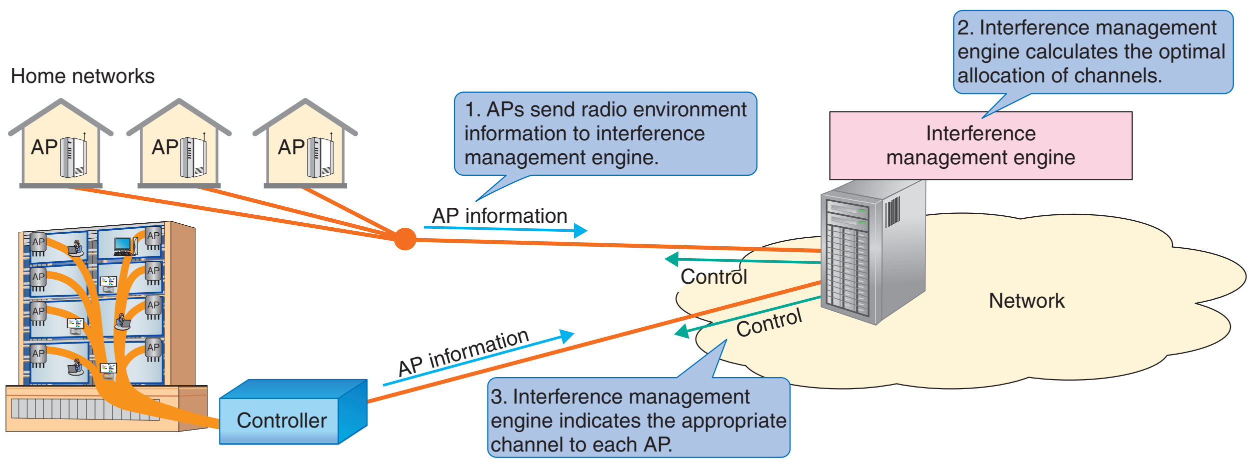



Fig. 6. Network control for wireless LAN.

### 3.3 Network control for wireless LAN

As mentioned above, the WLAN uses the CSMA/CA method as the medium access control scheme. Because CSMA/CA is based on autonomous distributed control, WLAN users can build a wireless home network simply by using the AP; the channels are selected freely by the users. However, in dense residential areas such as neighborhoods with many apartment buildings, a problem may occur where optimal allocation of channels used by each AP is not performed, and frequency resources are not used effectively.

One solution that we are working on is a network control technique for WLAN in which an interference management engine is set on the broadband network. This engine collects information on the radio environment such as channel utilization rates from each AP, calculates the optimal allocation of channels, and informs each AP of the appropriate channel (**Fig. 6**). This technique enforces optimal channel usage automatically. In addition, techniques to provide a synchronization signal from the Ethernet-based network, called synchronous ethernet (SyncE), and precision time protocol (PTP), have been standardized. These techniques can achieve frequency, phase, and time synchronization between APs, which is expected to make interference control between home networks more accurate by synchronizing the frequency and phase of radio signals transmitted by the APs.

## 4. Conclusion

WLAN is widely used today and has advanced considerably since it first came into use. These networks are continuing to evolve and to achieve higher speed, larger capacity, and greater functionality that will enable them to accommodate various data services in homes, offices, and public areas.

## References


[1] Q. H. Spencer, C. B. Peel, A. L. Swindlehurst, and M. Haardt, "An introduction to the multi-user MIMO downlink," IEEE Communication Magazine, Vol. 42, No. 10, pp. 60–67, 2004.

[2] NTT news release: World's First Successful Multiuser-MIMO (MU-MIMO) Transmission Above 1 Gbit/s, May 2010. http://www.ntt.co.jp/news2010/1005e/100507a.html

[3] T. Ichikawa, Y. Asai, and M. Mizoguchi, "World's First Successful 1 Gbit/s Multi-user MIMO Wireless Transmission," ITU-AJ New Breeze, Vol. 23, No. 1, Winter 2011.

[4] K. Ishihara, Y. Asai, R. Kudo, T. Ichikawa, and M. Mizoguchi, "Indoor experiments on real-time multiuser MIMO transmission in wireless LAN systems," Proc. of the 2012 IEEE Wireless Communications and Networking Conference (WCNC 2012), pp. 147–151, Paris, France.

[5] T. Murakami, R. Kudo, Y. Asai, T. Kumagai, and M. Mizoguchi, "Performance evaluation of distributed multi-cell beamforming for MU-MIMO systems," Proc. of the 8th IEEE International Symposium on Wireless Communication Systems (ISWCS 2011), pp. 547–551, Aachen, Germany.


**Takeo Ichikawa**

Senior Research Engineer, Supervisor, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees in electrical engineering from Waseda University, Tokyo, in 1991 and 1993, respectively. Since joining NTT in 1993, he has participated in R&D of PHS-based packet systems and high-speed wireless LAN systems. He received the Young Researcher's Award from the Institute of Electronics, Information and Communication Engineers (IEICE) in 1999. He is a member of IEICE and IEEE.

**Koichi Ishihara**

Researcher, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E., M.E., and Ph.D. degrees in communications engineering from Tohoku University, Miyagi, in 2004, 2006, and 2011, respectively. Since April 2006, he has been with NTT Network Innovation Laboratories. His current research interests include digital signal transmission techniques for broadband wireless and fiber-optic communication systems. He received the Young Engineer's Award from IEICE in 2009 and the 2011 IEICE RCS (Radio Communication Systems) Active Research Award in 2011. He is a member of IEICE and IEEE.

**Tomoki Murakami**

Researcher, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees from Waseda University, Tokyo, in 2006 and 2008, respectively. He joined NTT Network Innovation Laboratories in 2008. His current research interests include multiuser MIMO systems and resource allocation. He received the Young Researcher's Award from IEICE in 2010. He is a member of IEICE and IEEE.

**B. A. Hirantha Sithira Abeysekera**

Researcher, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E., M.E., and Ph.D. degrees in communications engineering from Osaka University in 2005, 2007, and 2010, respectively. He joined NTT in 2010. His research interests include design and performance evaluation of next generation wireless networks. He received the IEEE VTS (Vehicular Technology Society) Japan Student Paper Award in 2009. He is a member of IEICE and IEEE.

**Yusuke Asai**

Senior Research Engineer, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees in information electronics from Nagoya University, Aichi, in 1997 and 1999, respectively. Since joining NTT in 1999, he has been engaged in R&D of broadband MIMO-OFDM techniques for wireless LAN systems. He has been participating in the IEEE 802.11 working group and is one of the co-chairpersons of the coexistence ad-hoc group in task group ac. He received the Young Researcher's Award from IEICE in 2004. He is a member of IEEE.

**Yasushi Takatori**

Senior Research Engineer, Supervisor, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. degree in electrical and communication engineering and the M.E. degree in system information engineering from Tohoku University, Miyagi, in 1993 and 1995, and the Ph.D. degree in wireless communication engineering from Aalborg University, Denmark, in 2005. He joined NTT in 1995. He served as a co-chair of COEX Adhoc in IEEE TGac from 2009 to 2010. He was a visiting researcher at the Center for TeleInFrastruktur, Aalborg University, from 2004 to 2005. He received the Young Engineer's Award from IEICE in 2000, and the Best Paper Award of IEICE in 2011. He is a senior member of IEICE and a member of IEEE.

**Masato Mizoguchi**

Senior Research Engineer, Supervisor, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees in electrical engineering from Tokyo University of Science in 1989 and 1991, respectively. He joined NTT in 1991 where he has mainly been engaged in R&D of personal communication systems and high data rate wireless LANs including the IEEE 802.11a systems. He received the Young Researcher's Award in 1998, the Best Paper Award in 2000, and the Achievement Award in 2006 from IEICE. He is a senior member of IEICE and a member of IEEE.

# Flexible Wireless System for User-centric Wireless Home Network

*Shuichi Yoshino, Takana Kaho, Hiroyuki Shiba, Hideki Toshinaga, Takayuki Yamada, Mamoru Kobayashi, and Yushi Shirato*

**Abstract**

We are developing a flexible wireless system with the aim of achieving a wireless home network that users can use without being aware of wireless systems and that will be easy for network operators to operate and maintain. This article introduces an overview of the flexible wireless system, use cases for it, and key technologies needed to achieve it.

## 1. Introduction

### 1.1 Current wireless networks

Recently, considerable progress has been made in developing broadband wireless local area networks (LANs) for the 2.4-GHz and 5-GHz bands, reviewing frequency usage in the 920-MHz band to expand machine-to-machine (M2M) communication applications, and improving home automation and home security technology for the 300-MHz and 400-MHz bands. Various wireless systems that utilize the characteristics of each frequency band have been developed. However, in order to use these systems in home networks, users need a certain degree of knowledge of wireless systems, and they need to carry out the following tasks:

1) Selecting a wireless system that suits their purposes
2) Configuring the system's access point (AP) and building the wireless network
3) Fixing hidden problems such as interference caused by APs or wireless terminals in the neighborhood

### 1.2 Future home networks

In future home networks, the use of information and communications technology (ICT) will make it possible to further advance the development of smart homes or smart communities that provide more varied and efficient home and social activities. At that time, it will be necessary for everyone, even those without wireless skills, to be able to use their wireless network easily. We are now researching and developing a flexible wireless system on a wireless home network that will make the above three tasks unnecessary.

An image of the wireless home network of the future, as well as that of a conventional system, is shown in **Fig. 1**. The future network features a single flexible AP that supports all wireless systems from low-speed ubiquitous data transmission systems to high-speed wireless LANs. This makes it unnecessary for users to select a wireless system and build their own wireless home network. Furthermore, through remote analysis of radio spectra and remote support of wireless operations, we can provide a user-centric wireless home network that will enable users to use devices and applications without being aware of the wireless systems the network accommodates.

## 2. Technical overview of the flexible wireless system

To enable users to effortlessly access and use wireless home network services without even being aware of the wireless systems their network accommodates, much less having to manage or monitor them, it is necessary to build a common signal processing

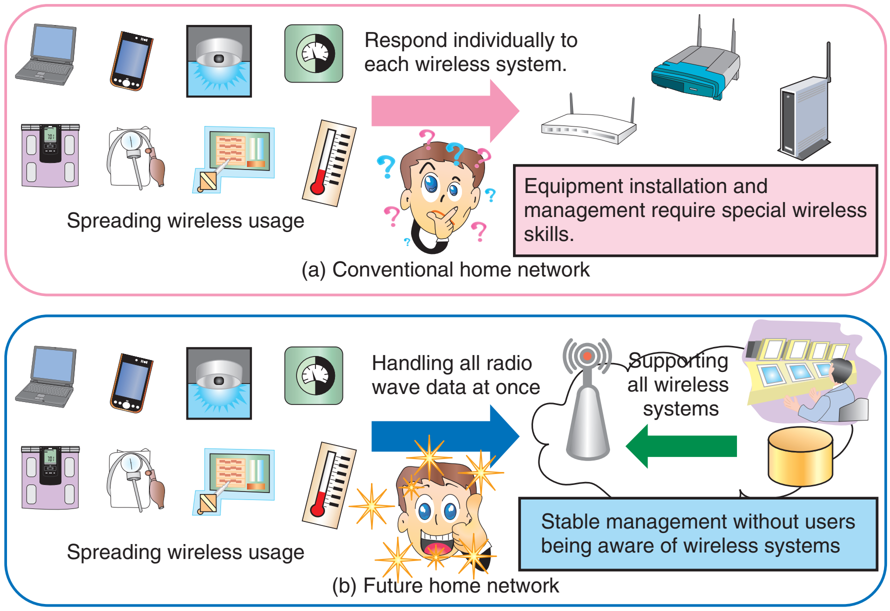



Fig. 1. Comparison of conventional and future home networks.

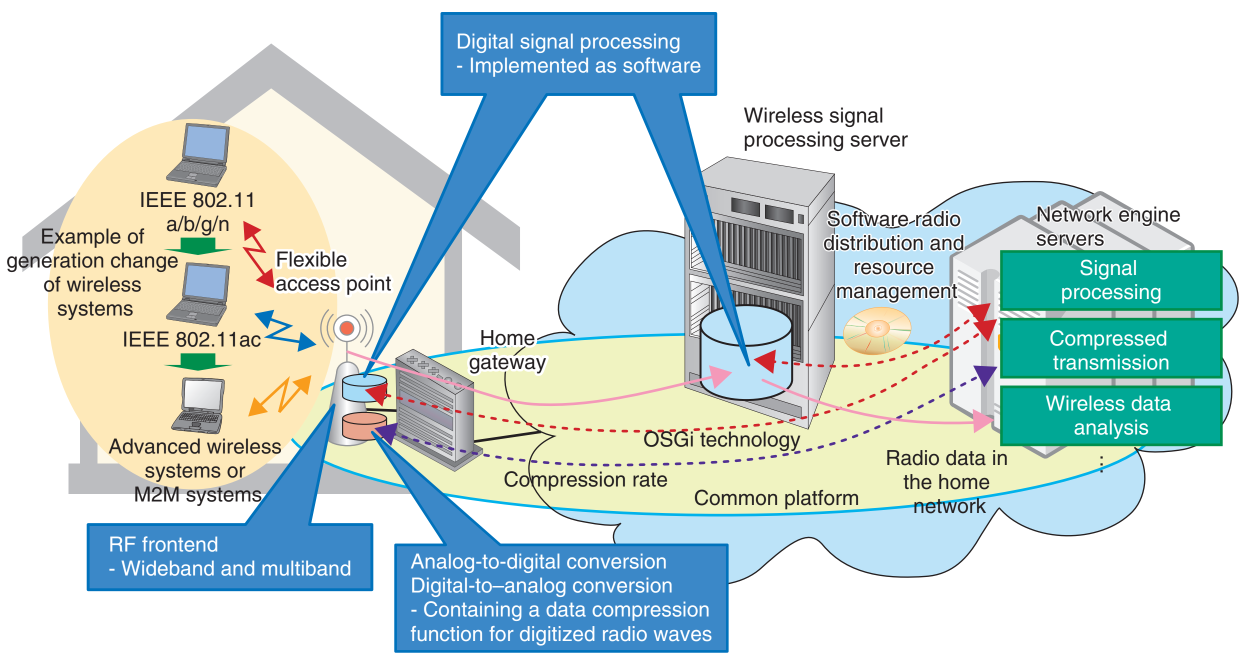



Fig. 2. System configuration.

platform that can accommodate a wide variety of wireless systems. The configuration of our flexible wireless system, which features such a platform, is shown in **Fig. 2**. The system comprises a flexible AP in the home network, a wireless signal processing server connected to the AP over the network, and engine servers to control them. In conventional wireless systems, an analog radio frequency (RF)

Table 1. Desired RF component performance.

| Item | Desired value |
|---|---|
| Frequency band | From 0.3 to 6 GHz |
| Receiving power | From –120 to +10 dBm |
| Power transmission | From –41 to +13 dBm |
| Independent gain control in each band | 90 dB |
| Spurious emission | –80 dBc |

frontend, an analog-digital converter (ADC)/digital-analog converter (DAC), and digital signal processing hardware are compressed into a single equipment unit. In our flexible wireless system, the analog RF frontend and ADC/DAC are incorporated into the flexible AP. The digital signal processing is performed through cooperation between the AP and the network server (**Table 1**). The system's wideband and multiband analog RF frontend, which allows multiple frequency bands to be used simultaneously, makes it possible for the single flexible AP to accommodate various wireless terminals regardless of what frequency bands are used.

Cooperative software in the flexible AP and the network server performs the digital signal processing that needs to be processed differently for each accommodated wireless system. In addition, correspondence between the diverse wireless systems and enhancements made to them later can be achieved merely by replacing the software. OSGi technology*1 makes it possible to replace the software in cooperation with the functions and services of the home gateway. Furthermore, the transmission to the network server of radio wave data received in the flexible AP makes it possible to balance the load of the signal processing resources under high load conditions and to analyze the home radio environment in the network. Since there is a huge amount of digitized radio wave data, the ADC's data compression function is deployed to transmit the data to the network server through fiber access networks. By aggregating the several nearby radio environments at the network, the system can analyze in detail hidden problems such as interference between different or identical systems. These distributed functions are controlled by the network engine servers, and this is what achieves the user-centric wireless home network.

## 3. Key technologies

In this section, we introduce two key technologies that have enabled the development of the flexible AP. One is wideband and multiband radio frequency circuits that can operate at frequencies from several hundred megahertz up to 6 GHz. The other is data compression of digitized radio waves.

### 3.1 Wideband and multiband radio frequency circuits

Recent wireless communication systems such as wireless LANs or cellular systems require unified terminals and APs that operate in several frequency bands. They also require wideband and multiband RF circuits. Reports have been published on systems using tunable band pass filters and multiband amplifiers [1]–[3]. Conventionally, there are two general system compositions: 1) those using a number of single-band circuits in parallel [4], and 2) those using wideband circuits and digitized wideband radio wave data. The former is advantageous in that it enables a number of commercial circuits to be used; however, the problem is that the number of circuits increases along with the number of frequency bands. The latter is advantageous in that it comprises only a small number of circuits; however, it requires a high-speed and expensive ADC that can process a huge amount of digitized radio wave data.

To overcome these problems, we developed a wideband low noise amplifier and a multiband simultaneous receiving mixer [5]. In contrast to conventional mixers that use a single local oscillator (LO) signal and receive a single RF signal, the mixer we developed uses multiple LO signals and receives multiple RF signals simultaneously, as shown in **Fig. 3**. Generally, multiband wireless systems require a wide dynamic range to handle multiple power levels with a relative difference of about 100 dB, which is caused

*1 OSGi technology: OSGi (Open Service Gateway initiative) is a standard framework for developing a Java-based module. It makes it possible to deploy a software component called a bundle, to run in conjunction with it. It has been standardized by the OSGi Alliance.

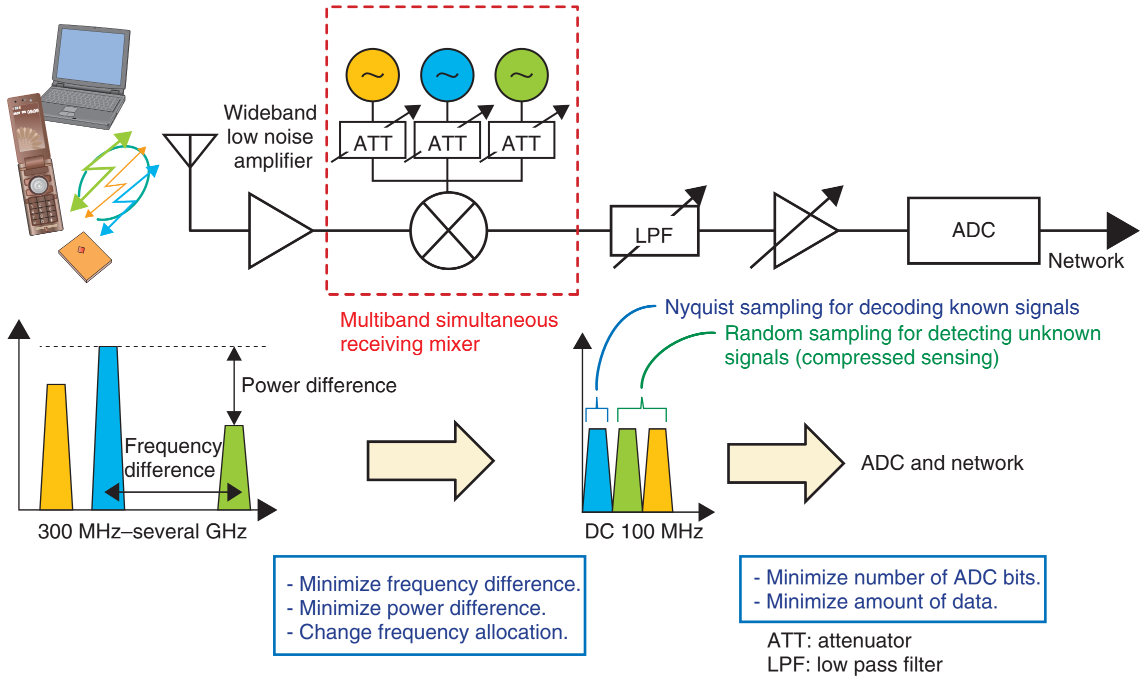



Fig. 3. Proposed multiband simultaneous receiver.

by the differences in terminal locations or transmission power levels of each wireless system. Our mixer can control the conversion gain for each frequency band independently by using variable attenuators to control the relative power of the multiple LO signals. This enables down-converted intermediate frequency (IF) signals to be controlled so that they all have the same power levels. This in turn enables the ADC to operate on fewer bits than for the case of a wide dynamic range receiver, which reduces the amount of radio wave data. The mixer can also change the frequency band allocation of the received signals; e.g., a signal to be demodulated is allocated to a lower frequency in the IF frequency band while others, such as power-sensing signals, are set in higher frequencies. This system configuration makes it possible to reduce the number of radio circuits and to produce a radio circuit that can be implemented in the batch digital signal processing of any wireless system.

### 3.2 Data compression of digitized radio waves

Broadband radio waves received in the flexible AP are digitized by an ADC so that they can be transferred to the digital signal processing server via fiber access networks. However, the amount of data in digitized radio waves becomes very large; for example, if an entire radio wave of the 2.4-GHz ISM (industrial, scientific, and medical) band*2 is digitized, the amount of data per second becomes 2 Gbits*3. Therefore, it is necessary to apply a data compression technique that can reduce the amount of data to between 1/100 and 1/1000 of the original amount in order to enable the digitized radio wave data to be transferred to the digital signal processing server via the access networks. To minimize the required bandwidth for transferring the radio wave data, we focus on a certain feature, i.e., the sparsity of radio wave data, and investigate data compression that makes use of compressed sensing technology [6].

An overview of the compressed sensing technology is shown in **Fig. 4**. Compressed sensing is a new method for solving ill-posed inverse problems by utilizing the sparsity of data [7]. It allows us to reconstruct data by using sub-Nyquist*4 rate information. We have already achieved 1/400 data compression for

*2 ISM band: The ISM bands are radio bands reserved for the use of RF energy for industrial, scientific, and medical purposes. They are used by wireless LANs, Bluetooth, etc.

*3 The 100-MHz bandwidth of the ISM band is sampled at the Nyquist rate and quantized with the 10 bits used in wireless LAN systems (100 MHz × 2 × 10 = 2 Gbit/s).

*4 Nyquist sampling: Nyquist sampling is sufficient to reconstruct a signal completely from samples.

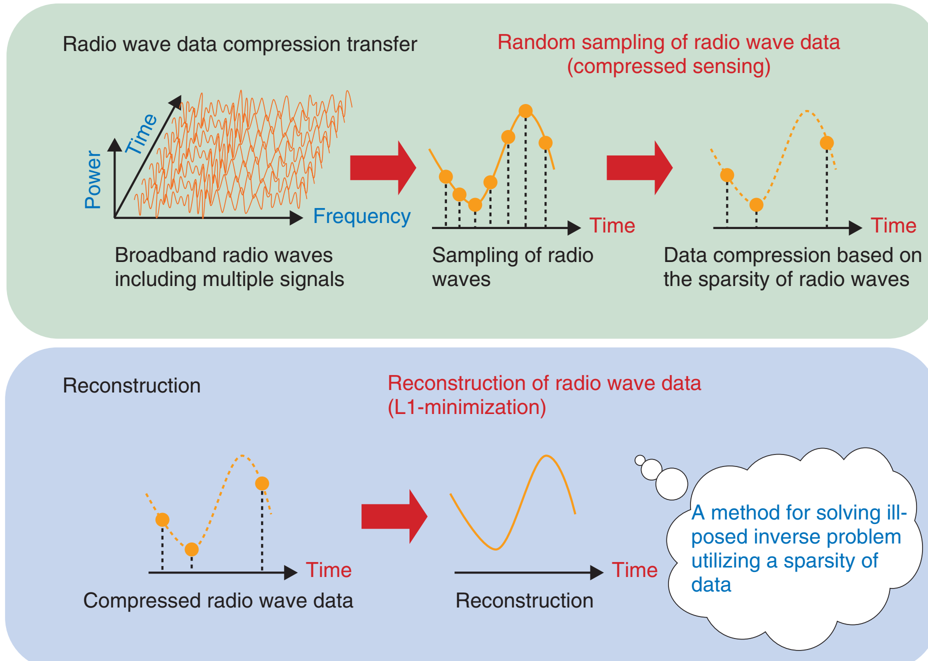



Fig. 4. Compressed sensing technology.

radio signal detection by using the frequency and time domain sparsity of radio wave data and 1-bit quantization. We will attempt to improve this to 1/1000 data compression by using the space domain sparsity of radio wave data and a weighting method based on known information on the presence of a signal [8]–[10].

## 4. Future efforts

In the future we can expect to see expanded use of ICT and wireless communications along with the continuous review of frequency band usage, the development of new standards, and changes in new generations of wireless systems. To meet the challenges of such changes, we plan to continue our research and development work with the aim of achieving a wireless home network that users can use without being aware of wireless systems and that will provide easy maintenance and operation for network operators.

## References

[1] K. Kawai, H. Okazaki, and S. Narahashi, “Center frequency, bandwidth, and transfer function tunable bandpass filter using ring resonator and J-inverter,” Proc. of the 39th European Microwave Conference (EuMC2009), pp. 1207–1210, Rome, Italy, 2009.

[2] T. Furuta, A. Fukuda, K. Kawai, H. Okazaki, and S. Narahashi, “Compact 1.5 GHz to 2.5 GHz multi-band multi-mode power amplifier,” IEICE Electronics Express, Vol. 8, No. 11, pp. 854–858, 2011.

[3] M. Kitsunezuka, K. Kunihiro, and M. Fukaishi, “Efficient Use of the Spectrum,” IEEE Microwave Mag., Vol. 13, No. 1, pp. 55–63, 2012.

[4] “UMTS/HSPA/GSM/GPRS/EDGE RF Transceiver LSI for Multi-mode/Multiband Communication,” FIND (Fujitsu semiconductor magazine), Vol. 28, No. 1, 2010.
http://www.fujitsu.com/downloads/EDG/binary/pdf/find/28-1e/2.pdf

[5] T. Kaho, Y. Yamaguchi, H. Shiba, K. Akabane, K. Uehara, and K. Araki, “A Simultaneous Receiving Multi-band Mixer with Independent Gain Control,” Proc. of the Asia-Pacific Microwave Conference 2011 (APMC2011), pp. 383–386, Melbourne, Australia.

[6] D. Lee, T. Yamada, H. Shiba, Y. Yamaguchi, and K. Uehara, “Combined Nyquist and compressed sampling method for radio wave data compression of a heterogeneous network system,” IEICE Trans. Commun., Vol. E93-B, No. 12, pp. 3238–3247, 2010.

[7] T. Tanaka, “Mathematics of Compressed Sensing,” IEICE Fundamentals Review, Vol. 4, No. 1, pp. 39–47, 2010 (in Japanese).

[8] T. Yamada, D. Lee, H. Shiba, Y. Yamaguchi, K. Akabane, and K. Uehara, “Experimental results of compressed sensing reconstruction for FSK signal demodulation in flexible wireless system,” Proc. of the Society Conference of IEICE 2011, B-17-5, Hokkaido, Japan (in Japanese).

[9] D. Lee, T. Sasaki, T. Yamada, K. Akabane, Y. Yamaguchi, and K. Uehara, “Spectrum Sensing for Networked System Using 1-bit Compressed Sensing with Partial Random Circulant Measurement Matrices,” Proc. of the IEEE 75th Vehicular Technology Conference (VTC2012-Spring), Yokohama, Japan.

[10] T. Yamada, D. Lee, H. Toshinaga, K. Akabane, Y. Yamaguchi, and K. Uehara, “1-bit Compressed Sensing with Edge Detection for Compressed Radio Wave Data Transfer,” Proc. of the 18th Asia-Pacific Conference on Communications (APCC2012), Jeju, Korea.

**Shuichi Yoshino**

Senior Research Engineer, Supervisor, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees in mechanical engineering from Kanazawa University in 1990 and 1992, respectively. He joined NTT Laboratories in 1992 and worked on satellite Internet system and wireless networking technology development. He is currently engaged in R&D of wireless technology for ubiquitous services.

**Takana Kaho**

Senior Research Engineer, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

She received the B.S. and M.S. degrees in physics from Tokyo Metropolitan University in 1994 and 1996 and the Dr.Eng. degree in communication engineering from Tokyo Institute of Technology in 2007. Since joining NTT Radio Communication Systems Laboratories in 1996, she has been engaged in R&D of MMICs. From 2010 to 2012, she was a Visiting Associate Professor at Research Institute of Electrical Communication, Tohoku University, Miyagi. She received the Japan Microwave Prize at the 1998 Asia Pacific Microwave Conference and the Young Researcher's Award in 2004 from the Institute of Electronics, Information and Communication Engineers (IEICE). She is a senior member of IEICE.

**Hiroyuki Shiba**

Senior Research Engineer, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees from Gunma University in 1995 and 1997, respectively. Since joining NTT Wireless Systems Laboratories (now NTT Network Innovation Laboratories) in 1997, he has been engaged in research on software defined radio and cognitive radio technologies. He received the Young Engineer's Award from IEICE in 2001 and 2012, and the 18th Telecom System Technology Award from the Telecommunications Advancement Foundation.

**Hideki Toshinaga**

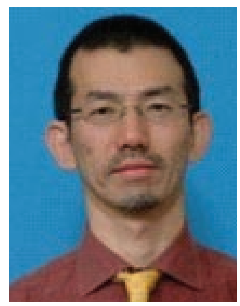
Research Engineer, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees from the Department of Electronics and Communications of Waseda University, Tokyo, in 1994 and 1996, respectively. He joined NTT Wireless Systems Laboratories in 1996. He is currently engaged in R&D of flexible wireless systems. He is a member of IEICE.

**Takayuki Yamada**

Research Engineer, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. degree in electronics from Doshisha University, Kyoto, in 2005 and the M.E. degree in communications and computer engineering from Kyoto University in 2007. Since joining NTT Network Innovation Laboratories in 2007, he has been engaged in research on flexible wireless systems. He received the Best Paper Award from IEICE Communications Society in 2012. He is a member of IEICE and IEEE.



**Mamoru Kobayashi**

Senior Research Engineer, Supervisor, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees in electronic engineering from Shizuoka University in 1987 and 1989, respectively. Since joining NTT Wireless Systems Laboratories in 1989, he has been engaged in research on channel control for satellite communications systems. He is currently engaged in R&D of flexible wireless systems and their services.

**Yushi Shirato**

Senior Research Engineer, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees in electrical engineering from Tokyo University of Science in 1990 and 1992, respectively. Since joining NTT Wireless Systems Laboratories in 1992, he has been engaged in R&D of adaptive equalizers, modems for fixed wireless access systems, and software defined radio systems. He is currently engaged in R&D of flexible wireless systems. He received the Young Engineer's Award from IEICE in 2000 and the 18th Telecom System Technology Award from the Telecommunications Advancement Foundation. He is a member of IEICE.

# Scalable M2M Wireless Access System

*Mitsuru Harada, Tomoaki Kumagai, Yoshitaka Shimizu, Kenji Suzuki, Nobuaki Mochizuki, Yosuke Fujino, and Akihiro Yamagishi*

**Abstract**

NTT Network Innovation Laboratories is collaborating in developing a machine-to-machine (M2M) wireless access method in order to expand the ways of communicating with machines. This method utilizes a standard system of simplified management that improves communication quality by controlling the access points and wireless terminals from a network. This article outlines the system being developed and introduces the functions and requirements of the wireless access M2M method. In addition, we describe how the method realizes the rapid construction of a wireless access network using existing Wi-Fi home devices in a disaster area.

## 1. Background of M2M wireless access

In recent years, considerable attention has been focused on machine-to-machine (M2M) communication, which refers to communication between various devices and is not necessarily limited to home devices. This form of communication utilizes various types of information about the devices that network servers collect, store, and analyze. M2M communications is expected to create new value in areas ranging from health care, the environment, and ecology to security and safety. Wireless access systems for M2M communication play an important role these days as a means of accessing the devices. The 920-MHz frequency band (ARIB-STD 108) [1] became available in Japan at the start of 2012, and wireless access systems for this band have been attracting a lot of attention with an eye towards increasing their use in the future.

ZigBee has been established as an attractive standard for M2M wireless systems for the 920-MHz band because it can use multi-hop network topology and has relatively low power consumption characteristics. Zigbee private wireless systems allow users to set up facilities that they operate themselves. To utilize wireless local area networks (WLANs), which are also private wireless systems, users buy an access point (AP) and a wireless terminal (WT) and input an authentication key into them to establish authentication between them. This must be done for private wireless systems that request operational management on the part of each user. However, for M2M communication that must accommodate a huge number of WTs, this imposes a heavy burden on users who have to set the authentication manually for each individual WT. Another problem that arises is unstable communication quality due to interference between APs set up independently by many users. Yet another is that communication protocol requirements, e.g., IP (Internet protocol) or non-IP, differ according to users' purposes.

We aim to solve these problems without losing the benefits of the private wireless system by means of a scalable M2M wireless access system. This system is based on the standard method used in private wireless systems but has an added function that enables it to control the APs and WTs from a network. This makes it possible to avoid interference between APs and to concentrate on operational management.

The salient feature of the M2M wireless system we are developing is that it is scalable. This enables the sizes of cells in the cellular communication system to

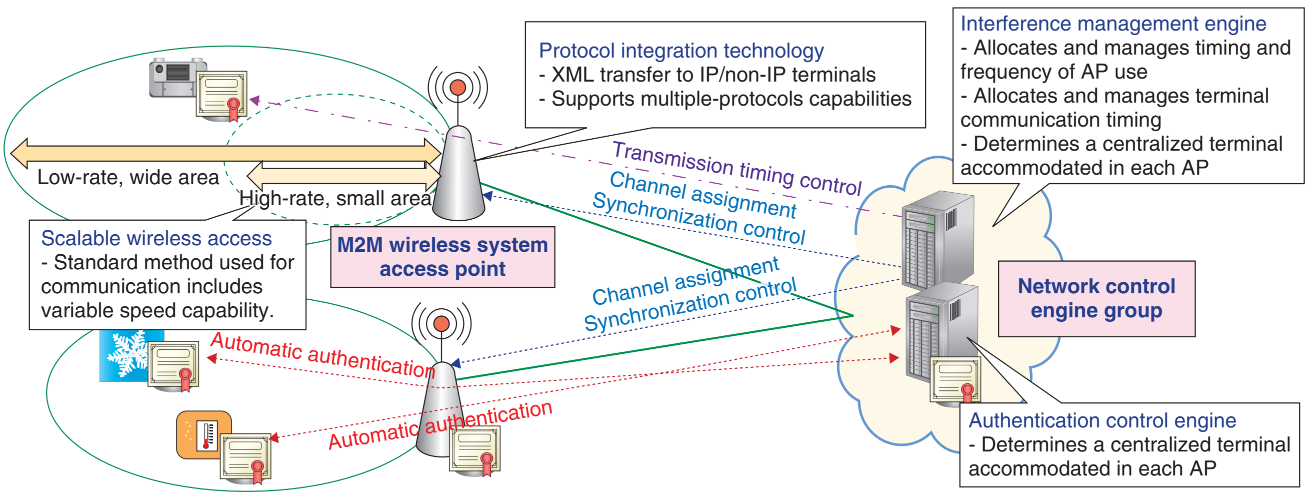



Fig. 1. Features of M2M wireless access.

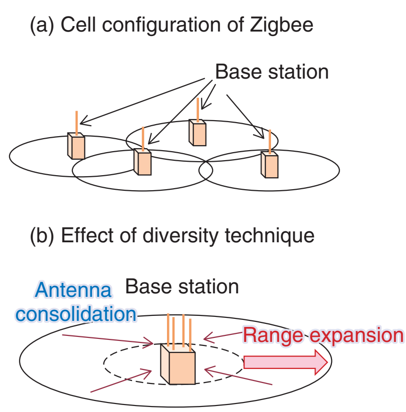



Fig. 2. Concept of diversity technique.

be flexibly designed from large to small by varying the cell size and communication speed according to demand. We also aim to establish multiple-protocol capabilities as the system's communication protocol, which will allow it to accommodate WTs using different protocols. Moreover, to achieve centralized control of APs and WTs from a network, we designed a WT that can be used without changing the connection settings to the APs when the WT moves among cells. This cooperative operation stabilizes the connection quality (**Fig. 1**). We aim to build an economical wireless system for M2M communication by using an AP that can use various commercial WTs made by the standard method.

## 2. Features of scalable M2M wireless access

### 2.1 Scalable M2M wireless access

Scalable M2M wireless access enables the communication range to be flexibly controlled by adjusting the transmit power and/or data rate. In outdoor environments, for instance, the communication range is about 1 km with 250 mW of transmit power and a 10-kbit/s communication rate. Moreover, the communication range can be approximately doubled by reducing the data rate to 1/10. In addition, as illustrated in **Fig. 2**, the communication range can be expanded without reducing the data rate by applying a diversity technique that consolidates antennas in the same location and combines their reception power levels.

In a non-line-of-sight environment between the transmitter and receiver, buildings often reflect signals, and this produces areas of weak received signal strength. In M2M communication where a fixed terminal position is assumed, a continuous communication failure known as fading frequently occurs as a result of this local degradation. It is therefore essential to develop a solution to combat the problem of fading.

The most common solution is to input a margin to compensate for the local degradation. However, in this solution, the margin limits the communication range. To solve this unique problem in M2M communication and to expand the communication range without reducing the data rate, we apply a diversity technique.

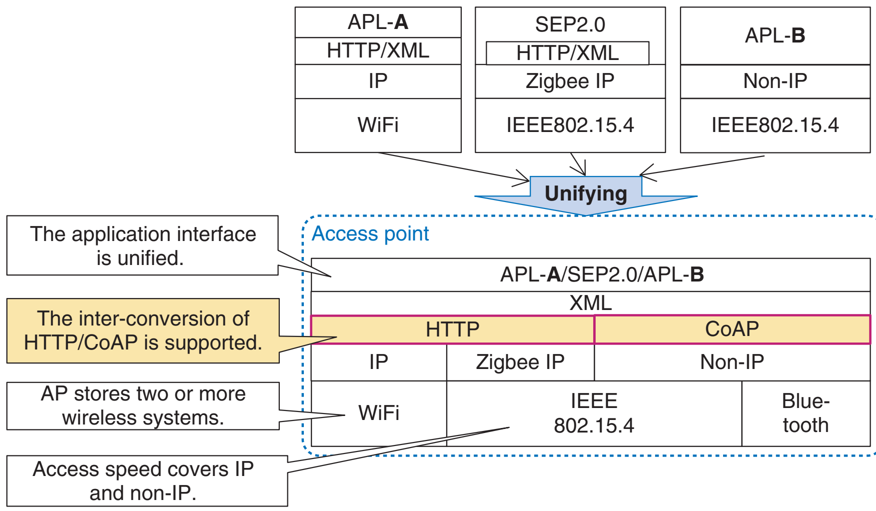



Fig. 3. Transparent XML transmission with HTTP/CoAP conversion function.

The application of diversity is generally limited in M2M communication because of its low signal-processing capability. Therefore, we developed a new method called *frequency offset transmitter diversity* that transmits only signals from two or more antennas at slightly different frequencies. This diversity method enables the communication range to be expanded by about 1.8 times using six transmitter antennas.

### 2.2 Multi-protocol correspondence of communication protocols

With respect to the communication protocol, an HTTP (hypertext transfer protocol)/CoAP (constrained application protocol) conversion function is mounted in an AP, and transparent XML (extensible markup language) transmission is achieved without being based on the protocol of a WT. Conventionally, the communication protocol is implemented using HTTP or an original system according to each application of M2M communication. This multi-protocol approach is intended to unify various protocols into the application interface of an XML base (**Fig. 3**). Although HTTP is usually used as a transfer protocol in IP connections, it is very difficult to achieve an IP connection and to mount HTTP into the low-performance terminals in M2M communication. Therefore, the IETF (Internet Engineering Task Force) has been advancing the standardization of CoAP in order to use it as a transfer protocol suitable for M2M communication. The main features of CoAP are that it is compatible with HTTP and that it reduces the required number of packet headers and sequences. These features make XML transmission possible at low-performance terminals for M2M communication. Supporting the HTTP/CoAP inter-conversion in an AP (Fig. 3) also enables the protocols to be unified into the application interface of an XML base to the WT of a non-IP connection. This enables users to develop applications without being base on the protocol of a WT.

### 2.3 Network-initiated authentication

M2M communication accommodates a huge number of WTs, and the connection setup needs to be established easily and securely between APs and WTs for authentication. Having to manually set individual WTs places an additional burden on users and should therefore be phased out or reduced as much as possible. WTs for M2M typically do not have any means of input (e.g., a keyboard or mouse), so the connection setup and authentication procedure for these terminals should be automated. In the system we are contemplating, a private-certification-authority server issues a digital certificate to a WT that contains a secure chip. After the power is activated, each WT automatically uses the certification server on the network to set up the connection with the AP for authentication. The tamper-resistant secure chip the WT contains provides a safe and secure wireless connection environment.

### 2.4 Centralized control with AP and WT from a network

Narrowband and limited frequency channels are

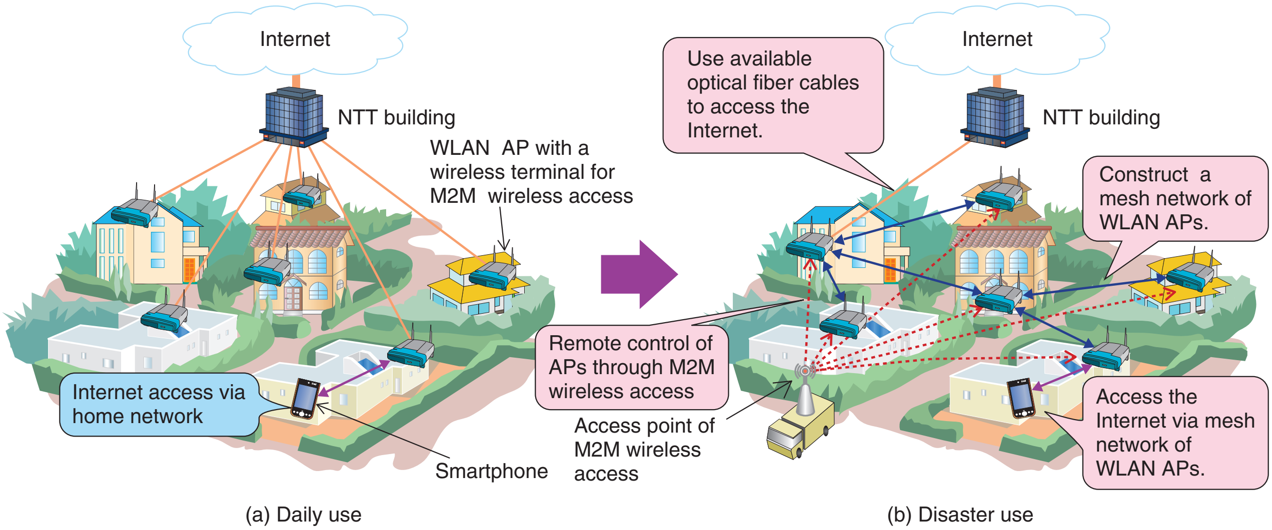



Fig. 4. Disaster recovery scenario using M2M wireless access.

used for M2M wireless access. An efficient approach to WT accommodation is for network-initiated management to coordinate the AP operation. For example, a cooperation scheme is needed where the network carries out synchronization between APs and allocates the frequency channel and communication timing to APs and WTs in order to prevent interference between adjacent APs and to enable the wide distribution of APs with fewer frequency channels. Another necessary scheme is one that ensures that data are transferred without fail, even though the currency of data may be limited to some extent. This is done by a function that distributes the WT's access timing in such a way as to prevent collision congestion when packet concentration is high in the network. This feature is suitable for M2M communication and could be effective for applications that do not require as high a degree of instancy as in human communications.

## 3. Disaster recovery solution using M2M wireless access

Smartphones with Wi-Fi capability have rapidly come into widespread use. They enable users to access the Internet outdoors via a cellular network and indoors via a home network, i.e., a WLAN. Consequently, the number of users who access the Internet with smartphones has recently been increasing. However, these access networks may not function in the event of a natural disaster such as an earthquake, so communication tools such as telephone and e-mail may not be available. In that event, users would have difficulty contacting relatives or gathering information about the disaster with these tools. To address this problem, in addition to restoring telephone services, it is important to construct new networks using existing Wi-Fi home devices, i.e., WLAN APs, to enable Internet access as quickly as possible. With this objective in mind, we are developing a prototype system that enables the rapid construction of a wireless access network by using M2M wireless access as a control link. This will make it possible for users to access the Internet with the Wi-Fi function on a smartphone, as shown in **Fig. 4**.

This system controls the Wi-Fi home (WLAN) APs attached to the M2M wireless terminal from the M2M AP installed by a carrier in a disaster area via an M2M wireless access link. Constructing relay links among the APs provides wide area coverage for communication around the area where the M2M AP is installed. Therefore, the system has two noteworthy features. The first is easy deployment. New APs and complicated settings done by engineers are unnecessary since APs for household use are used to construct the wireless access network for Internet access. The system also provides flexibility in establishing connections. For connection to the wireless access network, the system makes available access operations that any smartphone users can use, as well as those that only preregistered users can use. It should be noted that in either case, considerable discussion on the access operations is needed from the viewpoint of security. It is possible to access the Internet via optical fiber cables for household use if they have not been damaged in the disaster.

The second feature the system offers is flexible network management. When a disaster occurs, the number of available APs and the user distribution tend to vary from hour to hour. To deal with these variations, i.e., to accommodate a large number of users and handle a huge volume of traffic effectively, this system can control the network topology and assign the channel frequencies dynamically in accordance with the changes by using the M2M wireless access as a control link.

Finally, we mention the system's technical aspects. We are mainly developing two technologies relevant to this system under the national project; one is a means of effectively controlling data transmission of M2M wireless access in order to reduce overhead, since this access offers very low transmission rates ranging from several kilobits per second to several hundred kilobits per second. The other is technology to enable different WLAN AP devices to be controlled in a common manner.

## Acknowledgment

This work is being partially conducted under the national project, "The R&D on the reconfigurable communication resource unit for disaster recovery," supported by the Ministry of Internal Affairs and Communications (MIC), Japan.

## References

[1] The Association of Radio Industries and Businesses (ARIB), "Standard Specifications for 920-MHz Band Equipment," 2012 (in Japanese).
http://www.arib.or.jp/english/html/overview/doc/1-STD-T108v1_0.pdf

[2] D. Uchida, H. Matsumura, S. Kuwano, F. Nuno, N. Mochizuki, S. Kotabe, K. Suzuki, T. Fujita, and K. Mitani, "Technical Development Activities for Wide-area Ubiquitous Network," NTT Technical Review, Vol. 8, No. 6, 2010.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201006sf2.html

**Mitsuru Harada**

Senior Research Engineer, Supervisor, Group Leader of Wireless Communication Circuits Research Group, Smart Devices Laboratory, NTT Microsystem Integration Laboratories.

He received the B.S. and M.S. degrees in physics from Tsukuba University, Ibaraki, in 1985 and 1987, and the Ph.D. degree in electronic engineering from Tohoku University, Miyagi, in 2003. In 1990, he joined NTT Atsugi Electrical Communication Laboratories, where he engaged in research on thin-film SOI devices. Since 1997, he has been researching high-speed/low-power CMOS circuits for wireless terminals.

**Tomoaki Kumagai**

Senior Research Engineer, Supervisor, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees in electrical and communication engineering, and the Ph.D. degree in information science from Tohoku University, Miyagi, in 1990, 1992, and 2008, respectively. Since joining NTT in 1992, he has been engaged in R&D of personal communication systems and high-speed wireless LAN systems. He received the Young Engineer's Award from the Institute of Electronics, Information and Communication Engineers (IEICE) in 1999. He is a member of IEICE and IEEE.

**Yoshitaka Shimizu**

Wireless Systems Innovation Laboratories, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees in electrical engineering from Tokyo Institute of Technology in 1995 and 1997, respectively. He joined NTT Wireless Systems Laboratories in 1997. He studied wide area sensor network (WASN) systems and contributed to WASN standardization efforts in ITU-R. He is currently engaged in research on wireless access systems. He is a member of IEICE.

**Kenji Suzuki**

Senior Research Engineer, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees in electrical and electronic engineering from Tokyo Institute of Technology in 1999 and 2001, respectively. In 2001, he joined NTT Telecommunications Energy Laboratories, where he worked on a wireless transceiver LSI architecture for low power dissipation. His interests include analog and RF IC design for wireless communications. He is currently developing WAUN systems. He is a member of IEICE and IEEE.

**Nobuaki Mochizuki**

Senior Research Engineer, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees from Tohoku University, Miyagi, in 1992 and 1994, respectively. He joined NTT in 1994 and engaged in R&D of a modulation/demodulation scheme for a broadband 5-GHz wireless access system and synchronization scheme for coded OFDM. He is currently engaged in developing WAUN wireless access systems. He is a member of IEICE.

**Yosuke Fujino**

Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees in electrical and electronic engineering from Shizuoka University in 2002 and 2004, respectively. He joined NTT Network Innovation Laboratories in 2004 and engaged in research on multiuser detection for a multiantenna, multiuser wireless system. He is currently working on the design of WAUN physical layer protocols and algorithms. He is a member of IEICE.

**Akihiro Yamagishi**

Senior Research Engineer, Wireless Systems Innovation Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees in electrical engineering from Toyama University and the Ph.D. degree in electrical engineering from Tohoku University, Miyagi, in 1986, 1988, and 2005, respectively. In 1988, he joined NTT LSI Laboratories, where he engaged in R&D of frequency synthesizer ICs. From 2000 to 2004, he studied 1-V-operation CMOS RF circuits for wireless systems. He is currently studying a wireless terminal for the WAUN. He is a member of the Institute of Image Information and Television Engineers of Japan.

# Virtual Sensor Construction Technique for Participatory Sensing Environments

*Hiroshi Sato, Atsushi Yamamoto, Hisashi Kurasawa, Hitoshi Kawasaki, Motonori Nakamura, and Hajime Matsumura*

**Abstract**

Much attention is being focused on participatory sensing, in which real-world data are collected using personal mobile devices as sensor nodes to sense various conditions of the world we live in. In this approach, sensor nodes are not controlled by a sensing system; they move and sense independently. Therefore, the sensing data may include noise or missing values and are therefore difficult to use as-is for applications. We are investigating a technique to construct virtual sensors in order to provide reliable and flexible sensing data. In this article, we introduce a construction technique that consists of three core methods to enhance data quality: participation promotion using our Top of Worlds technique, noise reduction, and missing value estimation. We also describe a simple demonstration we conducted that shows how these factors enhance data quality.

## 1. Introduction

Worldwide smartphone use is currently estimated to be 12% and is predicted to increase to 50% in five years [1]. These mobile devices are usually equipped with several sensors that capture visual, acoustic, tactile, location, and other data. This makes them suitable devices for participatory sensing, which has been attracting global attention [2]. Participatory sensing, also called human/people-centric sensing, is an approach for collecting and analyzing data in which individuals, acting alone or in groups, use their personal mobile devices and cloud services to sense and share various conditions of their surroundings. We call such data real-world data. The concept of participatory sensing is shown in **Fig. 1**. This approach is an alternative to conventional sensing environments where stationary sensor nodes that are dominated, i.e., controlled, by a sensor system are installed in a target area. The conventional approach is not suitable for wide-area sensing because it requires a large number of sensor nodes that are expensive to install and maintain. Such costs are not incurred with the participatory sensing approach, which can be used with existing devices. The data obtained in participatory sensing will be useful in applications that have a significant socio-economic impact. Such applications include, but are not limited to, environmental monitoring, pedestrian navigation, urban planning, pandemic prevention, disaster recovery, and energy management.

Recent advances achieved in sensor devices and wireless networking technologies mean that participatory sensing is becoming more and more possible; however, technical challenges remain. One of the key challenges is determining how to enhance defective data. In participatory sensing, sensor nodes are not under the control of a sensing system; they move and sense independently. The system cannot sense targets systematically as in conventional controlled sensing and cannot always obtain the intended data in the intended form when needed. That is to say, raw

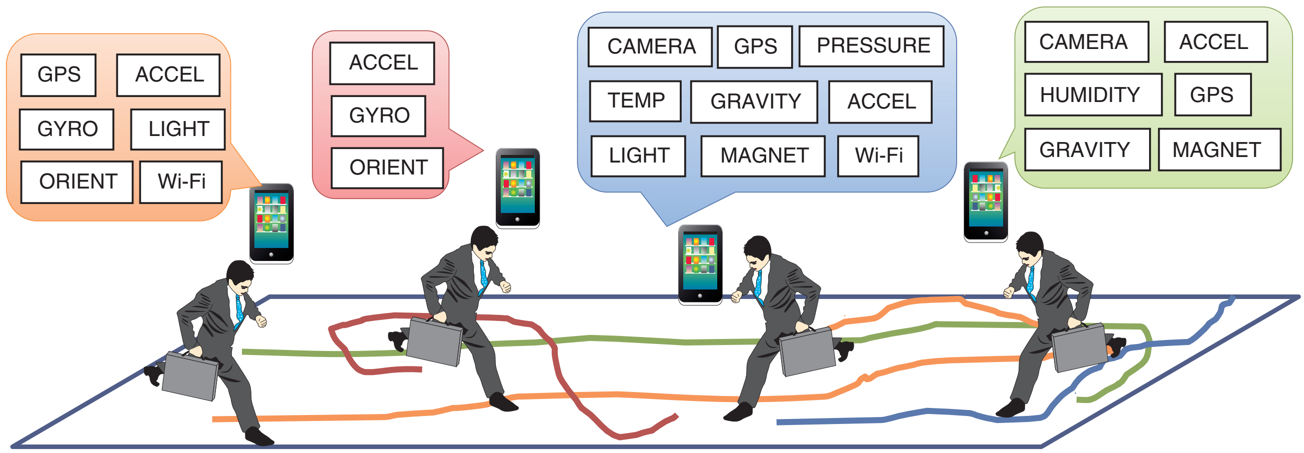



Fig. 1. Concept of participatory sensing; users collect various kinds of data with their own smartphones.

participatory sensing data are defective and difficult to use as-is for applications. Therefore, we believe that sensor virtualization, which provides reliable virtual sensor data produced from related (actual) data, is essential for participatory sensing.

We introduce here three techniques to enhance data quality: participation promotion, noise reduction, and missing-value estimation. These techniques enhance the quality of participatory sensing data and make virtual sensors reliable and flexible. In section 2, we discuss various issues concerning participatory sensing data. Then we briefly review related work in section 3. In section 4, we explain the three data quality enhancement techniques used in virtual sensor construction. In section 5, we discuss a demonstration of virtual sensors constructed using our techniques based on a sample scenario. Finally, we conclude the article in section 6.

## 2. Issues concerning participatory sensing

This section addresses participatory sensing issues, specifically defective data. The largest difference between conventional and participatory sensing is that sensor nodes of the former are dominated; i.e., they are controlled by a system, whereas sensor nodes of the latter are not. In participatory sensing, sensing conditions such as time, location, and angle depend on each individual's behavior, and sensor module specifications such as type and accuracy depend on the individual devices; we cannot typically control them. Moreover, whether or not to sense or to transmit data also depends on the will of individual participants. This means that most of the collected data is defective—sparse, noisy, and distorted. We discuss these three issues below.

### 2.1 Sparseness (insufficient quantity of data)

The first issue is data sparseness, namely, the insufficient supply of data. Participatory sensing does not work without people's participation. However, participants must use their own battery power and pay the data transmission charge, so it may be difficult to collect sufficient data solely by depending on volunteers; therefore, the collected sensing data may be sparse. One way to collect data is to provide a financial incentive to people. This improves their extrinsic motivation to participate; however, it may increase sensing system operating costs. Furthermore, a psychological study [3] found that extrinsic motivation is unsustainable. Therefore, a method to promote participation by improving intrinsic motivation is necessary.

### 2.2 Noise (inaccurate data)

The second issue is noise, namely, inaccuracy. Participatory sensing involves sensor modules installed in personal mobile devices. In general, such sensor modules are less accurate than specially tuned stationary sensors used in conventional sensing. Additionally, the accuracy of such personal use sensor modules is probably not uniform because there are many types of products. Therefore, the sensing data may be noisy. We must reduce the noise and enhance the accuracy of the data in order to use such data in applications.

### 2.3 Distortion (incomplete data)

The last issue is distortion of data, namely, incompleteness. In participatory sensing, the sensing time and location are basically left up to the participants. Participants can freely move, sense objects, and transmit the sensing data. Consequently, it is easy to collect sensor data in spaces where many people gather, whereas it is difficult to collect data where fewer people gather. In addition, the type of sensor to carry depends on the participant's device. For example, one participant's device may be equipped with sensor modules A and B, while another participant's device may only have sensor module A. Therefore, it is easy to collect data from commonly used sensors but difficult to do so from sensors that are used less frequently. As a result, participatory sensing data are unevenly distributed in time and space and are therefore incomplete; in other words, they include many missing values. We must compensate for any missing values in applications.

## 3. Related work

Many studies have been conducted on sensor virtualization for participatory sensing, and some have focused on enhancing the quality of sensing data. Weinschrott et al. [4] proposed virtual sensor abstraction algorithms, collectively called StreamShaper, for mobile urban sensing. They focused on enhancing the coverage of virtual sensors; however, they did not take the reliability of virtual sensor values into account. Ganti et al. [5] proposed a navigation service called Green GPS that suggests the most fuel-efficient routes to drivers. They focused on compensating for missing values. Green GPS builds a generalized hierarchical model for various vehicle types and merges the various sensor data by using the model; this increases the service coverage, but it requires an elaborately tuned model.

The issue of participant motivation has also been investigated in several studies. Reddy et al. [6] investigated a method to motivate users to participate in sensing; however, they presuppose the incentive payment model. To motivate users to participate in a paragliding community service, Kaenel et al. [7] developed a method of presenting the rank of each user's paragliding distance calculated from GPS data as information for users to compare with other users. However, because this method only ranks each user among all other users, most users have little chance of being ranked in the top group. Therefore, we believe that the motivational effect of this method would be small for most users.

We believe that a comprehensive approach to enhancing the quality of sensing data is important to provide reliable virtual sensors for applications.

## 4. Virtual sensor

We are researching virtual sensor construction techniques that enhance the quality of participatory sensing data against the issues mentioned in section 2 and that produce virtual sensor data from enhanced sensor data sets for various applications. The flow of our construction technique is shown in **Fig. 2**. First, sufficient sensor data are collected by using a technique to promote user participation. Second, the reliability of sensor data sets is enhanced using a noise reduction technique. Finally, incomplete data are compensated for using a multiple regression technique. Additionally, a new sensor data set that fuses the data collected from all sensors is produced if necessary. In this section, we explain each of our data quality enhancement techniques.

### 4.1 Participation promotion

Because participatory sensing requires input of sensor data from users, the users must feel motivated to continue participating. We focused on improving users' intrinsic motivation by promoting a sense of superior achievement.

We proposed *Top of Worlds* [8], a method for strengthening the motivation of users to participate in sensing by presenting rankings in multidimensional hierarchical sets. A previously proposed method [7] only ranks each user among all other users, so most users have little chance of being ranked in the top group and may have little motivation to continue. Top of Worlds creates many sets with varying granularity to increase the chance of many users being ranked in the top group and presents these rankings in those sets. An example of values used to compare rankings is the amount of sensor data transmitted by users. Top of Worlds is based on two hypotheses:

- **H1.** If a user is ranked in the top group, her/his motivation will increase compared to when the user is not in the top group.
- **H2.** If a user is ranked in the top group in multiple sets, the coarser the granularity of the set is, the more her/his motivation will increase.

On the basis of H1, our proposed method is composed of the following steps: 1. many sets are created with varying granularity to increase the chance of many users being ranked in the top group; 2. sets are

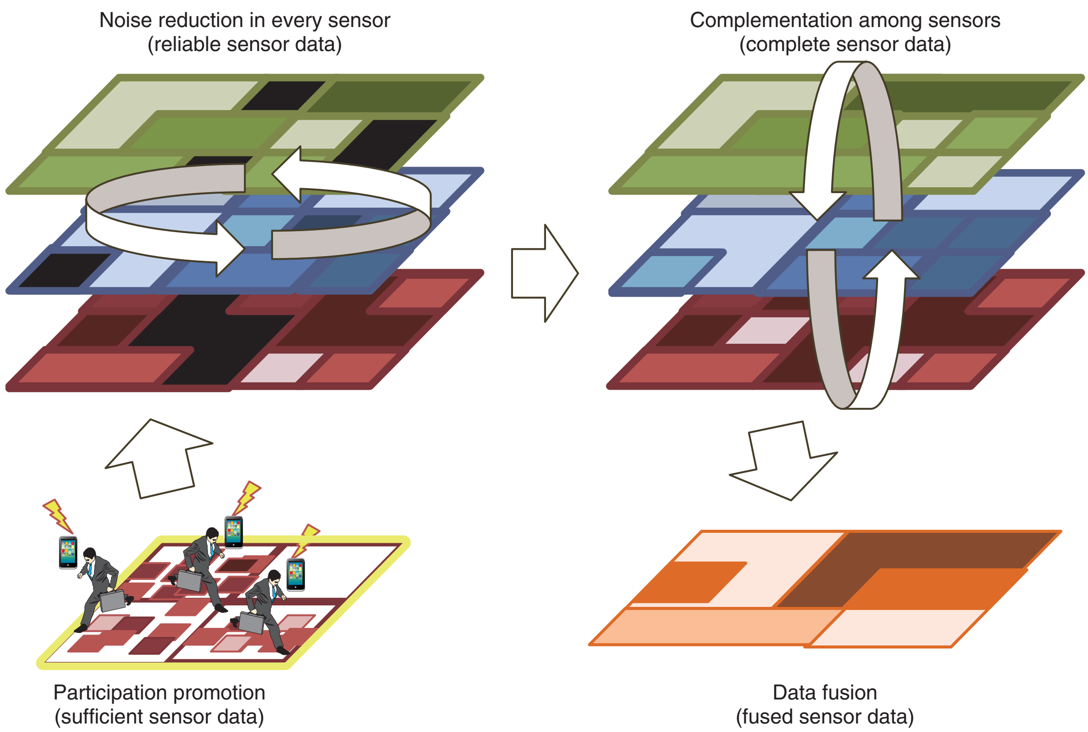



Fig. 2. Flow of virtual sensor construction.

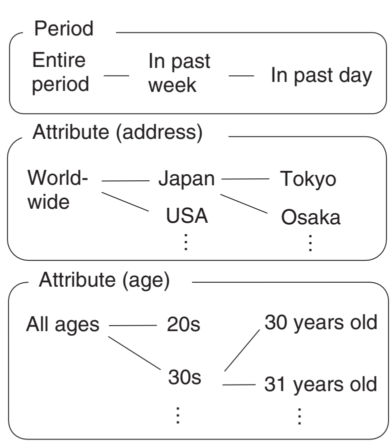



Fig. 3. Hierarchical sets.

selected in which a user ranks in the top group. For example, step 1 involves creating multidimensional hierarchical sets by time period and by attribution (address, age, or sex). In step 2, sets are selected among multidimensional hierarchical sets in which a user ranks in the top group. We define hierarchical sets based on time period (entire period, in the past week (one-week period up to now), in the past day (one-day period)), address (worldwide, nationwide, statewide (citywide)), and age (all ages, a certain age range, e.g., 20s and 30s, or a specific age), as shown in **Fig. 3**. We define a multidimensional hierarchical set as a common subset of each hierarchical set.

On the basis of H2, if a user ranks in the top group in multiple sets, Top of Worlds is composed of the following additional steps: 3. a set with the coarsest granularity (the longest period, largest address segment, or broadest age range) is selected; 4. information on the set and the rank is presented to the user (we skip step 3 if the user ranks in the top group in only one set).

An example of Top of Worlds is shown in **Fig. 4**. We assume the user lives in Tokyo and is 31 years old. If the user is given information such as *You are 50,000th in Japan among all ages out of 100,000 people*, the user may not be motivated to continue. Therefore, Top of Worlds selects a hierarchical set focused on the user and presents information such as *You are ranked 1st in Tokyo among fifty 31-year-olds* to the user. As a result, the user will be motivated to continue participating. Thus, Top of Worlds effectively increases the motivation of many users.

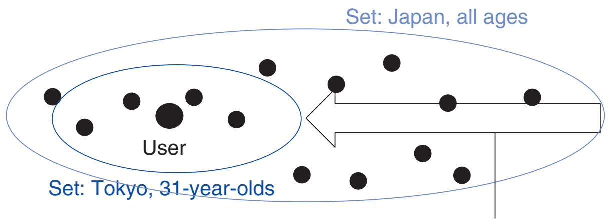



Fig. 4. Example of Top of Worlds.

### 4.2 True value estimation

#### 4.2.1 Basic idea

Participatory sensing produces noisy sensor data due to the use of sensors with low accuracy or a mix of sensors with diverse performance capabilities. It is meaningless to analyze each value in the noisy sensor data in order to use it in applications. We have to estimate true values from the noisy sensor data to provide reliable data for applications.

We recently proposed a method for statistically estimating the true values of population means by using noisy sensor data as random samples [9]. This estimation method is aimed at accurately estimating the population means while preserving their spatio-temporal patterns.

This method can be used to accurately estimate a population mean by expanding a spatio-temporal region where a sample is obtained in order to increase the sample size. This is because of the well-known fact that an estimate for a population mean becomes more accurate as the sample size increases.

However, expanding the region makes the spatio-temporal granularity of the estimate coarse, which leads to a loss of spatio-temporal patterns of the population means. This estimation method preserves those spatio-temporal patterns by the use of a constraint condition in which the region must consist of elements with the same population mean when the region is expanded.

In other words, this estimation method partitions an entire spatio-temporal region into the largest possible regions, each of which consists of elements with the same population mean, and then estimates each population mean by using samples obtained in the regions.

#### 4.2.2 Detailed steps of estimation method

The above-mentioned estimation method consists of three steps: initialization, region expansion, and interval estimation. The region expansion and interval estimation steps are repeated until the entire spatio-temporal region is covered. An overview of this estimation method is shown in **Fig. 5**, where a spatio-temporal region is drawn as a simplified two-dimensional region.

(1) Initialization

In this step, the entire spatio-temporal region is divided into elements of the same size, which are united into regions in the region expansion step.

(2) Region expansion

In this step, one of the elements is randomly selected and added to a region, which is then expanded by uniting the neighboring elements with the same population mean.

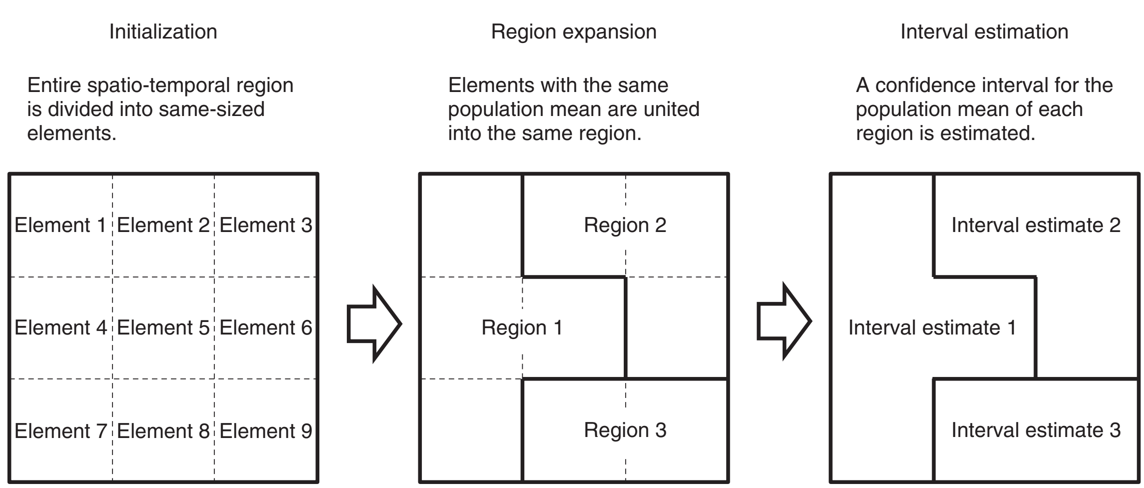



Fig. 5. Overview of estimating true values of population means.

This step statistically tests the null hypothesis, which states that the population mean of the region equals that of each of the neighboring elements, against the alternative hypothesis. If the null hypothesis is accepted or not rejected, this expansion step basically adds each of the neighboring elements to the region. However, a statistical hypothesis test may produce a type II error, which is the incorrect acceptance of a false null hypothesis. Thus, this step adds each of the neighboring elements to the region with the statistical power, which is the probability of not making the type II error. In this way, this step adheres to the constraint condition that the region consists of elements with the same population mean when expanding the region.

In this step, the region expansion with statistical hypothesis testing is repeated until no neighboring elements are newly added to the region, which maximizes the region under the constraint condition in order to increase the sample size for estimation.

(3) Interval estimation

In this step, a confidence interval is statistically estimated for the population mean by using a sample obtained in the expanded region. This ensures that applications can not only obtain a more accurate estimate but can also assess the accuracy of the estimate by the width of the interval.

The above steps, particularly the region expansion step, allow us to achieve the intended aim of accurately estimating the population means while preserving their spatio-temporal patterns.

### 4.3 Missing value estimation

#### 4.3.1 Basic idea

In participatory sensing, the sensor data are often affected by missing values, which makes the data incomplete. The sensors and sensing area respectively depend on the mobile devices of the participants and the participants' trajectories. It is not feasible to force a participant to stay in a target area as a stationary sensor.

Our goal was to accurately estimate the missing values of a sensor from incomplete sensor data by using multiple regression. A simple way of analyzing incomplete sensor data would be to delete all the missing records and then use only the complete records. However, excluding all records having more than one missing value would result in a decrease in the quantity of training sensor data available for estimation. Thus, we should select the minimum number of sensors needed to estimate the missing values and exclude all records that have missing values of the selected sensors.

We previously proposed a method to estimate a missing sensor value by using incomplete sensor data [10]. This estimation method was designed to improve the regression model and increase the quantity of training sensor data. This method roughly prunes inessential sensors by using small training sensor data and improves estimation accuracy while repeating sensor selection and updating the training sensor data. An overview of this estimation method is shown in **Fig. 6**.

#### 4.3.2 Detailed procedure

Let $R_{init}$ be incomplete sensor data that consist of $n_{init}$ records $r_{init,1}$, $r_{init,2}$, … , $r_{init,ni}$. Each record $r_{init,j} \in R_{init}$ has values of multiple sensors $V$, which may include some missing values. Here, $r_{init,j}(v)$ is $r_{init,j}$'s value of the sensor $v \in V$. Given the incomplete sensor data $R_{init}$ as the initial training sensor data and a missing value $Q(q)$ of a sensor $q$ in one record $Q$ as a query, we set the estimation task as estimating $Q(q)$.

Our estimation method consists of the following six steps: inputting incomplete sensor data and queries, maintaining training sensor data, conducting locally weighted measurements, selecting sensors, evaluating accuracy, and doing the final estimation. The steps from training sensor data maintenance to accuracy evaluation are repeated until the accuracy satisfies quality conditions.

(1) Incomplete sensor data and query input

This estimation method receives $R_{init}$, which is detected through participatory sensing. The sensors initially selected for regression are set to be the observed sensors of the query record.

(2) Training sensor data maintenance

When arranging the training sensor data, our estimation method completely removes the records that do not include the selected sensors from the incomplete sensor data, then puts the remaining records in order.

(3) Locally weighted measurement

This estimation method weighs the nearest neighbor records for regression. This is for sensors that are not generally correlated but locally correlated. For example, illuminance and ultraviolet light are often correlated if the spatio-temporal range is limited. The weight is measured based on the selected sensors. This means that the weight of a record updates every correlated sensor selection.

(4) Sensor selection

This estimation method selects sensors correlated

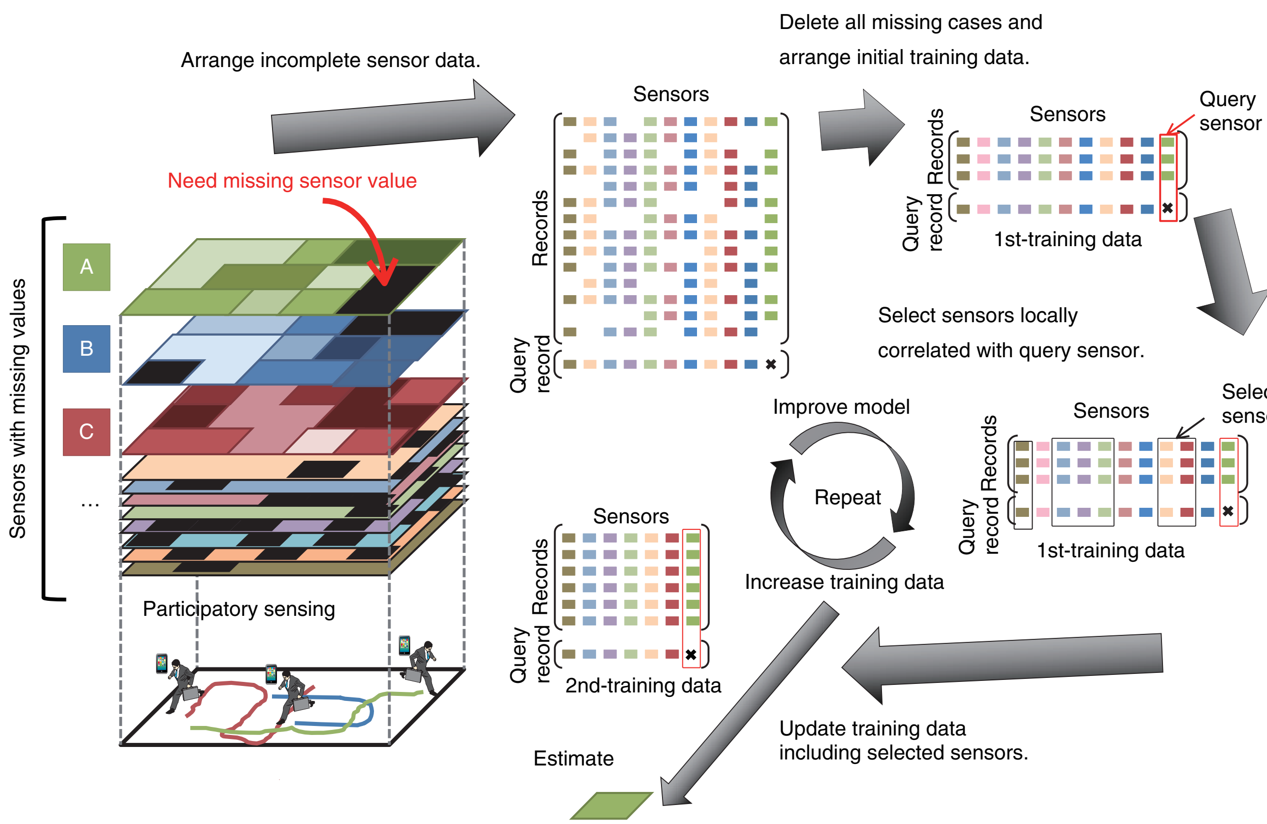



Fig. 6. Overview of missing-value estimation.

with the sensor that includes the missing value by using Lasso, which is an L1-norm regularization technique. Lasso does both continuous shrinkage and automatic variable selection at the same time. It is widely used in high-dimensional regression for variable selection.

(5) Accuracy evaluation

The estimation method determines whether it should continue the repeated steps. It stops repeating the steps when one of the following two conditions is satisfied. One is that the amount of training sensor data does not increase after sensor selection. This is because the accuracy would not be expected to improve. The other is that the accuracy measured by K-fold cross-validation satisfies the predefined threshold, which represents the mean squared error. If these conditions are not satisfied, it executes the steps from training sensor data maintenance to accuracy evaluation again.

(6) Final estimation

The final estimation value is then calculated.

## 5. Demonstration

We developed a demonstration system to simulate participatory sensing and indicate the effects of our true-value and missing-value estimation methods described in subsections 4.2 and 4.3. In this section, we explain how the quality of participatory sensing data is improved by using our estimation methods with the demonstration system. Our demonstration scenario is to visualize the fused values of five types of participatory sensing values as a heat map. For the data collection, we assume that 100 people participate in sensing.

### 5.1 Simulation of participatory sensing

We prepared five synthetic datasets of sensors, A, B, C, D, and E, in a square area for the demonstration. Their heat maps are shown in **Fig. 7**. Red indicates a higher value and blue a lower value. The visualization target X is the sum of the five sensor values. We divide the 100 participants into five groups. Each group consists of 20 people and is assigned one of the

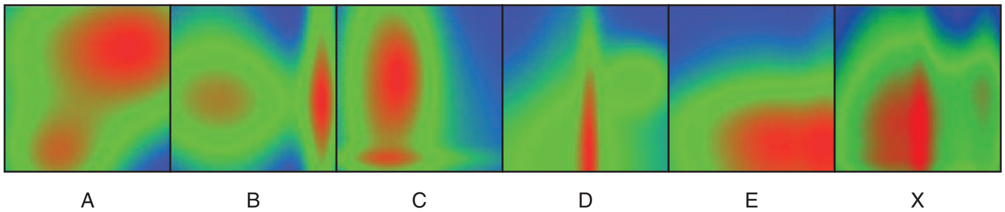



Fig. 7. Heat maps of original sensor data and sum of their values.

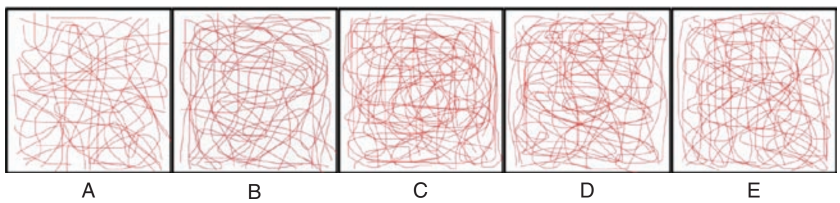



Fig. 8. Trajectories of participants.

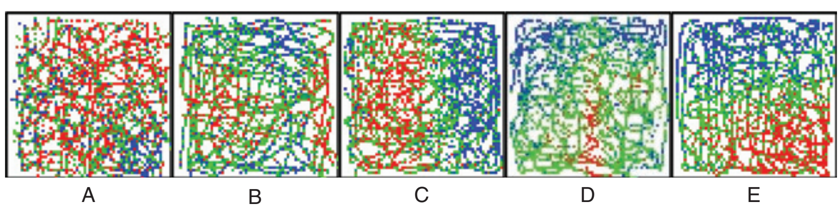



Fig. 9. Heat maps of raw sensing data.

five types of sensors. We assume that each sensor module has its own error rate, and participants walk around the area while capturing sensor data.

To simulate participatory sensing, each participant freely draws a curved line on the area instead of walking. The trajectories are shown in **Fig. 8**. The temporal axis is omitted from the simulation to simplify the heat maps, so all sensing actions of all participants are regarded as concurrent. The sensing results are shown in **Fig. 9**. Noise and missing values can be seen compared to the original data in Fig. 7.

### 5.2 Effects of our two estimation methods

We estimated the population means for each sensor. The results are shown in **Fig. 10**. The noise was reduced compared to the raw data in Fig. 9; however, there were still many missing values. Moreover, points where all kinds of data exist are very rare (**Fig. 11**). This means that it is impossible to calculate and visualize X on the map.

In this demonstration, we directly compensated for missing values of X instead of the values of each of the five sensors A to E. We estimated the missing values of X using other sensors' values. These results are shown in **Fig. 12**. Although some errors remained, almost all of the data were compensated for.

## 6. Conclusion

We discussed participatory sensing and pointed out three defects that can occur in sensed data: sparseness, noise, and distortion. We also introduced three core techniques to enhance the quality of participatory sensing data. A demonstration showed that our enhancement techniques worked well. We believe that using our enhancement techniques in sensor

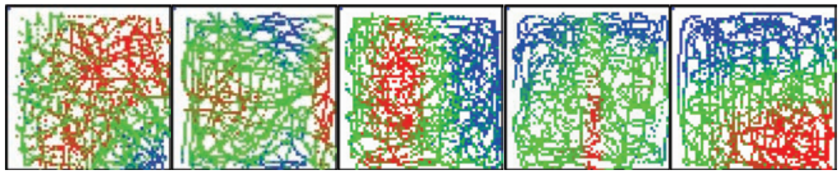



Fig. 10. Results of estimating population means.

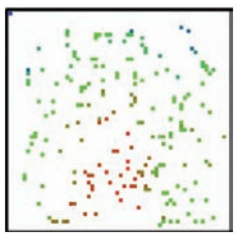



Fig. 11. Heat map of X (intersection only).

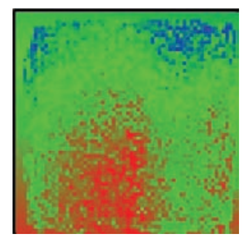



Fig. 12. Results of estimating missing values of X.

virtualization environments will make it possible to support many useful applications that use real-world data.

We are currently investigating ways to evaluate data quality and value and developing sample applications of participatory sensing.

## References

[1] Press release by Seed Planning, July 26, 2012 (in Japanese). http://www.seedplanning.co.jp/press/2012/2012072601.html

[2] J. Goldman, K. Shilton, J. Burke, D. Estrin, M. Hansen, N. Ramanathan, S. Reddy, V. Samanta, M. Srivastava, and R. West, "Participatory Sensing: A citizen-powered approach to illuminating the patterns that shape our world," Woodrow Wilson International Center for Scholars, Washington, D.C., May 2009.

[3] E. L. Deci and R. M. Ryan, "Intrinsic Motivation and Self-Determination in Human Behavior," Plenum Press, New York, 1985.

[4] H. Weinschrott, F. Dürr, and K. Rothermel, "Streamshaper: Coordination algorithms for participatory mobile urban sensing," Proc. of the 7th IEEE International Conference on Mobile Ad-hoc and Sensor Systems (IEEE MASS 2010), pp. 195–204, San Francisco, CA, USA.

[5] R. K. Ganti, N. Pham, H. Ahmadi, S. Nangia, and T. F. Abdelzaher, "Green GPS: A Participatory Sensing Fuel-efficient Maps Application," Proc. of the 8th International Conference on Mobile Systems, Applications, and Services (MobiSys 2010), pp. 151–164, San Francisco, CA, USA.

[6] S. Reddy, D. Estrin, M. Hansen, and M. Srivastava, "Examining Micro-payments for Participatory Sensing Data Collections," Proc. of the 12th ACM International Conference on Ubiquitous Computing (Ubicomp 2010), pp. 33–36, Copenhagen, Denmark.

[7] M. V. Kaenel, P. Sommer, and R. Wattenhofer, "Ikarus: Large-scale Participatory Sensing at High Altitudes," Proc. of the 12th Workshop on Mobile Computing Systems and Applications (HotMobile 2011), Phoenix, AZ, USA.

[8] H. Kawasaki, A. Yamamoto, H. Kurasawa, H. Sato, M. Nakamura, and H. Matsumura, "Top of worlds: method for improving motivation to participate in sensing services," Proc. of the 14th ACM International Conference on Ubiquitous Computing (Ubicomp 2012), pp. 594–595, Pittsburgh, PA, USA.

[9] A. Yamamoto, H. Kawasaki, H. Kurasawa, H. Sato, M. Nakamura, and H. Matsumura, "Proposal of an Accuracy-aware Virtual Sensor for Participatory Sensing," Forum on Information Technology 2012 (FIT2012), Vol. 4, No. RM-001, pp. 17–20, Tokyo, Japan.

[10] H. Kurasawa, H. Sato, A. Yamamoto, H. Kawasaki, M. Nakamura, and H. Matsumura, "Variable Selection Method in Multiple Regression with Incomplete Sensor Data," IEICE Technical Report, USN2012-54, Vol. 112, No. 242, pp. 149–154, 2012.

**Hiroshi Sato**

Senior Research Engineer, Ubiquitous Service Systems Laboratory, NTT Network Innovation Laboratories.

He received the B.S. and M.S. degrees in mathematics from Tohoku University, Miyagi, in 1994 and 1996, respectively. In 1996, he joined NTT Communication Science Laboratories, where he engaged in research on natural language processing. Since moving to NTT Network Innovation Laboratories in 2007, he has been researching ubiquitous data management. His research interests include uncertain information processing. He received the Best Paper Award of the Information Processing Society of Japan (IPSJ) National Convention in 1999. He is a member of the IPSJ and the Japan Society for Fuzzy Theory and Intelligent Informatics.

**Atsushi Yamamoto**

Research Engineer, Ubiquitous Service Systems Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees from Kyushu University, Fukuoka, in 2001 and 2003, respectively. He joined NTT Network Innovation Laboratories in 2003. His research interests include large-scale data processing and statistical inference. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) and IPSJ.

**Hisashi Kurasawa**

Researcher, Ubiquitous Service Systems Laboratory, NTT Network Innovation Laboratories.

He received the B.E., M.E., and Ph.D. degrees in information science and technology from the University of Tokyo in 2006, 2008, and 2011, respectively. He joined NTT Network Innovation Laboratories in 2011 and has been studying data mining. His research interests include similarity search, distributed systems, and context-aware computing. He is a member of IEICE, IPSJ, and the Database Society of Japan.

**Hitoshi Kawasaki**

Researcher, Ubiquitous Service Systems Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees in computer science from Keio University, Kanagawa, in 2007 and 2009, respectively. He joined NTT Cyber Solutions Laboratories in 2009. He is currently studying data mining and persuasive technology. He is a member of IPSJ and IEICE. He received the Best Paper Award for Young Researchers at the 73rd Annual IPSJ Conference.

**Motonori Nakamura**

Senior Research Engineer, Supervisor, Ubiquitous Service Systems Laboratory, NTT Network Innovation Laboratories.

He received the B.E. and M.E. degrees in information engineering from Nagoya University, Aichi, in 1990 and 1992, respectively. Since joining NTT Switching System Laboratories in 1992, he has been researching distributed telecommunication service software architectures, ad-hoc routing protocols, and software platforms for ubiquitous services. He is a member of IEICE and IPSJ.

**Hajime Matsumura**

Senior Research Engineer, Supervisor, Ubiquitous Service Systems Laboratory, NTT Network Innovation Laboratories.

He received the B.E., M.E., and D.E. degrees in engineering from the University of Tokushima in 1987, 1989, and 2000, respectively. Since joining NTT in 1989, he has been engaged in R&D of STM switching systems, common software platforms for switching systems, distributed network architecture and distributed network performance simulation, network-linked broadcasting systems based on home servers, and business operation support systems for FLET'S and NGN services. He is currently researching ubiquitous networking systems. He is a member of IEEE and IEICE.

# Trends in the International Standardization of HVDC Power Feeds

***Toshimitsu Tanaka, Kaoru Asakura, and Tadayoshi Babasaki***

**Abstract**

Higher-voltage direct current (HVDC) power feeds are attracting attention as an efficient means of supplying 380-V DC electricity to datacenters and telecommunications facilities, and it is expected that this technology will eventually be put to practical use in many places worldwide. In this article, we describe the characteristics of HVDC power feeds and the international standardization efforts related to this technology, including an overview of ITU-T Recommendation L.1200 of May 2012 ("Direct current power feeding interface up to 400 V at the input to telecommunication and ICT (information and communications technology) equipment").

## 1. Introduction

In recent years, with the arrival of cloud computing and other network-enabled technologies, demand for communications and datacenters has continued to grow. However, as more equipment is installed in datacenters, their power consumption is steadily increasing. This trend is not exclusive to Japan, but is being seen all over the world. To realize a sustainable low-carbon society, the need for greener, more energy-efficient information and communications technology (ICT) equipment and facilities has therefore been recognized as a pressing issue.

Worldwide attention has recently been focused on the idea of distributing direct current (DC) electric power inside datacenters and supplying the servers directly with higher-voltage DC (HVDC) power feeds as a key technology for reducing losses [1], [2]. In response to this trend, international standards organizations such as the ITU-T (International Telecommunication Union, Telecommunication Standardization Sector) and IEC (International Electrotechnical Commission) are now working on the standardization of device specifications, system configurations, safety measures, and component/device specifications that are needed for the practical implementation of this technology.

## 2. Benefits of HVDC power feeds

A comparison of alternating current (AC) and DC power feed systems in a datacenter is given in **Fig. 1**. The internal components (CPU (central processing unit), memory, etc.) of the ICT equipment (servers etc.) operate with DC supply voltages such as 5 V and 3.3 V, and the backup storage battery for use during power outages also runs on DC. With an AC power feed, power conversion between AC and DC is typically performed four times in order to connect this equipment, which results in conversion losses. By contrast, with a DC power feed, the AC power can be converted into DC and connected directly to the storage battery. Therefore, power conversion is typically performed just twice (including DC/DC conversion inside the equipment), so a DC feed can in principle achieve better efficiency due to the need for fewer power conversion stages than with an AC power feed.

ITU-T Recommendation L.1200 assumes that a DC voltage of 380 V will be used. This is because this

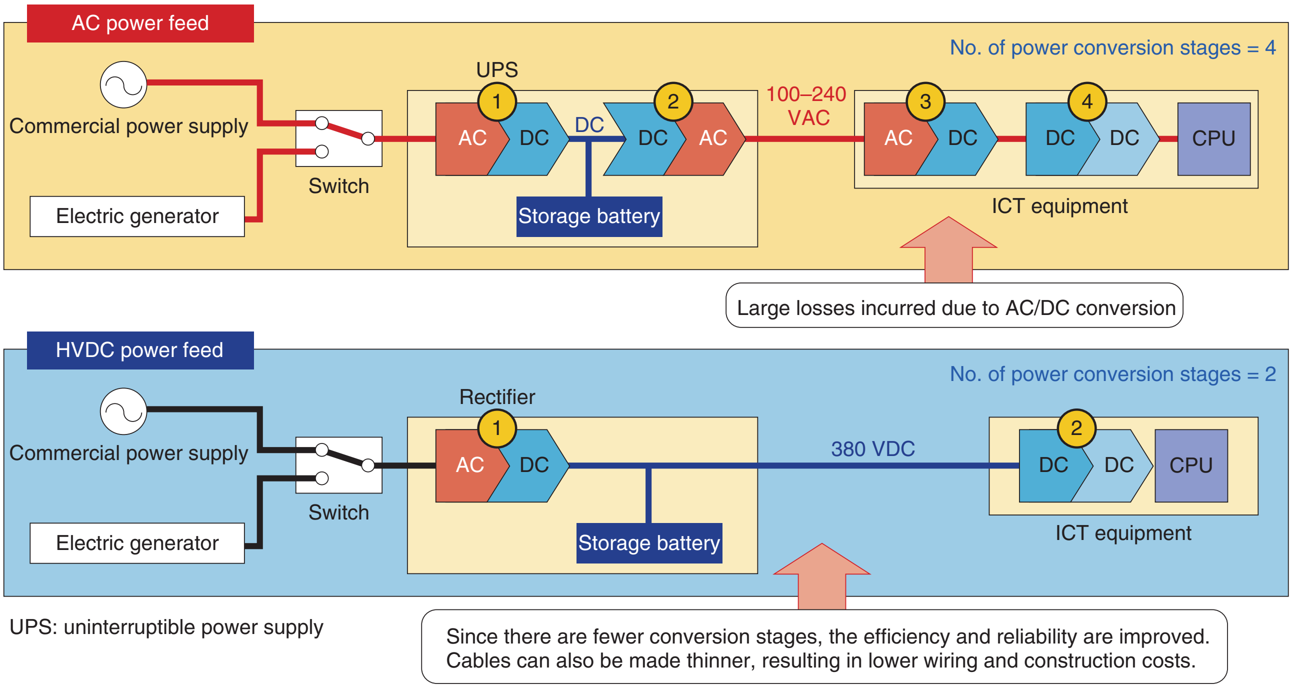



Fig. 1. Comparison of AC and HVDC power feed systems in a datacenter or communications building.

voltage has traditionally been used as the intermediate bus voltage of server power supply units worldwide, making it highly compatible with existing equipment. Also, since the higher voltage means that the power current can be suppressed to approximately one eighth that of a conventional DC 48 V power feed system used for communication equipment, it can reduce the power distribution losses and heat dissipation. These characteristics make the power supply equipment more efficient and compact and allow the use of thinner power distribution cables, thereby reducing the wiring and construction costs while allowing the equipment to be laid out with greater flexibility.

Another reason why this power feed system has attracted international attention is the high reliability of DC power feed systems. Although there is always a risk of breakdowns, DC power feeds are known to be over ten times as reliable as AC power feeds because the use of AC necessitates complex mechanisms such as frequency synchronization during power switching. By contrast, with DC power feeds the storage battery can be connected directly to the power supply line, and the likelihood of breakdowns is therefore smaller [3].

When applied to higher-voltage DC power feeds, the designation *HVDC* corresponds to a voltage approximately eight times higher than the DC 48 V traditionally used to power communication equipment, and this is the definition that started to take hold in the field of communications facilities. However, HVDC is also used in the field of DC power supply technology, where it refers to electrical power systems operating at 100 kV or more. To avoid confusion, the ITU-T uses the designation “up to 400 VDC” instead of HVDC when referring to power feed systems.

## 3. Activities of standards organizations

Discussions on the standardization of HVDC power feeds operating at up to 400 V are mostly being held by the ITU-T, the IEC, and the ETSI (European Telecommunications Standards Institute). These three organizations have coordinated their efforts through liaison relationships enabling them to cooperate and exchange information.

The groundwork for standardization of HVDC power feeds aimed at datacenters and communication buildings was started by the ITU-T in 2009. In May 2012, the ITU-T gave its approval to Recommendation L.1200 (“Direct current power feeding interface up to 400 V at the input to telecommunication and ICT equipment")* by study group 5 (SG5). In the same year, the ETSI published a similarly specified European standard EN300-132-3-1 ("Power supply interface at the input to telecommunications and datacom (ICT) equipment"). NTT also participated in the discussion on this ETSI standard as an associate member.

The IEC has also continued to work proactively. The SMB (Standardization Management Board)/SG4 (low voltage DC distribution systems) is discussing the issues of DC power distribution at voltages up to 1500 V, as well as the items that require standardization, for application not only to communication buildings and datacenters but also to ordinary buildings, households, solar power generation facilities, and to storage batteries (including electric vehicles). It is also studying the technical issues related to DC power delivery and a systematic approach to standardization, and is currently preparing a roadmap for this field. TC (Technical Committee) 23/WG (Working Group) 8 is conducting draft deliberations on connectors for DC 400-V power feeds (rated at 2.6 kW and 5.2 kW), TC64 is studying the construction, maintenance, and safety protection of indoor electrical facilities, and SC (Subcommittee) 23 is conducting fresh discussions relating to DC circuit breakers.

Another standardization organization is the EMerge Alliance, which is also engaged in discussions relating to the preparation of standards [4]. This is a North American industry organization that promotes the use of DC power distribution within buildings (for lighting etc.). It plans to publish a standards document within the 2012 fiscal year. Another North American industry organization called The Green Grid [5] aims to improve the efficiency of resources used by data centers and in 2010 published a white paper on HVDC power feeds (Japanese translation published in 2011).

## 4. ITU-T SG5 standardization activities

Within ITU-T SG5, a working party focusing on environment and climate change issues (WP3/5: Working Party 3/Study Group 5), has been investigating how the use of ICT is affecting the environment and has been working on related recommendations (**Fig. 2**). As of December 2012, WP3/5 has been addressing six questions (Qs). One of these questions (Q19/5) is being discussed in relation to three points connected with HVDC power feeds: (1) specifications of ICT equipment power supplies compatible with HVDC power feeds, (2) power feed system configurations, and (3) power feed performance evaluation methods.

* When the recommendation was approved in June 2012, it was titled "Specification of DC power feeding system interface"; it was subsequently changed after a proposal was made by the committee.

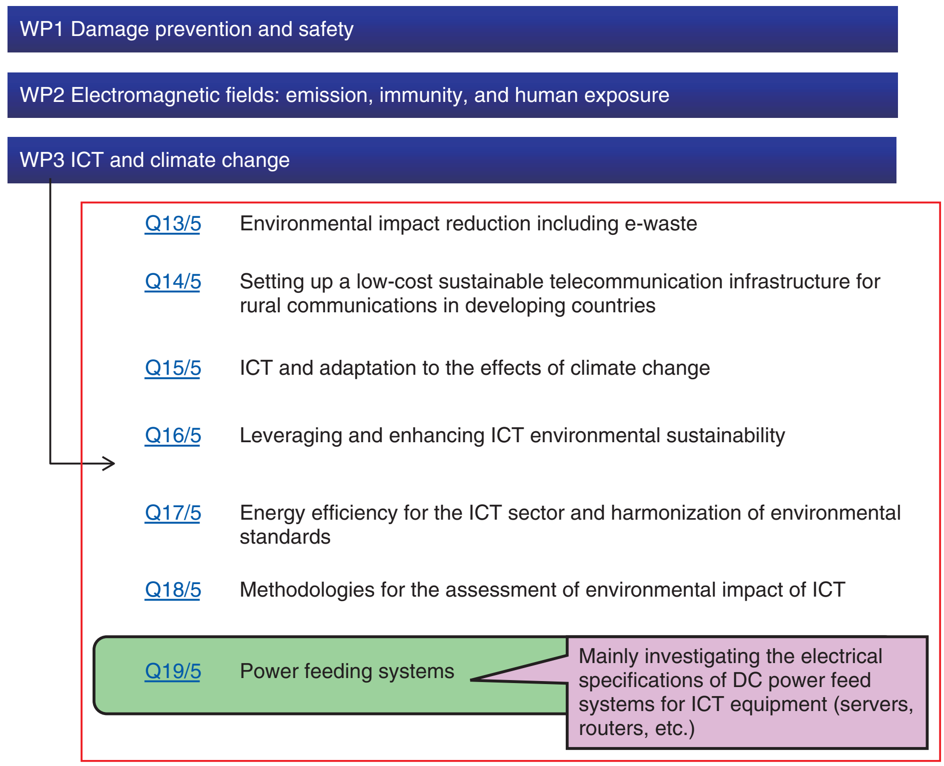
## 5. Overview of L.1200

ITU-T Recommendation L.1200 is a basic specification relating to ICT equipment power supplies that are compatible with HVDC power feeds. NTT and other Japanese members have contributed greatly to the drafting work of this recommendation. This recommendation applies primarily to communication carrier buildings and datacenters and describes the minimum requirements and specifications for achieving reliable communication services. An overview of a power feed system to which L.1200 applies is shown in **Fig. 3**. The basic configuration is based on a DC 48-V system that is used worldwide. To show the interface conditions (power supply specifications) at the input terminals of power supplies for ICT equipment, the points of contact between the power feed system and ICT equipment are defined as *interface P*, for which various types of electrical specifications are provided.

### 5.1 Operating voltage range of ICT equipment

A crucial item in determining the power source specifications is the equipment's operating voltage range. Here, the voltage range is set by assuming a configuration where electricity is supplied directly from a storage battery, which is the main feature of a DC power feed, and the standard voltage range was chosen to be 260–400 V. ICT equipment compatible with newly installed HVDC power feeds is required to continue operating stably within this voltage range without any stoppages, failures, or malfunctions. With regard to the voltage range setting when considering the operation of this storage battery during power outages, there has been considerable support from communications carriers in Europe.

In the initial discussions on the standardization of voltage ranges, no agreements could be reached for several years. Meanwhile, NTT was also participating in the discussions on the ETSI standard (EN300-132-3-1), which was approved in 2011. Furthermore, research in this area stimulated a lot of product development and verification trials, mainly in Europe and North America, and this subsequently led to the




Source: http://www.itu.int/en/ITU-T/studygroups/2013-2016/05/Pages/structure.aspx

Fig. 2. Questions being discussed by ITU-T SG5 WP3.

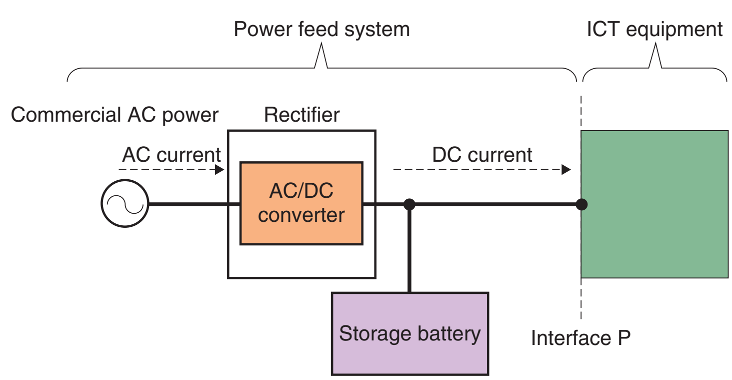



Fig. 3. Overview of power feed system that L.1200 applies to (commercial power supply).

adoption of the voltage range proposed by Japan and Europe in ITU-T Recommendation L.1200. An agreement was reached on the voltage range in 2011, and standardization was achieved in 2012.

### 5.2 Dealing with transient voltage fluctuations

It is essential to consider transient voltage fluctuations in power supply devices for communications equipment. As shown in **Fig. 4**, even when transient voltage fluctuations occur due to a problem such as a blown fuse or tripped breaker in the power feed system, the ICT equipment must continue with normal

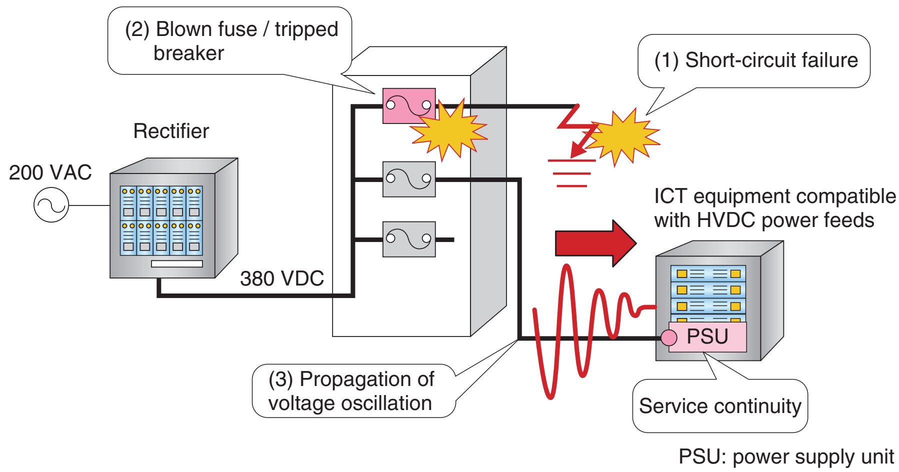



Fig. 4. Propagation of voltage fluctuations.

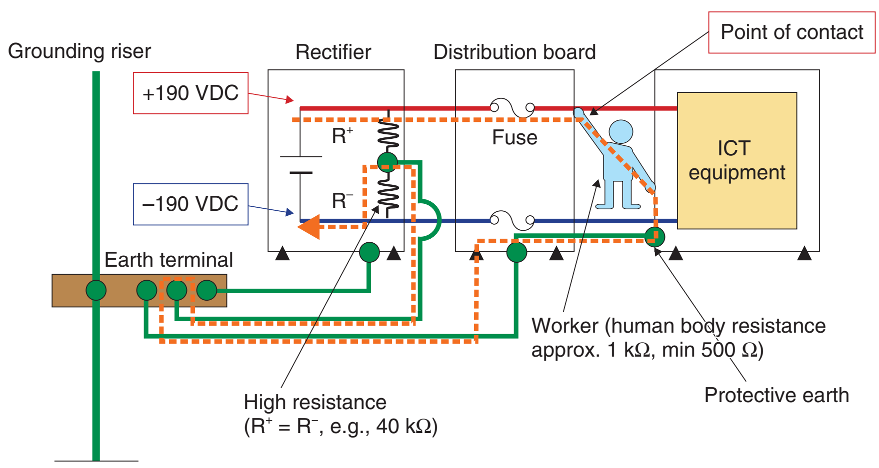



Fig. 5. Grounding configuration and earth fault currents in an HVDC power feed.

operations (service). The test methods reference the IEC61000-4 series, and the test equipment is compatible with existing commercial products. Tests are performed with standard voltage fluctuations and voltage drops relative to the test voltage chosen according to system requirements.

### 5.3 Grounding and isolation

In this specification, grounding is implemented by a high-resistance scheme considering the safety not only of the engineers using the ICT equipment but also of the facility managers. An overview of this grounding scheme is shown in **Fig. 5**. When there is a ground fault or current leakage, the large intervening resistance suppresses the resulting current so that even if someone touches the equipment, the flow of current is so weak as to cause no injury or discomfort. Power sources for ICT equipment are also required to use isolating converters as shown in **Fig. 6**, and are configured so that the primary side (DC feed) and secondary side (e.g., motherboard) are isolated from each other in order to provide secure protection against electric shocks.

## 6. Future prospects

HVDC power feed technology shows great promise as a means of reducing the power consumption of

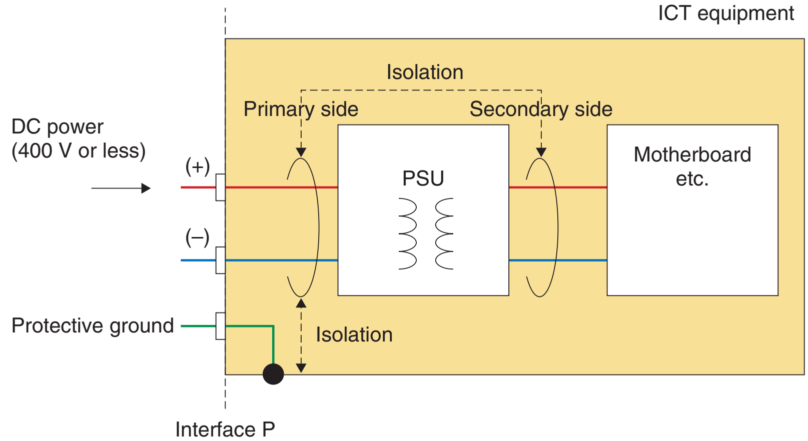



Fig. 6. Isolation conditions of power supply unit in ICT equipment.

ICT equipment and facilities because the losses incurred during power conversion are small in principle. It is also characterized by a strong affinity with DC power sources such as those used in solar electricity generation, electric vehicles, and fuel cells, and is expected to be used in a wide range of applications. At the NTT Group, we are pressing ahead with international standardization efforts in order to promote the widespread use and technical development of DC power feed technology.

## References

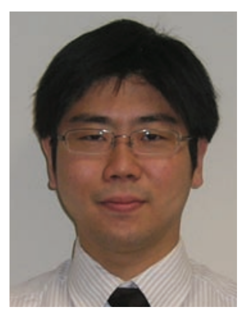

[1] K. Asakura, T. Tanaka, and T. Babasaki, "Higher-voltage Direct Current Power-feeding System," NTT Technical Review, Vol. 9, No. 2, 2011.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201102fa2.html

[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] H. Ikebe, "Power Systems for Telecommunications in the IT Age," Proc. of the 25th International Telecommunications Energy Conference (INTELEC'03), pp. 1–8, Yokohama, Japan.

[4] Emerge Alliance. http://www.emergealliance.org/

[5] The Green Grid. http://www.thegreengrid.org


**Toshimitsu Tanaka**

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

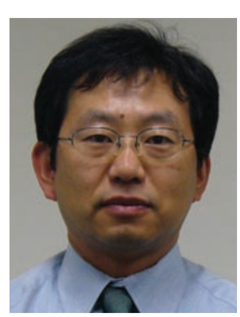
He received the M.S. and Ph.D. degrees in electronic engineering from Chiba University in 2001 and 2007, respectively. He joined NTT in 2007. He has mainly been engaged in analyzing the stability of DC power feeding systems for telecommunications. He received the Young Researcher's Award from the Institute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



**Kaoru Asakura**

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

She received the B.E. and M.E. degrees in applied chemistry from Keio University, Kanagawa, 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 systems for telecommunications. She received the ITU-AJ Award Encouragement Award ICT Accomplishment Field, Japan in 2012.


**Tadatoshi Babasaki**

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

He received the M.S. and Ph.D. degrees in electronic engineering from Nagasaki University in 1990 and 2011, respectively. He joined NTT Applied Electronics Research Laboratories in 1990. He has mainly been engaged 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.

# External Awards

### CEATEC JAPAN 2012 Innovation Awards As Selected by U.S. Journalists GrandPrix

**Winners:** NTT DOCOMO, Inc.
**Date:** October 4, 2012
**Organization:** CEATEC JAPAN

For "translator Appli".
http://www.ceatec.com/2012/en/event/event05_02_02.html

### The 18th Asia-Pacific Conference on Communications (APCC 2012)
### Best Paper Awards

**Winners:** Hiromasa Fujii, Shunji Miura, and Hidetoshi Kayama, NTT DOCOMO, Inc. Research Laboratories
**Date:** October 16, 2012
**Organization:** APCC

For "Novel cognitive radio technique for using white space in public cellular networks".

In this study, we investigate the potential of cognitive radio systems (CRSs) with the aim of using the white space (WS) in public cellular networks (PCNs). We first clarify the difficulties specific to PCN WS usage and propose a CRS technique with a Cognitive-radio Supportive Accommodation System (CSAS) as a scheme to overcome the difficulties. The main concept of the scheme is that CSAS, which is the primary system that owns the frequency band, agrees to support CRS functions required for spectrum sharing. The spectrum sharing scheme is designed on the PCN signal formats so as to suppress inter-system control signal overheads. We outline the prototype devices equipped with the proposed scheme and present some initial evaluation results obtained on an indoor testbed composed of the prototype devices.

**Published as:** H. Fujii, S. Miura, and H. Kayama, "Novel cognitive radio technique for using white space in public cellular networks," Proc. of the 18th Asia-Pacific Conference on Communications (APCC 2012), pp. 266–271, Jeju, Korea.

### Best Paper Award

**Winners:** Yuki Kurauchi, Toshio Uchiyama, and Tadasu Uchiyama, NTT Service Evolution Laboratories
**Date:** November 21, 2012
**Organization:** WebDB Forum

For "Inferring user profiles in social networks using Markov random field" (in Japanese).

If user profiles in social networks are estimated, we can analyze users' postings in each profile and utilize the profiles for marketing. Studies have been done on inferring user profiles from their content, but there is still room for improving accuracy. Thus, we advance the studies by combining this idea with the knowledge that social neighbors tend to share traits with each other. We propose a method of inferring true user profiles by modeling user profiles in social graphs using a Markov random field. In our evaluations, the proposed method removed 54% of artificial noise in the inferred psychographic profiles and improved 9.1% points of accuracy in the inferred demographic profiles.

http://db-event.jpn.org/webdbf2012/award.html (in Japanese).

### FY2012 Industrial Standardization Awards, Industrial Science and Technology Policy and Environment Bureau Director-General's Awards

**Winner:** Yoshiaki Tarusawa, NTT DOCOMO, Inc. Research Laboratories
**Date:** December 15, 2012
**Organization:** Ministry of Economy, Trade and Industry

For contributions to supporting international standardization activities in various ways.

http://www.meti.go.jp/english/press/2012/1012_01.html