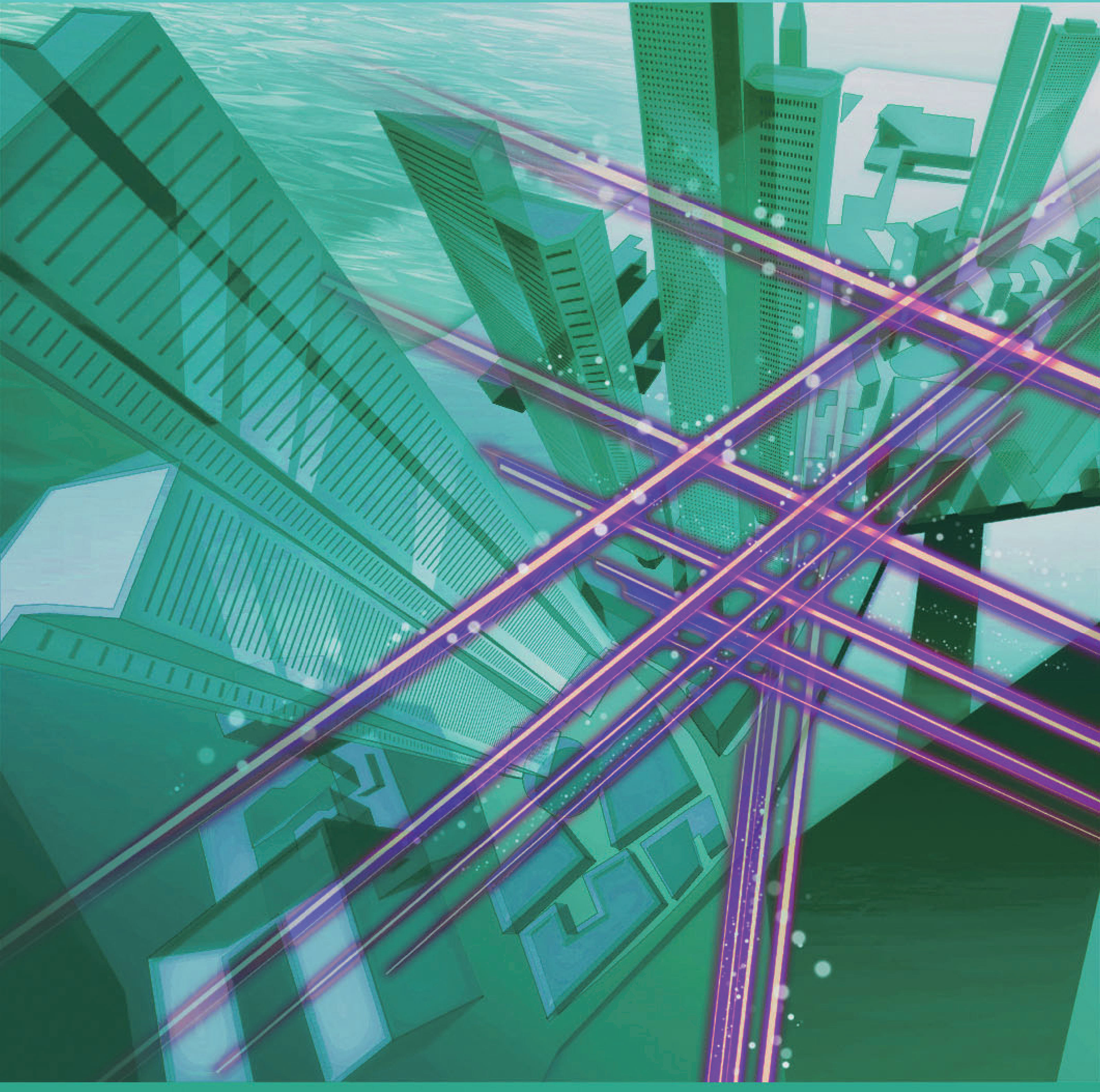
NTT Technical Review

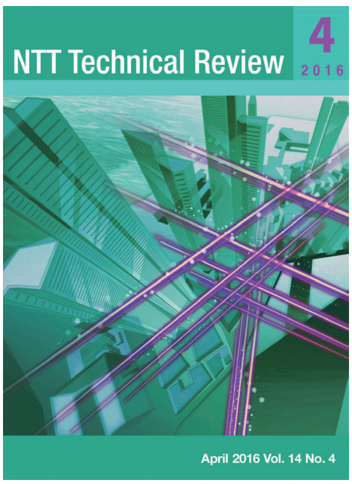
4
2016



April 2016 Vol. 14 No. 4

NTT Technical Review

April 2016 Vol. 14 No. 4



Business Transformation of NTT Group —The Use of IoT and Big Data—

Hiroo Unoura
President and Chief Executive Officer, NTT

Overview

This article introduces NTT Group initiatives towards advanced application of the Internet of Things (IoT) and big data. The contents of the article are based on the keynote lecture presented by NTT President and Chief Executive Officer Hiroo Unoura at NTT R&D Forum 2016 held February 18–19, 2016.

Keywords: IoT, big data, data protection

1. The era of IoT and big data

The amount of digital data in the world is expected to increase by about 6,000 times in the 20-year period from 2000 to 2020, while the number of devices connected to the Internet should reach about 50 billion by 2020, a figure about seven times the population of the world. During this time, the machines (computers) for processing this massive amount of data will also evolve; the supercomputers in the year 2020 are expected to have a processing performance greater than 80,000 times that of supercomputers in 2000 (**Fig. 1**).

This evolution of machine performance will be accompanied by an evolution of artificial intelligence (AI). In chess, IBM's Deep Blue supercomputer defeated the world champion in 1997, and in the game Othello, the Logistello program defeated the world champion in the same year. The number of moves in Othello and chess is about 10^{60} and 10^{120}, respectively, while that of *shogi* (Japanese chess) and *go* is about 10^{220} and 10^{360}, respectively. It has been said that AI cannot easily beat human beings in the world of *shogi* and *go*, but even professional players have come to be defeated by AI programs in recent years. There is also a project now in progress to bring AI up to a level high enough to pass the University of Tokyo entrance exam by 2020.

The era of Internet of Things (IoT) and big data is fast approaching. In this era, IoT will drive the creation of a massive amount of data beyond anything we have seen before, and the use of evolved machines and AI will enable a level of data analysis that conventional computer processing can in no way achieve.

The use of big data will likely begin in the corporate world with the aim of improving productivity. In this case, companies will use big data that they collect on their own in order to promote more efficient and advanced business processes. A company that analyzes big data that it has collected will be able, for example, to predict the occurrence of equipment failures or optimize equipment operation. The keys to achieving this are machine-to-machine (M2M) technology as well as AI and machine-learning technologies for analyzing big data (**Fig. 2**). This initiative, called Industrie 4.0 in Germany and Industrial Internet

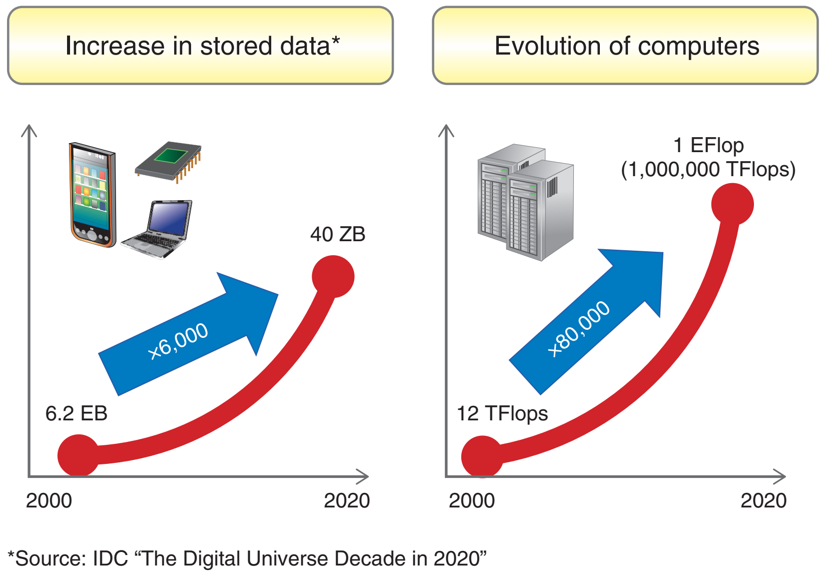


Fig. 1. Era of IoT and big data.

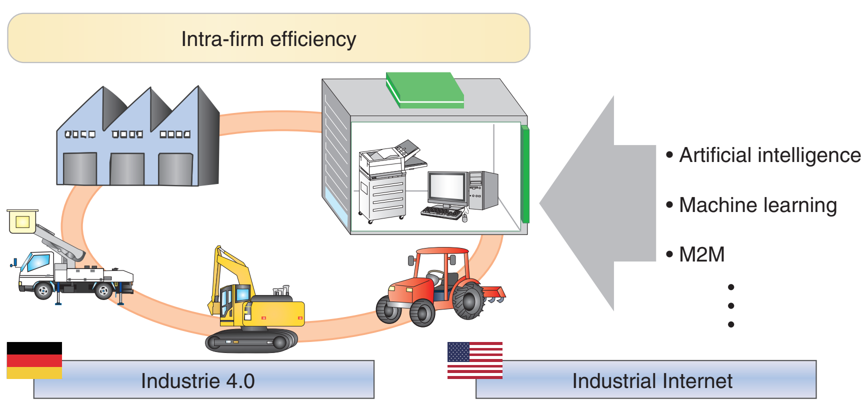


Fig. 2. Transformation of industrial structure.

in the United States, is helping to transform the corporate business model and the industrial structure.

For example, Rolls-Royce Holdings has begun to provide airplane engines under a completely new business model known for its long-term, comprehensive contract called TotalCare*. In this program, fees stipulated in the contract are calculated based on the total operating time of a jet engine, so the company naturally tracks the condition of engines using sensors and optimizes equipment repair plans. I believe that this model will help transform the business model of the aviation industry in the years to come.

2. Solving social and global concerns

Another important initiative is the use of big data to address social and global concerns (**Fig. 3**). The idea here is to collect information from all sorts of fields such as transportation, medical care, the environment, agriculture, manufacturing, and education in the form of big data, and to provide it to the world as a public asset for use in solving a wide variety of social and global problems.

For example, transportation and medical care data

* TotalCare is a registered trademark of Rolls-Royce Holdings plc.

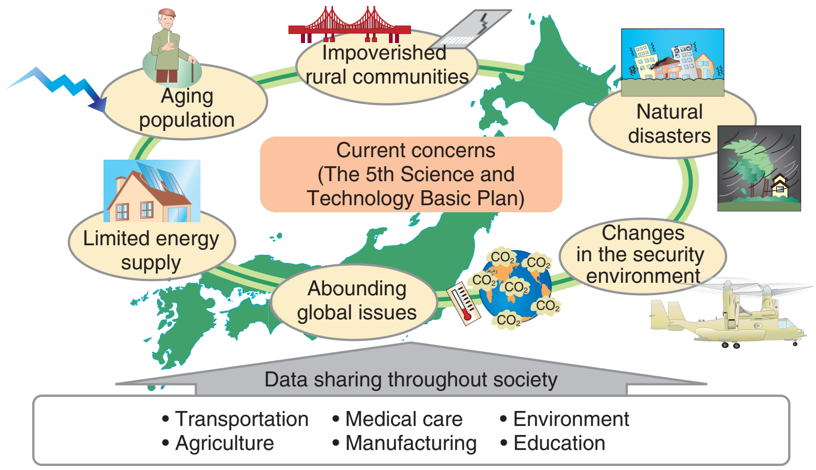


Fig. 3. Solving social and global concerns.

could be combined to reduce the time needed to transport a patient in an emergency, and environmental and manufacturing data could be linked in order to minimize wasteful consumption of electricity and help solve the energy problem.

This type of inter-industry linkage of information has the potential to create new value. Thinking back to the German and American initiatives mentioned in section 1, we can ask whether Japan should create a mechanism for sharing and using data throughout society. On January 22, 2016, the 5th Science and Technology Basic Plan was approved by the Cabinet Office in Japan. This plan points out current concerns such as the limited supply of energy, the aging population and a low birth rate, impoverished rural communities, natural disasters, changes in the security environment, and various global issues. To solve these problems, we need to promote Japan-oriented usage of IoT and big data. These problems are most striking in regional communities, so this initiative should also lead to regional revitalization.

2.1 Maintenance of social infrastructure

Maintenance of the regional social infrastructure is now a pressing issue in Japan. Tunnels, bridges, roads, and other facilities constructed during Japan's high economic growth period (from 1955 to 1973) are deteriorating with the passage of time and need to be maintained, and the potential collapse of aged building walls and signboards is also a danger to society. The NTT Group handles the maintenance of utility poles, cable tunnels, and manholes, which are essential to maintaining Japan's telecommunications infrastructure. Over the years, we have developed and enhanced efficient maintenance technologies such as prediction of facility deterioration through vibration and image analysis as well as rainwater detection. However, if this know-how were to be applied in its present form to the theme of maintaining the social infrastructure, the scope of maintenance operations would broaden immensely. For this reason, it is important that analysis incorporate not just the values detected by vibration sensors and the data provided by image sensors but also other forms of information such as online posts and reports from citizens as big data. In this way, dangerous locations could be identified beforehand, and plans for maintenance and upgrading could be efficiently formulated.

2.2 Self-driving cars

Self-driving cars have been receiving lots of attention of late. In this field too, sharing of data throughout society is essential. For example, if information describing the destinations of each automobile on the road could be shared, AI could distribute the routes taken by those cars in a way that prevents traffic congestion. In addition, if accident reports, road conditions such as icing, and information on emergency vehicles on the road could be shared in real time, not just individual driving but overall traffic could be optimized.

3. Issues in data sharing and usage

There are two main issues in achieving data sharing and data usage throughout society as described

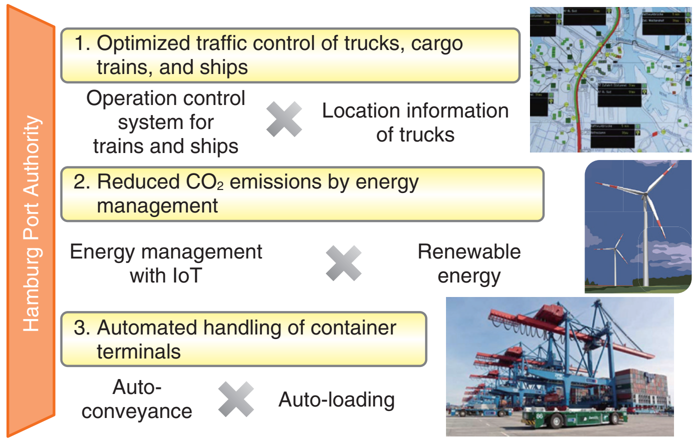


Fig. 4. Case study: Port of Hamburg.

above. The first is a data gathering framework that can enrich both the quality and quantity of data. For example, a basic rule in using open data is that the data created from its use must flow back to society as big data and open data to be shared. There is a need here for a neutral institution that serves as a data gathering coordinator so that the gathered data do not become biased toward a particular corporate group or industry. Of course, there will also be a need for various types of data standards and protocols in data gathering.

The other main issue is rule-making for safe and secure data use. The use of data for malicious purposes and the leakage of personal information must, of course, be prevented. Furthermore, in the handling of big data, due consideration must be given to the preservation of anonymity in addition to the application of encryption to prevent spoofing (impersonation) and data tampering. There have been cases in which mixing certain data with other types of data lowers anonymity. In addition, data usage rules covering the purpose of use, the method of use, and the handling of information must be implemented.

While it is necessary to combine and handle diverse types of information to solve social issues, the monopolization of information by a single enterprise would hardly be acceptable. To promote a data-sharing initiative, I believe that local municipalities must take the lead and play the role of a data-handling hub. In particular, a local municipality could merge basic data that it possesses—such as demographic information, map information, and disaster prevention information—with big data gathered via IoT by individual companies and provide that data back to industry as publically owned open data. In this way, diverse types of information can be integrated and used via a local municipality without confining it to a single enterprise, which should vastly expand the possibilities of big data and facilitate the development of regional business. Moreover, as mentioned earlier, feeding back the results of using big data can lead to secondary and tertiary use of big data, which should promote the preparation of open data at an even higher level of quality and quantity. We can expect such locally originated initiatives to vitalize local industry and to contribute to the creation of a Japan-oriented ecosystem. Furthermore, the usage fee of big data in a performance-based manner should promote the use of big data by local startups.

Unfortunately, some companies are considering the resale of data gathered by free Wi-Fi. I have been saying to NTT Broadband Platform, an NTT Group company involved in the Wi-Fi business, that we should not make small change from the primary use of such data. This is because such a way of using data involves privacy issues and hinders the sound development of the use of big data.

4. Enhancement of urban infrastructure by IoT

Two case studies involving the use of IoT are introduced in this section.

4.1 Port of Hamburg

The first case study is the Port of Hamburg in Germany (**Fig. 4**). The Port of Hamburg is Germany's largest port, handling more containers than the combined total of the Port of Tokyo and Port of Yokohama,

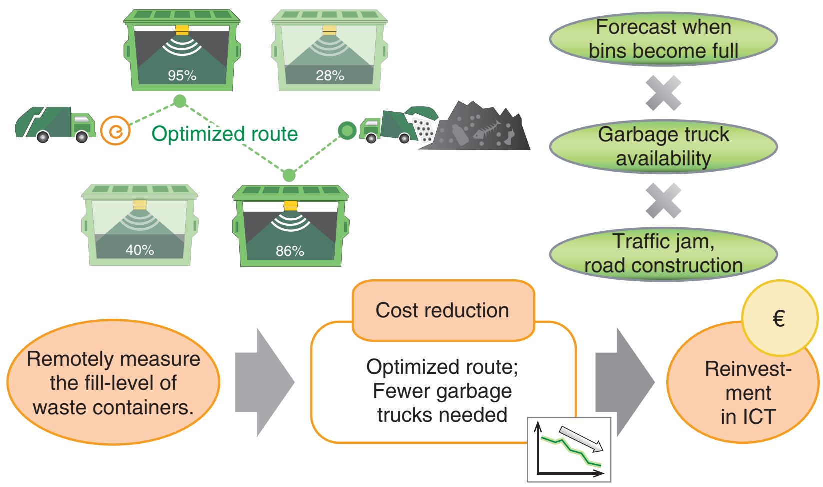


Fig. 5. Case study: Enevo Corporation.

Japan's No. 1 and No. 2 ports. About 33,000 trucks come and go daily in a site equal to about 1,600 times the space of the Tokyo Dome (4.7 hectares x 1,600: 7,500 hectares), which has led to chronic congestion. The site includes movable bridges to allow large ships to pass, which has also contributed to the congestion. To resolve this congestion problem, all data on the movement of trucks, trains, ships, and other vehicles and that on the raising and lowering of the bridge are now gathered as big data and analyzed, resulting in the optimization of multimodal traffic. In addition, the conveyance of containers and their loading onto trains and other means of transport are automated, with the result that the number of containers handled per hectare is currently more than twice that of the Port of Nagoya, Japan's most efficient port.

4.2 Enevo Corporation

The next case study is Enevo Corporation in Finland (**Fig. 5**). In Europe and the United States, it is common for garbage trucks to pick up trash daily from large trash bins placed on street corners. This system adds to traffic congestion and causes various other social problems. Enevo has addressed this issue by using IoT technology to convert the level of trash in each bin to big data so that the trash bins to be emptied can be selected appropriately and optimal routes for trash collection can be created. This method has been provided to local municipalities. As a result, these local municipalities have been able to halve the number of garbage trucks they operate. They have also been able to reduce the number and severity of traffic jams and achieve cost reductions.

The use of IoT technologies in these ways has helped create a beneficial cycle in which waste is eliminated and the amount of money saved is reinvested in information and communication technology.

5. Collaboration with local municipalities

With the aim of advancing concrete initiatives with local municipalities, the NTT Group concluded a comprehensive partnership agreement with Fukuoka City in April 2015 and a development partnership agreement with the City of Sapporo in September 2015. These initiatives are being undertaken as concentrated case studies toward regional revitalization by exploiting the local characteristics of Fukuoka and Sapporo. The urban scale of both cities involves a sum just under a total of two trillion yen in general accounts, special accounts, and corporate accounts, which we consider to be an optimal urban scale for testing a variety of initiatives.

At present, the port at Fukuoka City has nearly reached saturation due to inbound demand generated by Chinese tourists and other factors, while the City of Sapporo is faced with various problems that need quick attention, as it plans to hold the 2017 Asian Winter Games. In these cities, the aim is to collect big data from companies, citizens, and organizations, accumulate it at the local municipality level, and use the data throughout society as open data. There are expectations that the use of such data in a variety of fields such as tourism, transportation, medical care, and nursing will be promoted and will lead to

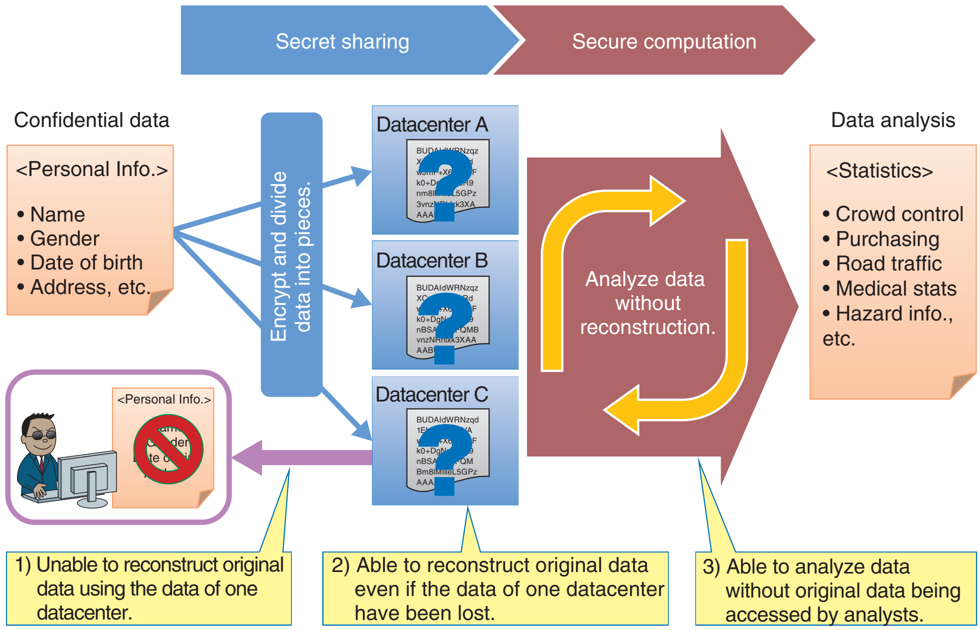


Fig. 6. Data protection technologies.

industrial development, disaster prevention, and public infrastructure management.

However, there are limitations as to what the NTT Group can do on its own here. I look forward to collaborating with diverse players that have already agreed to participate in these initiatives.

6. Security technologies for IoT and big data

In this section, issues concerning data security are explained.

6.1 Data protection

Data protection technologies are essential to the use and application of big data. These include secret sharing and secure computation now under development by the NTT Group (**Fig. 6**). Secret sharing achieves robust security through the encryption and division of data into pieces that are then stored in multiple servers in the cloud. Secure computation, meanwhile, enables data to be computed and analyzed in that divided state without having to decrypt the data. With these technologies, dividing and storing a set of data among multiple datacenters means that information cannot be leaked even if the data at one datacenter are stolen. It also means that the entire set of data can still be reconstructed even if data at one datacenter were to be lost due to a natural disaster or other mishap. The data can also be analyzed without analysts having to come into contact with the original data.

6.2 Personal data anonymization and analysis

In October 2015, the Special Interest Group on Computer Security of the Information Processing Society of Japan (IPSJ) held its first Privacy Workshop. This event featured competitions that were held focusing on technologies used for handling personal data, and an NTT laboratories' team won the anonymization and reconstruction competition. In the case of big data, any use of personal data needs to be anonymized, but at the same time, the information itself needs to be analyzed. In other words, there is a simultaneous need for anonymization that conceals data in order to obfuscate the original information, and for analysis that can provide useful information for the real world from the original information.

Security technologies such as these constitute a field that the NTT Group excels at. We aim to become even stronger in this field in collaboration with industry, government, and academia.

7. Information processing technologies in the era of IoT and big data

I previously mentioned the application of big data to self-driving cars. This system requires quick

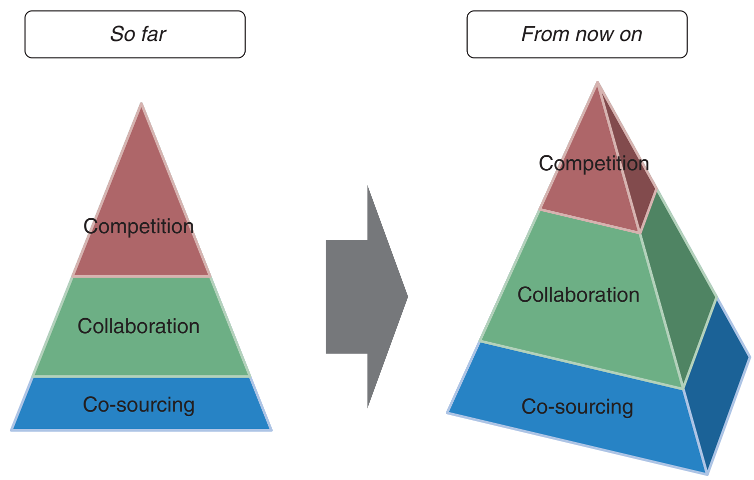


Illustration is created based on "Creating Shared Value for Management Innovation" (Takashi Nawa).

Fig. 7. Era of collaboration.

response (real-time characteristics) in order to be feasible. When a traffic jam occurs, local processing is likely to become congested, but since this system functions as a social infrastructure, even a momentary interruption is unacceptable. In response to this problem, NTT is researching edge-computing technology.

Edge computing reduces the response time by the installation of servers at the edge of the network, that is, in the locations nearest the automobiles targeted for processing. When connecting to ordinary Internet servers, the response time is about 100 ms, but with this technology, the aim is to reduce that time to less than 5 ms.

8. The era of collaboration

About three years ago, I expressed the belief that we were entering an era of collaboration. I recently read a book by Professor Takashi Nawa of Hitotsubashi University, which talked about the three layers of competition, collaboration, and co-sourcing (**Fig. 7**). In the coming era of IoT and big data, I believe that collaboration—the middle layer—will become increasingly important if data sharing continues to expand. Moreover, if collaboration expands in all sorts of fields, competition will take on a more diversified form, and the world may take on an entirely new dimension.

Incidentally, the focus of the fiber-to-the-home (FTTH) business model of NTT EAST and NTT WEST was redirected from retail sales to wholesale (Hikari Collaboration Model) in February 2015. In other words, the business model was transformed to one that promoted collaboration by enabling other operators to sell FTTH, which had formerly been positioned in the competition layer, in combination with their own services. At present, several players including NTT DOCOMO are rolling out original services combined with FTTH and competing with each other in this way. In the future, we can envision a migration of mobile services as well to the collaboration layer. This collaboration model should stimulate competition in novel services and produce added value.

9. Society 5.0

Japan's 5th Science and Technology Basic Plan mentioned earlier points out a number of social issues. The government advocates the concept of a super smart society as a means of solving these issues.

The super smart society is defined as "a society where the various needs of society are finely differentiated and met by providing the necessary products and services in the required amounts to the people who need them when they need them, and in which all the people can receive high-quality services and live a comfortable, vigorous life regardless of their various differences such as age, gender, location, or language."

Such a society will be created by broadening the

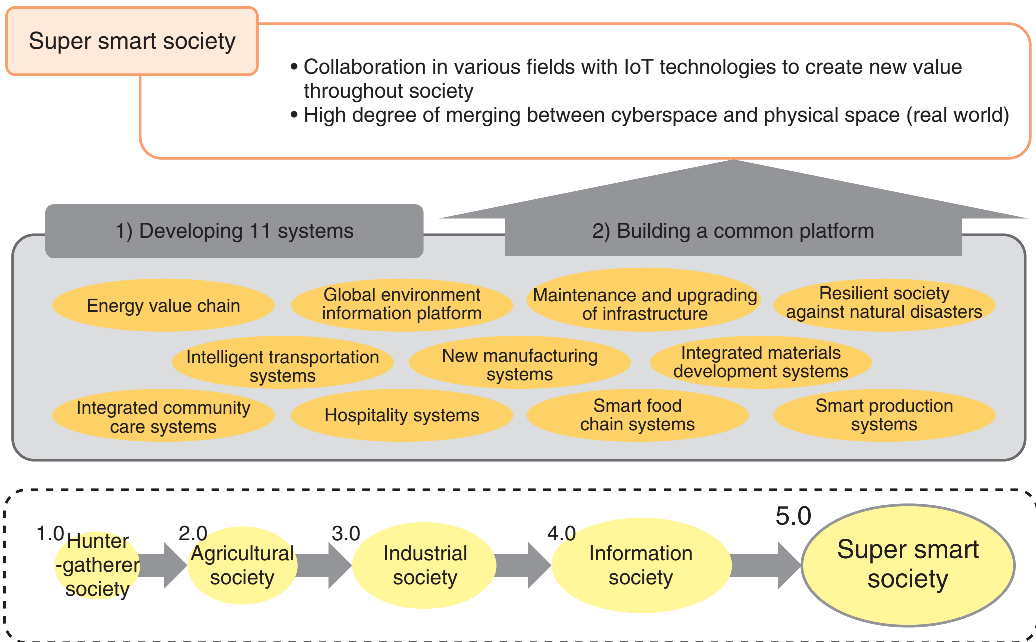


Fig. 8. Society 5.0.

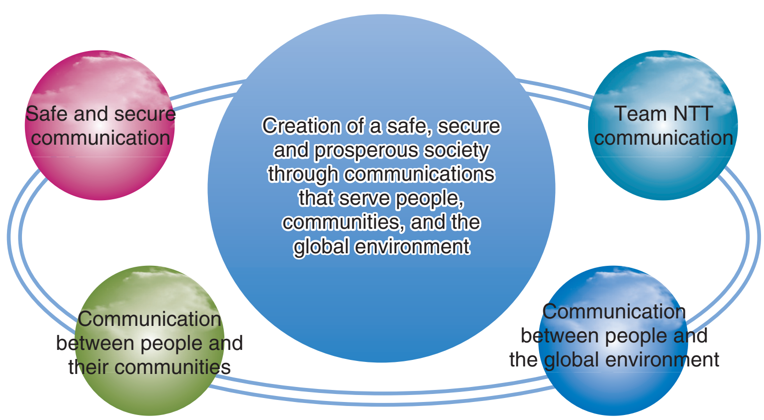


Fig. 9. NTT Group CSR Charter.

scope of IoT application beyond manufacturing to a wide variety of fields in order to transform society and by achieving a high degree of merging between cyberspace and physical space (the real world). The government has named this series of initiatives Society 5.0 (**Fig. 8**).

The 5th Science and Technology Basic Plan calls, in particular, for the development of systems in 11 fields and the building of a common platform for running these systems to achieve a super smart society. It should be easy to see that the aim here is to achieve data sharing throughout society. Incidentally, the notation 5.0 here signifies that the super smart society is the fifth type of society to develop in human history after the hunter-gatherer society, agricultural society, industrial society, and information society.

10. NTT Group CSR Charter

The NTT Group CSR (corporate social responsibility) Charter drawn up in 2006 is shown in **Fig. 9**. The main theme of this charter is the *creation of a safe,* *secure, and prosperous society through communications that serve people, communities, and the global environment* through four types of communication. I was initially a bit unsure of these somewhat abstract declarations, but I now feel strongly that we are on the verge of such an era. As a major direction in its business transformation toward the future, the NTT Group is doing everything in its power to shape communication between people and their communities and between people and the global environment.

NTT Research and Development for the Age of Transformation

Hiromichi Shinohara
Senior Executive Vice President and Senior Vice President of Research and Development Planning, NTT

Overview

This article introduces NTT's research and development (R&D) activities designed to create new value by providing cutting-edge technologies and also through collaboration with various partners toward realizing a better society. This article is based on the keynote lecture presented by Hiromichi Shinohara, NTT Senior Executive Vice President and Senior Vice President of Research and Development Planning, at NTT R&D Forum 2016 held February 18–19, 2016.

Keywords: R&D strategy, artificial intelligence, IoT

1. Introduction

In response to increases in the number of security threats and in the volume of traffic on the network, the various research and development (R&D) laboratories at NTT (hereafter, NTT R&D) are carrying out R&D to address social issues, reinforce industrial strength, help revitalize local economies, and thereby build a better society by providing advanced technologies that enable information and communication technology (ICT) to further penetrate our lives.

Toward these ends, NTT R&D is focused on networking, cloud, security, and basic technologies that provide foundations for those technical areas. This article first addresses artificial intelligence (AI) and the Internet of Things (IoT), both of which have come under the spotlight in recent years.

2. Directions for AI technologies

AI has become a hot topic and aims at duplicating the intellectual faculties of humans using machines. The workings of the human brain can be regarded as consisting of three processes: 'recognition/understanding of the external world,' 'inferring/judging,' and 'providing feedback to the external world.' Based on this understanding, AI is beginning to be used in a number of different fields. What are the intellectual faculties of humans? Human activity for perceiving/recognizing the external world means recognizing not only objects and people but also human emotions and nuances of human expression. Naturally, we make the most of all five senses. Human activity for *judging and generating answers* does not necessarily mean capturing and processing all available information but rather, concentrating on the information needed to facilitate judgment. An AI machine playing a game of *go* can determine its next move but cannot explain why it has selected that move. Human activity for *providing feedback to the external world* includes the ability to take actions that please others and to communicate with them while taking care to sense what is pleasing, which can vary from person to person and also depends on the historical background.

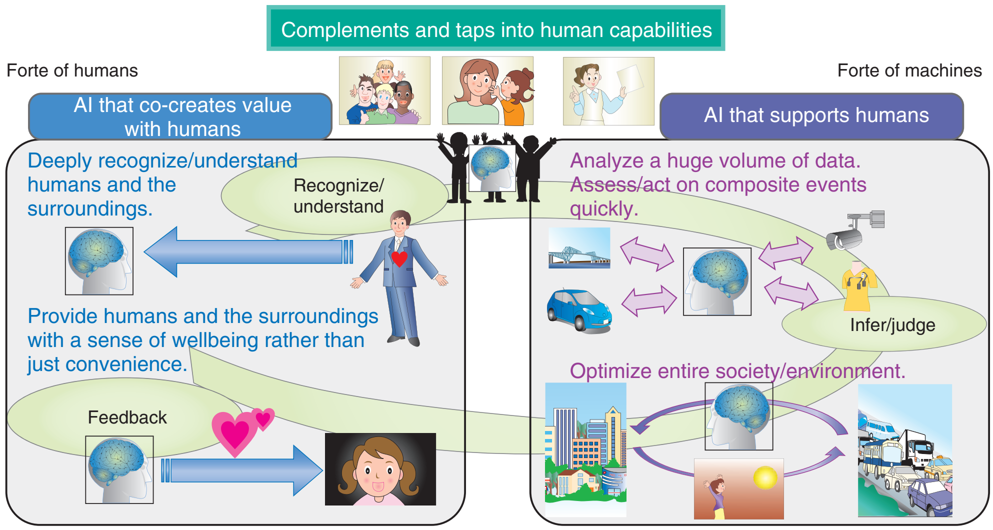


Fig. 1. AI targeted by NTT R&D.

When we humans touch a cup containing a piping hot beverage, then instantly let go of it to avoid being burned, we do so intuitively, without thinking. Similarly, there is a gap between the AI that is currently attracting interest and the intellectual faculties of humans.

With this gap in mind, NTT R&D believes that the role of AI is not to emulate the intellectual faculties and thinking of humans but, rather, to complement and tap into human faculties. In other words, our concept of AI's role is as a facility to substitute for or support some human activities in such ways that it can co-exist with humans or co-create value with humans to enrich their lives (**Fig. 1**). Naturally, there are areas in which machines are more effective and/or efficient and other areas in which humans are more adept. For example, machines are better at analyzing enormous volumes of data and rapidly assessing composite events. It is necessary to thoroughly polish this ability and incorporate it into NTT R&D's AI. On the other hand, humans are still way ahead of machines in recognizing and profoundly understanding other human beings and the environment, and in providing agreeable feedback to humans. NTT R&D will polish its technologies in order to bring its AI closer to those human faculties. Thus, our goal is to combine the AI that supports humans and the AI that co-creates value with humans in order to develop a type of AI that complements and taps into human faculties.

2.1 Four types of AI targeted by NTT

We have defined four specific types of AI—Agent-AI, Heart-Touching-AI, Ambient-AI, and Network-AI—and we are undertaking R&D in line with these categories (**Fig. 2**).

Agent-AI is the closest to the type of AI that is attracting interest today. It interprets information generated by humans, understands the surroundings, intentions, and emotions of humans, makes inferences based on enormous volumes of data, and enables robots to conduct a sophisticated dialogue with humans. A major feature of Agent-AI is that it expands the parameters of our daily lives, for example, substituting for or supporting the routine work done in a contact center, supporting intellectual activities such as medical diagnosis, and assisting humans in moving and communicating.

Heart-Touching-AI goes beyond the type of AI that is based on superficial knowledge. It interprets subconscious human mental and physical conditions and gains an understanding of the deep psyche, intellect, and instincts of humans in order to help build a society that provides a sense of well-being rather than merely convenience.

Ambient-AI seeks to give objects a kind of knowledge and make them behave in an organized manner. NTT R&D proposed the concept of *ambient intelligence* in 2006. In those days, computer power was lacking, and no satisfactory cloud environment was available. Now that these conditions have improved, we believe that Ambient-AI has become a realistic

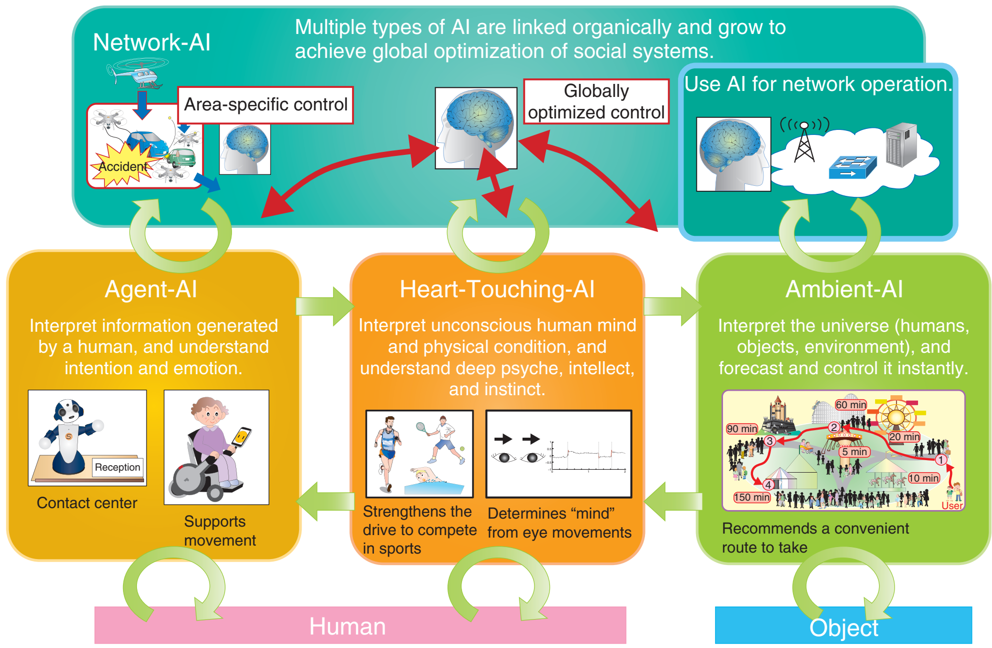


Fig. 2. Four types of AI in NTT R&D.

proposition as an evolved form of ambient intelligence. It encompasses IoT technology in that it interprets humans, objects, and the environment, and forecasts and manages them instantaneously.

Network-AI includes two concepts. The first is to apply AI to network operations so that, for example, cyber-attacks can be detected early and signs of impending failures in communication equipment can be discovered, resulting in stable network operation. The other is to interconnect a number of AIs and make them grow in such a way that they will optimize the overall social system. The AI being discussed today is designed to substitute for and tap into the thinking of just a single person. In contrast, Network-AI is aimed at having various AIs work together in order to acquire collective knowledge and thereby create new value. For example, in times of disaster, it is important to make decisions and act based on information in a small area, but it is also important to seek total optimization from a nationwide perspective. In short, Network-AI is aimed at emulating what is done by the human cerebellum and cerebrum.

Implementation of these four types of AI requires three technical elements. The first is to recognize and understand humans and objects by decoding, rather than simply measuring, data about them. The second is to infer and judge through exploration rather than simple analysis, which is the case with machine learning. The third is to provide feedback in a pleasant manner by design rather than simply by control. We will build a circle of these technical elements on three foundations: data science, human science, and a mathematical base (**Fig. 3**).

2.2 Main AI technologies

Representative AI technologies being studied by NTT R&D are introduced below.

In the area of Agent-AI, NTT R&D's distortionless noise reduction technology has been combined with our deep-learning speech recognition technology. The resultant technology attained the world's top speech recognition level among 25 competitors in CHiME-3 (the 3rd CHiME Speech Separation and Recognition Challenge), an international technology evaluation event in which participating organizations competed in the ability to recognize English speech in a noisy environment (**Fig. 4**). Our intonation and accent conversion of speech can convert a speech in standard Japanese into one with the intonations of, say, an Osaka or Nagoya dialect without losing naturalness. It enables a robot to speak with pronunciation similar to that of a human.

In the area of Heart-Touching-AI, the body- and mind-reading technology can infer the condition of a person—for example, how deeply he is concentrating or if he is sleepy—from tiny eye movements or pupil

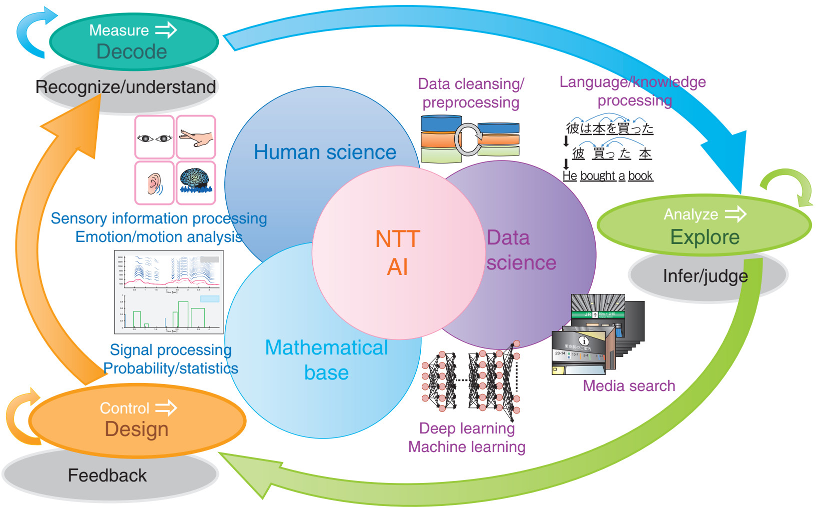
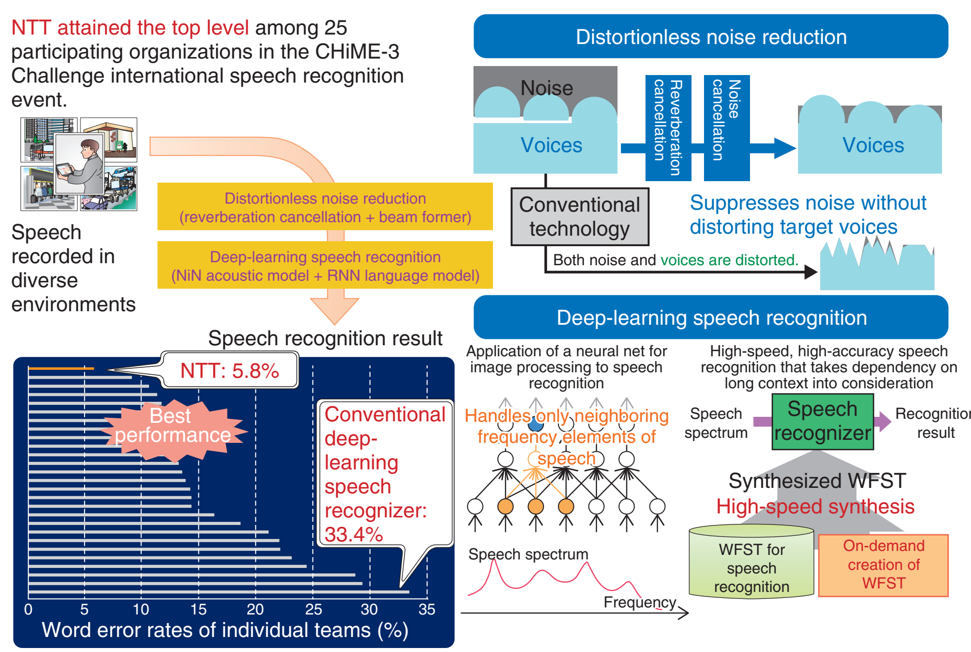


Fig. 3. Technical elements that support AI.



NiN: network-in-network
RNN: recurrent neural network
WFST: weighted finite-state transducer

Fig. 4. Agent-AI technologies.

reactions. We are also studying how a person can train his or her brain to be able to achieve victory in a sports contest, based on brain science that involves analyzing the muscle activity patterns and heart rates of professional sports players. We are also considering use of tactile information presentation technology (Buru-Navi) to convey feedback not only through speech or video but also by appealing to the tactile sense with vibrations.

In the area of Ambient-AI, spatio-temporal analysis/

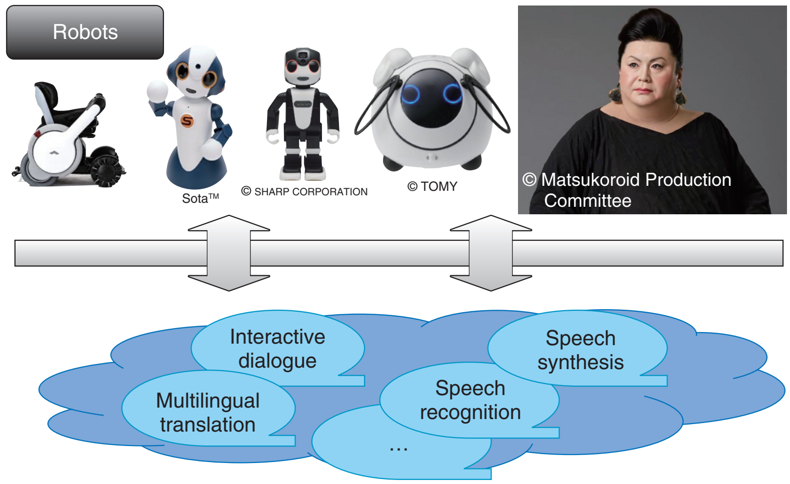


Fig. 5. Cooperation example of robot and AI.

mathematical optimization technology makes it possible to predict the near future of just a few minutes from now rather than predicting a vague future.

In the area of Network-AI, in which AI is applied to networks, resource and QoE (quality of experience) optimization technology is being studied with a view to achieving stable telecommunication service quality through proactive control of various traffic-fluctuating factors.

2.3 AI utilization cases

NTT R&D's activity related to the use of AI in robots is introduced here. Robot hardware will continue to evolve in different forms. Some robots will evolve to converse with people, and some will evolve to support construction work. We believe that focusing on a robot designed for a specific purpose and trying to make it smarter will not bring far-reaching change to society. Our approach is to apply our AI technologies to all kinds of robots. We will advance and enhance the capabilities of robots by providing common technologies such as speech synthesis, interactive dialogue, and multilingual translation to a variety of robots, as shown in **Fig. 5**.

Agent-AI technology is now being used in contact centers. AI assists operators not merely in comprehending what the customer says but, more importantly, in discriminating whether or not the customer is angry, which is considered to be particularly important for contact center operators. This may be peculiar to the Japanese, but we are working on understanding two distinct types of anger: hot anger, which is easy to recognize because the angry person shouts, and cold anger, which is hard to recognize because the person pretends to be calm while silently seething. NTT R&D's AI makes it possible to recognize a caller's cold anger by analyzing the conversation flow and vocabulary. The NTT Group already offers systems that adopt this technology in contact centers and is convinced of its effectiveness.

3. Directions for IoT technologies

NTT R&D's activities related to IoT are described below from three aspects: sensing, security, and networking/clouds (**Fig. 6**).

We believe that penetration of a variety of sensors into our lives should not impose extra pressures on people or society. Sensors should merge with humans and society in a natural way. We express this requirement as *natural*. An example of a technology that reads information about a human is one that makes it possible to read the heart rate and muscle activity of a person, who needs only to wear a shirt or support garment made of the functional material called *hitoe*. One way to read information about an object is to install a sensor. It is also necessary to consider using a drone to photograph an object and analyzing the captured images. Given that it is not *natural* if an IoT device must be replaced each time its measurement or performance requirement changes, we are studying IoT device virtualization technology, which would allow an IoT device to be reprogrammed from a remote site.

When we provide added value using data from IoT devices, it is important to ensure data security. We

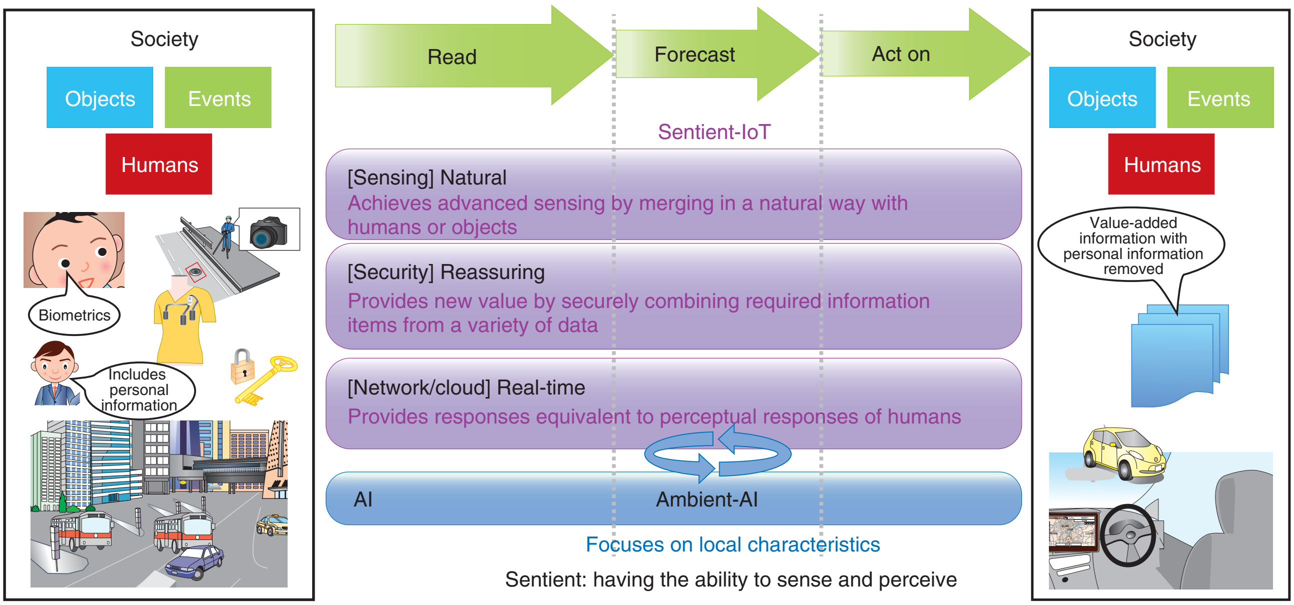


Fig. 6. IoT targeted by NTT R&D.

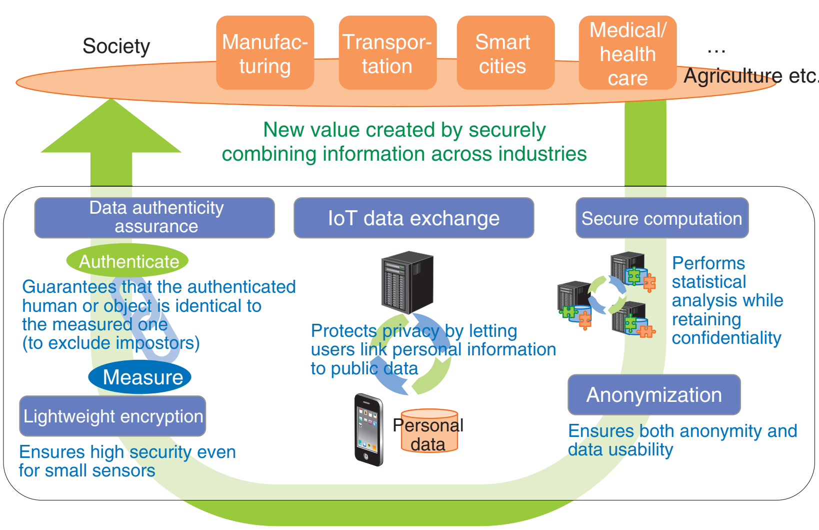


Fig. 7. IoT security: Reassuring.

express this requirement as *reassuring* (**Fig. 7**). Since sensors used in the IoT world do not have high computing power, data must be encrypted, and the authenticity of data must be guaranteed under severe functional constraints. Diverse types of data may be gathered from IoT devices across many industries, so in addition to our secure computation and data anonymization technologies, we are developing a technology that attempts to protect privacy by leaving it up to users to link personal data to public data.

In agricultural monitoring, a small amount of IoT data can be processed without constraints on data processing time. In contrast, if IoT data are to be used to operate a machine in a factory or to control a vehicle, the delay time for data processing must be minimized to prevent accidents. We express this requirement as *real time* (**Fig. 8**). We are studying coordinated scheduling technology, which minimizes

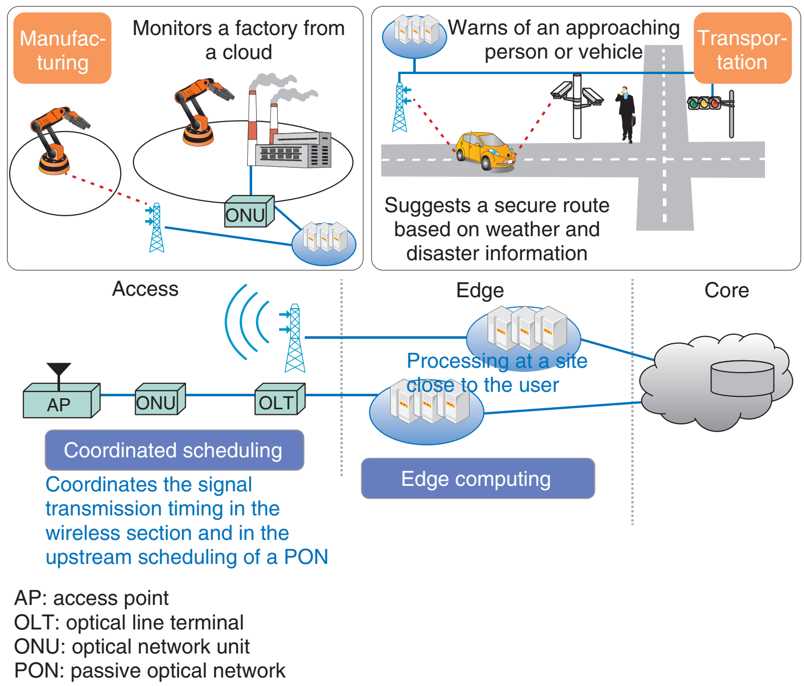


Fig. 8. IoT network/cloud: Real-time.

delay in access sections, in addition to edge computing, which processes data at points close to control terminals.

Like the Internet, IoT evokes a global perspective—being able to communicate worldwide. However, it is also important to build a network that focuses on a local perspective. For example, when controlling traffic lights in Tokyo, it is not necessary to consider the traffic situation in Osaka.

NTT R&D is aiming to develop an IoT that collaborates with the above-mentioned Ambient-AI technologies to create new value. We call this *sentient IoT*.

We believe that it will be important in coming years to have an environment that allows different types of services to be created flexibly by combining a variety of IoT devices, including robots. To build such an environment, it is necessary to have a general-purpose interface that allows these devices to be easily connected with the engines for tasks such as big data processing, image recognition, and speech recognition, and to have a programming language that can be used to simply define those connections. For this purpose, we have developed a technology called R-env™ that provides a mechanism enabling various parties to enter the world of IoT without difficulty (**Fig. 9**). For example, NTT DATA has collaborated with Resona Bank, Ltd. to combine R-env with a robot and sensors so that the robot can interact with customers at the bank's reception desk. NTT DOCOMO has combined R-env with a power wheelchair from WHILL that provides greater maneuverability and encourages the user to move about. Daiichikosho Co., Ltd. has developed a robot that works with a karaoke machine to provide preventive care for seniors. We are also holding a hackathon to forge a community for R-env.

3.1 IoT utilization cases

NTT R&D's IoT technology can be used to detect abnormalities in equipment or to forecast an impending fault (**Fig. 10**). If sensor data are simply fed into Jubatus, which is a real-time, large-scale, distributed data analysis platform, Jubatus may make a false detection. Instead, sensor data are appropriately cleansed and preprocessed. As a result, Jubatus can detect abnormal behavior in real time and thus prevent faults from occurring. In a joint research project with the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), we have begun using edge computing for advanced weather forecasting. The wide-area simulation on JAMSTEC's supercomputer is combined with area-specific processing on NTT R&D's edge server in order to enhance the level of forecasting accuracy.

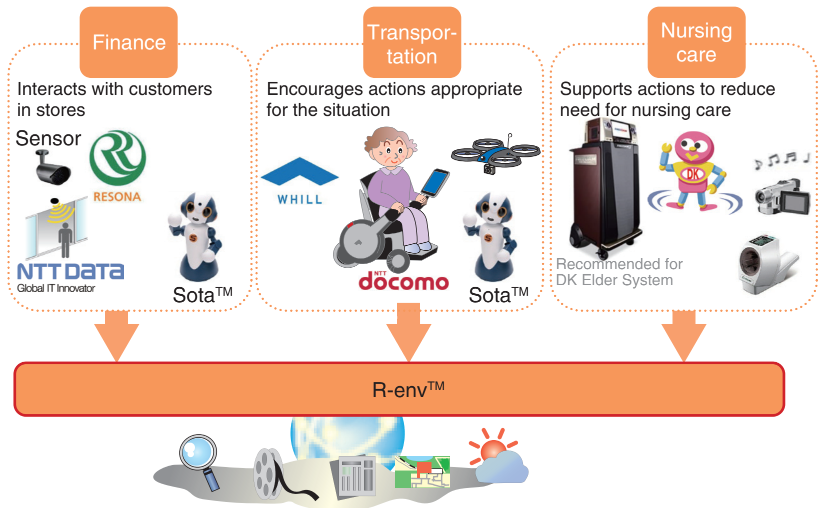


Fig. 9. R-env^{TM}: Interaction control.

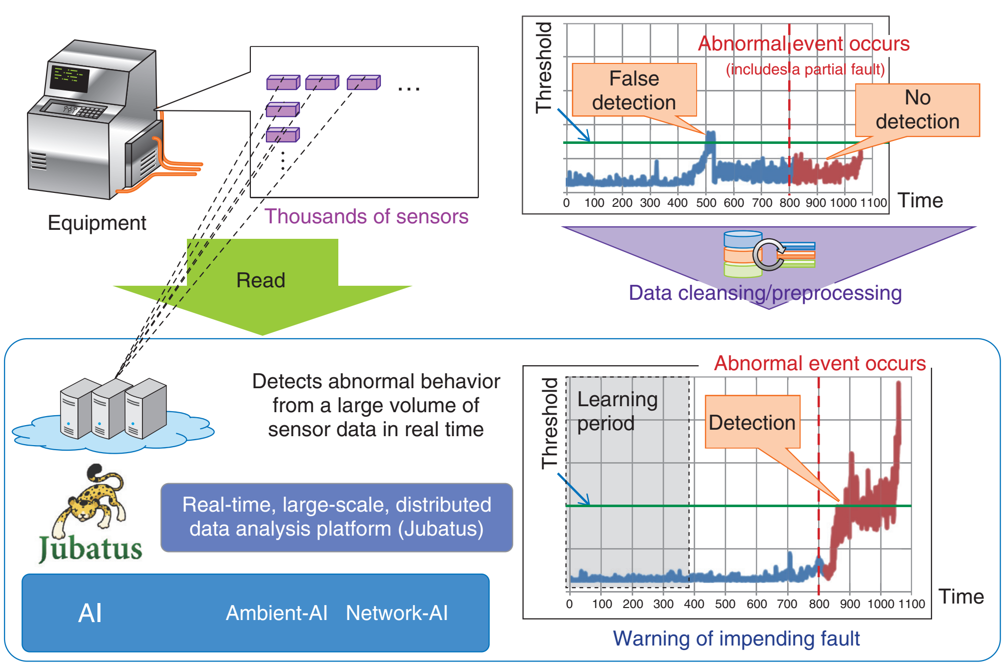


Fig. 10. Detection of abnormality in a machine.

3.2 Security technology

In promoting AI and IoT, it is important to continue R&D of security technology. DDoS (distributed denial of service) attacks are growing in scale and sophistication in Japan. We urgently need to be able to implement prompt and effective measures against such attacks. NTT R&D is working on security orchestration that will enable us to respond to attacks from a network-wide perspective. The security orchestrator takes the specific network condition into consideration. It blocks attacks at the optimal point, recovers service through automatic control of routing and routing policy, or dynamically controls traffic in a manner that is appropriate for the attack.

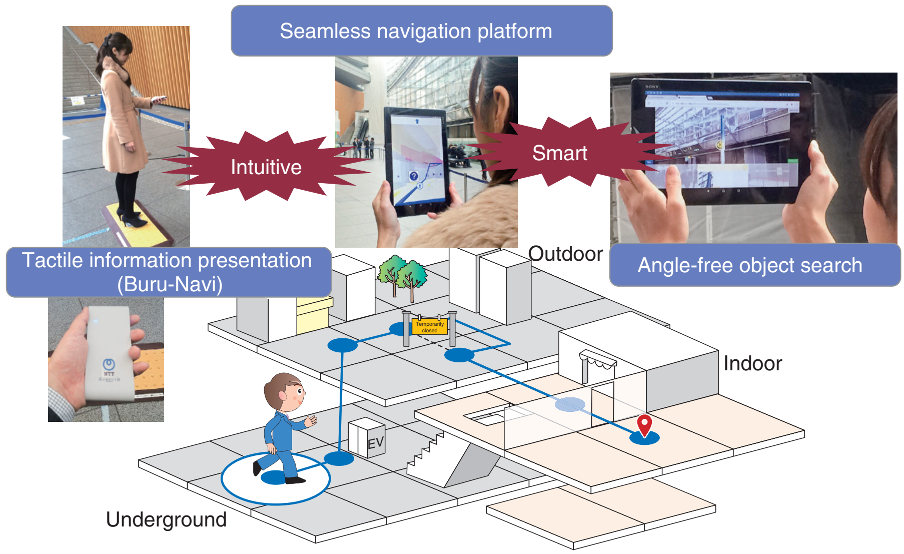


Fig. 11. Trial near Tokyo Station.

As we approach the year 2020, it is necessary for not just NTT but all major infrastructure companies to share information about and develop human resources for security. No matter how skilled it may be, a single company cannot ensure strong cybersecurity. All concerned parties need to work together.

4. Activities looking towards 2020

By 2020, NTT R&D should have fulfilled three major missions: providing high-quality and stable network services, implementing reliable network security measures, and providing hospitality that leaves a deep and positive impression. Our activities related to the third mission are described below. In last year's NTT R&D Forum, I introduced the technologies that NTT R&D had conceived for the third mission as a proof of concept. As the next step, we have initiated some pilot trials.

A pilot trial being conducted in the international terminal of Haneda Airport is aimed at enabling visitors to Japan who cannot read Japanese or who are handicapped in some way to move around without barriers. One service already provided at Haneda for visually impaired persons is an intelligent sound sign service, which provides information using speech technology. The terminal building is full of noise from various sources. The conventional measure for coping with such noise is to increase the speech volume. Instead, NTT slightly modifies the frequency spectrum of the voice so that the sound will carry well. Neither the volume nor the type of voice is changed. The user can hear sound signs clearly, even amid a cacophony of background noise. Our angle-free object search technology enables visitors to understand information on a direction board by simply pointing their smartphones toward the board; the information is translated and displayed on their phone screens.

A pilot trial is also being carried out near Tokyo Station (**Fig. 11**). The station is very complex, with a number of passageways and floors, including several underground floors. Currently available maps of the station are not efficiently linked to one another. The main aim of the service developed by NTT R&D is to connect the maps seamlessly so that people can move about intuitively and smartly.

A pilot trial being operated at a stadium uses a technology that integrates a video generated using immersive telepresence (Kirari!), a real video, and computer graphics. This technology has been developed for use in sports activities. For example, in a public viewing, the life-size hologram of a player at a remote stadium is projected on a super-wide screen in synchronization with a video that shows the background. Or, a user wearing a head-mounted display stands in a batting box and experiences the sensation of a ball thrown by a pitcher coming toward him or her.

In the 2020 Showcase at R&D Forum 2016, a screen in the exhibition hall displayed a three-dimensional

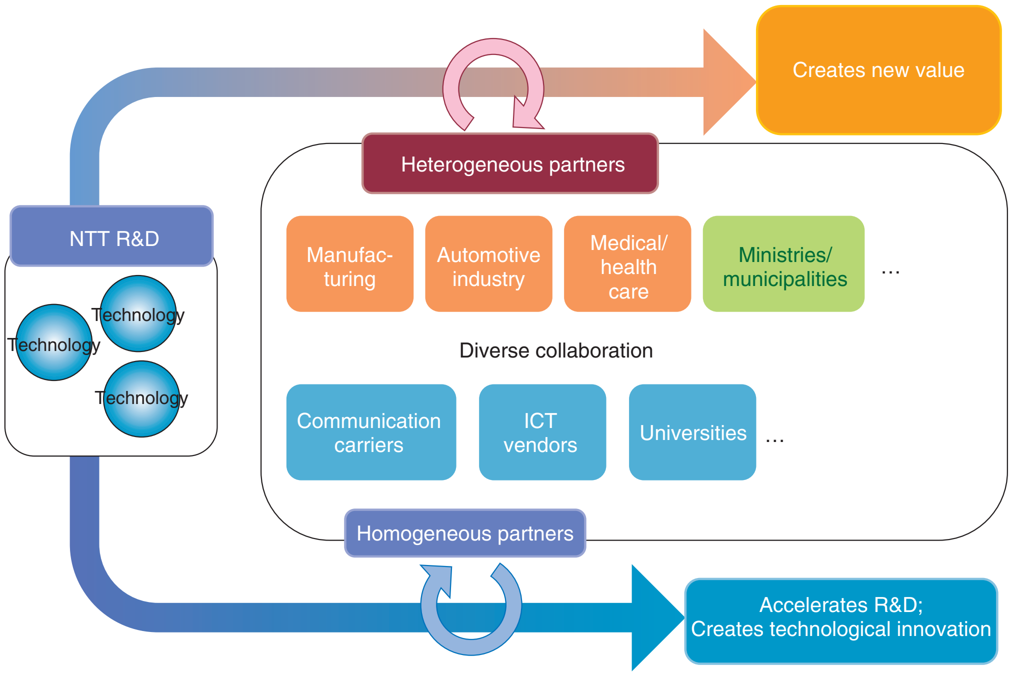


Fig. 12. Objectives of R&D collaborations.

video of the lecture being given in the main hall. The video, generated by Kirari!, provided the sensation of the speaker talking in the exhibition hall. The conventional way of achieving this has been to extract a segment from a recorded video and project it, but on this occasion the video was displayed in close to real time. In addition, angle-free object search technology was used to enable any user who pointed his or her smartphone at an exhibit panel to obtain detailed information displayed on the screen.

5. R&D collaborations

We have been collaborating with several partners on various projects. Our collaborations over the past year are described below.

In the area of networking, last year we announced NetroSphere, an initiative that indicates the direction of networks by NTT R&D. The key concepts of NetroSphere are three types of separation: separation between optical and electrical, separation between functionality and hardware, and separation between functions. To be able to implement these separations and combine the disparate parts to build a scalable and flexible network, we need to cooperate with multiple ICT vendors and providers. Over the last 12 months, we have identified a number of parties that support these concepts and have initiated joint R&D programs with them.

In the area of security, we are developing a common, sharable interface for the security orchestrator so that various combinations of security appliances and switches can be controlled in a timely manner. We will collaborate with other telecommunication providers to address cyber-attacks because it is not sufficient for us to be concerned solely with the NTT Group's networks.

There can be two types of partners for R&D collaboration: homogeneous and heterogeneous (**Fig. 12**). In the areas of networking and security, collaborations with relatively homogeneous partners are expected to produce massive technical innovation and facilitate rapid development of new products. Our experience with collaborations with heterogeneous partners in the last couple of years has convinced me that this approach is conducive to generation of hitherto undreamed of new value. Some of our collaborations with heterogeneous partners are as follows:

(1) Panasonic

We are collaborating with Panasonic Corporation to enable users with only very simple terminals to receive services equivalent to those that are normally available only to smartphone users (**Fig. 13**). Panasonic

Fig. 13. Panasonic × NTT.

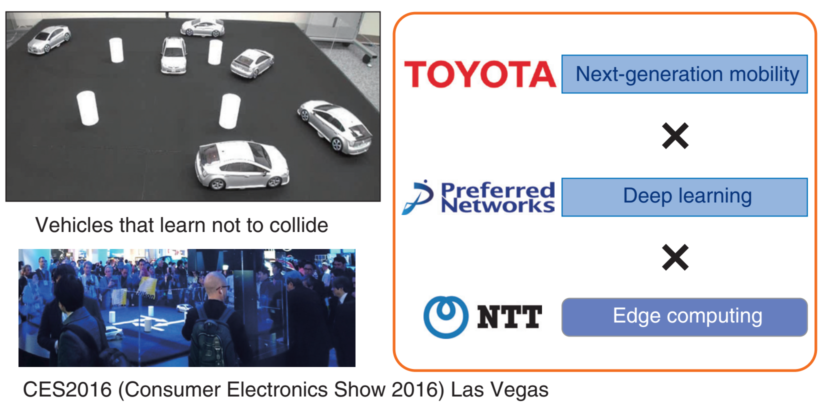


Fig. 14. Toyota × PFN × NTT.

has developed a prototype of a transparent see-through device with minimal functions. By providing it with additional capabilities via a cloud using NTT R&D's device virtualization function, we will be able to create new service possibilities.

(2) Mitsubishi Heavy Industries

Our collaboration with Mitsubishi Heavy Industries, Ltd. (MHI) in the environmental area has led to the world's first successful laboratory test of online measurement of gas concentrations. By combining MHI's gas analysis technology with NTT R&D's laser technology for optical communication, it has become possible to measure gas concentrations within several minutes, as against the one to two days required for conventional chemical analysis based on sampling.

(3) Toyota and PFN

We are seeking to implement the concept of vehicles that learn not to collide. A prototype was exhibited at CES2016 (Consumer Electronics Show 2016), which was held in Las Vegas in January 2016 (**Fig. 14**). By combining Toyota's next-generation mobility technology, PFN's deep learning technology, and NTT R&D's edge computing technology, it has become possible for vehicles to share information about their statuses and to learn how to avoid collisions so that they can run autonomously without colliding with other vehicles.

(4) Dwango

We provided visitors to Dwango's Game Party Japan 2016, held in January 2016, with a smartphone application that displayed the current congestion state and also forecast future congestion. The application assisted some 5000 visitors in moving around the exhibition hall. In addition, we trialed live video delivery of the event using an HEVC (High Efficiency Video Coding) encoder for a *niconico* live broadcast. A high-definition video was broadcast using half the amount of data that would be required with the conventional method.

(5) Daiichikosho

We are conducting feasibility tests with Daiichikosho Co., Ltd. on the use of karaoke not just for entertainment but also for providing preventive care to elderly persons. One feasibility test uses NTT R&D's noise removal technology to clearly pick up a speaker's voice, even in the middle of a loud karaoke performance, so that the user can search for a song by voice input. Another feasibility study is being conducted at a nursing care center. R-env, mentioned earlier, is used to interconnect a robot, a karaoke machine, and biometric sensors. The robot talks with the elderly persons so that they can better enjoy karaoke sessions.

(6) Shochiku

We are collaborating with Shochiku Co., Ltd. in the use of ICT to create a new form of Kabuki, which will be performed during the Japan KABUKI Festival in Las Vegas, in May 2016.

(7) Various uses of *hitoe*

In the area of materials technology, we are conducting feasibility tests on hitoe, which is capable of measuring two biometric signals: cardiac electrical activity and heart rate. In collaboration with Obayashi Corporation, Japan Airlines Co., Ltd., and NTT Communications, we are testing how wearing a shirt incorporating hitoe can improve the work safety of construction workers and airport personnel in the field. To expand its application area, hitoe is now being given the ability to measure myoelectrical (muscle) activity. We are testing measurement of biometrics using a suit equipped with an anti-G-device in collaboration with the Acquisition, Technology and Logistics Agency of the Ministry of Defense, and we are measuring the physical stress on drivers in the IndyCar Series in collaboration with NTT DATA. At the Casio World Open golf tournament, we measured a player's muscle activity during a swing. We are hoping that this technology will be able to support athletes as they prepare for the 2020 Olympic Games. Together with NTT DOCOMO, we are providing a software development kit that facilitates use of biometric information obtained by hitoe so that other parties will be able to develop applications that utilize biometrics.

6. Conclusion

NTT R&D will continue to expand the scope of its collaboration with various partners. Meanwhile, we will endeavor to pursue groundbreaking R&D and enhance our technical capabilities so that we will continue to be selected as a value partner. Concerning the question of whether we should seek exclusive or non-exclusive collaboration, we believe that non-exclusive is the way to go because, in the world of AI, a single robot becoming smart will not change the world and because, in the world of IoT, the degree of added value created by a single industry through gathering information is not high enough.

NTT's R&D Activities Focused on NetroSphere Concept

Yoshikatsu Okazaki

Abstract

In February 2015, NTT announced the development of a future communication network concept called NetroSphere that is aimed at providing a wide range of rapid, flexible, low cost, and secure services to customers and service providers. This article presents an overview of the concept and the research activities that NTT laboratories are carrying out to bring it to fruition. These Feature Articles are based on presentations made at the Tsukuba Forum 2015 Workshop held on October 16, 2015.

Keywords: NetroSphere, separation and combination, service co-creation network

1. Introduction

In 2012, the NTT Group announced its medium-term management strategy *Towards the Next Stage* [1]. The group had previously focused on the idea of being a provider that started up its own services, but with this management strategy it shifted its focus to transforming markets and its own business models. The idea was to meet customer needs with added suitability, simplicity, and security so that customers would select the group as a *value partner*.

For the *Towards the Next Stage 2.0* strategy announced in May 2015, the group proposed a business-to-business-to-X (B2B2X) business model as a means of furthering market development and accelerating the group's transformation into a value partner [2]. The specific model reported here was the *Hikari** *Collaboration Model*, for which the main ideas were strengthening the collaboration platform, using cross-group projects to form partnerships with a wide range of business entities, and creating high-value-added services and new business models with our partners by serving as a catalyst in order to achieve sustainable growth [3].

The next step is to take a new look at the entire network concept by further advancing this model.

2. Limitations of conventional network development

Up to now, the approach used to develop carrier network systems has been to develop dedicated equipment for each service and function and to combine them to form networks. This approach is called silo development since components of dedicated hardware and software equipment are integrally configured and individually optimized for each service and function. With this type of development, however, the following problems need to be considered.

(1) It is difficult to add or change some services immediately even if the additions or changes are minor because their supply depends on the roadmaps of the vendor's products or technology, or because the added functions will affect the system as a whole.

(2) Developing individual carrier-grade hardware and software for each piece of dedicated equipment will keep capital expenditures (CAPEX) high. In addition, the need for multiple pieces of dedicated equipment will result in high operating expenses (OPEX).

* *Hikari* is a Japanese word that means *optical*.

(3) Sharing computing and other resources between different types of dedicated equipment makes it impossible to maintain resource flexibility, thus producing inefficiency.
(4) It is difficult to provide service systems when certain components that make up the systems cannot be procured. Some system parts govern the end of life (EoL) of the entire service system. For example, it will be very costly to renew the entire system when a subsystem (such as the Internet protocol system) in a piece of dedicated equipment becomes obsolete.

We expect that in the future, extending the B2B2X model will result in an increase in the number of service types that are offered and in turn, the volume of traffic, and this will ultimately impose limits on the conventional silo development and dedicated equipment operations because it will increase the number, functions, and types of dedicated equipment that are needed.

We consider that network functions virtualization (NFV) [4] is an effective means of broadening such limits. We are therefore looking ahead and focusing on virtualization as one of NTT's principal research and development (R&D) objectives. The NetroSphere concept has been developed with the aim of implementing networks that will enable these limits to be surpassed.

3. NetroSphere concept and architecture

The NetroSphere concept was formulated and announced in February 2015 [5]. There are three aims for the concept. The first is service co-creation, in which we hope to quickly satisfy the needs of a lot of partners through B2B2X collaboration. The second aim is to achieve a drastic TCO (total cost of ownership) reduction. Specifically, we hope to reduce CAPEX and OPEX by increasingly using general-purpose equipment so as to realize a maintenance-free and EoL-free network. The third aim is open innovation. Although NTT laboratories have conventionally developed network equipment, our goal here is to establish and expand partnerships with a wide range of partners including overseas carriers and vendors from the concept planning stage of NetroSphere.

These aims can be achieved through modularization and materialization of various network functions, enabling them to be combined flexibly and in an on-demand manner through operations. The key ideas here involve three *separations* and one *combination* (**Fig. 1**). The first of these, separation of optics and electronics, means there is a maximum separation of the optical and electronic parts that compose the network structure. This will make it possible to minimize electronic processing so as to establish a simple and permanent infrastructure, and to reduce energy loss through optical-to-electrical conversion. The second, separation of functions and equipment, means modularizing and materializing network functions through software running on general-purpose servers and general-purpose switches, thus enabling flexible and quick responses to customer needs. The third, separation of resources and equipment, means separating network resources from equipment to enable improved operational efficiency and reliability of equipment. This can be expected to eliminate the resource allocation inefficiency seen in silo development and dedicated equipment operations, particularly from the standpoint of operational efficiency. The combination of these separated network elements under the control of the operation provides the required network service functions and capacity, flexibly and economically.

The technology development for NetroSphere is oriented toward increasing network flexibility through strengthened cooperation among multiple services and technology by utilizing general-purpose products. Another aim is to reduce costs by commonizing specifications for and automating operations of general-purpose products for carriers (**Fig. 2**). The main point here is modulation achieved by separation, and for the future we plan to study ways to modulate components up to the sub-device level in order to meet the needs of our customers more flexibly.

4. Approaches to achieving NetroSphere concept

Here, we briefly describe the main element technologies for achieving the NetroSphere concept: the server system MAGONIA, the transport system MSF (Multi-Service Fabric), the access network system FASA (Flexible Access System Architecture), and the operating system OaaS (Operation as a Service)/Integrated Control (**Fig. 3**). Service network flexibility can be enabled by modularizing and combining the server system, transport system, and access network system functions provided by MAGONIA, MSF, and FASA, on the OaaS/Integrated Control operating system.

4.1 MAGONIA

Up to now, service functions have been implemented

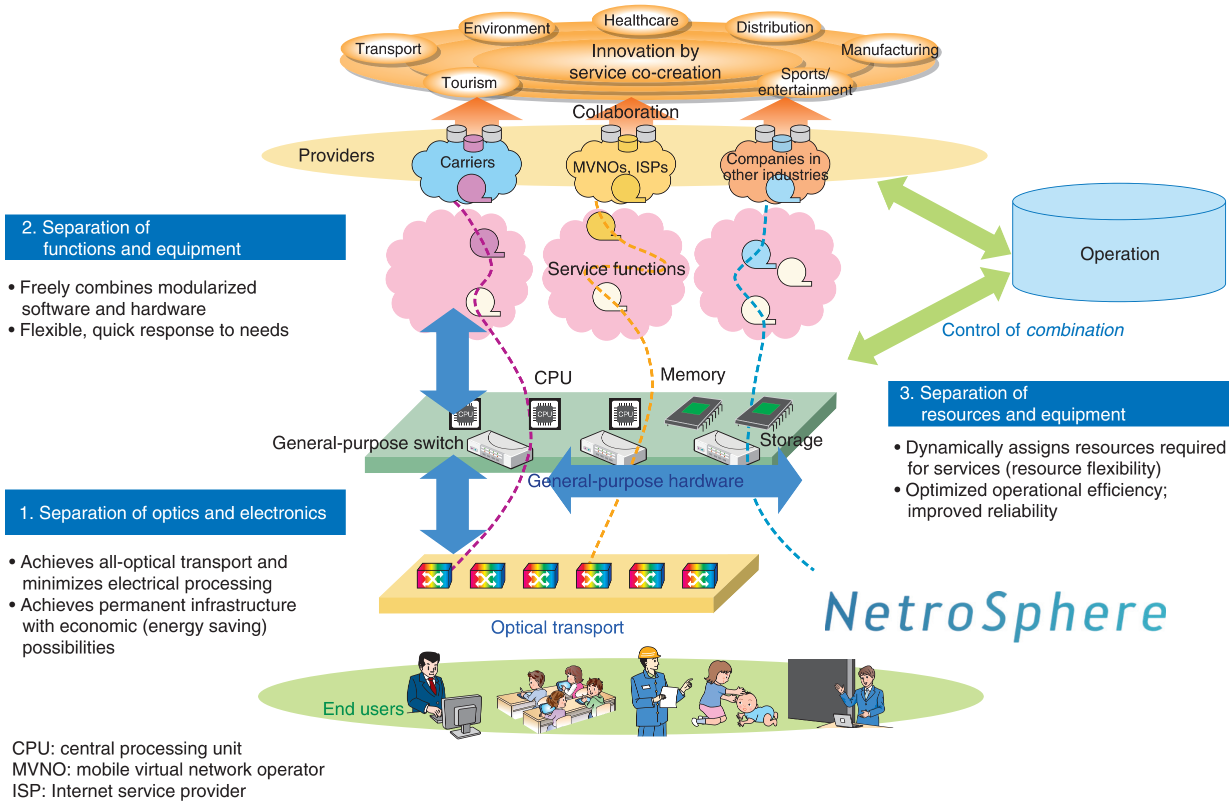


Fig. 1. The concept of separation and combination.

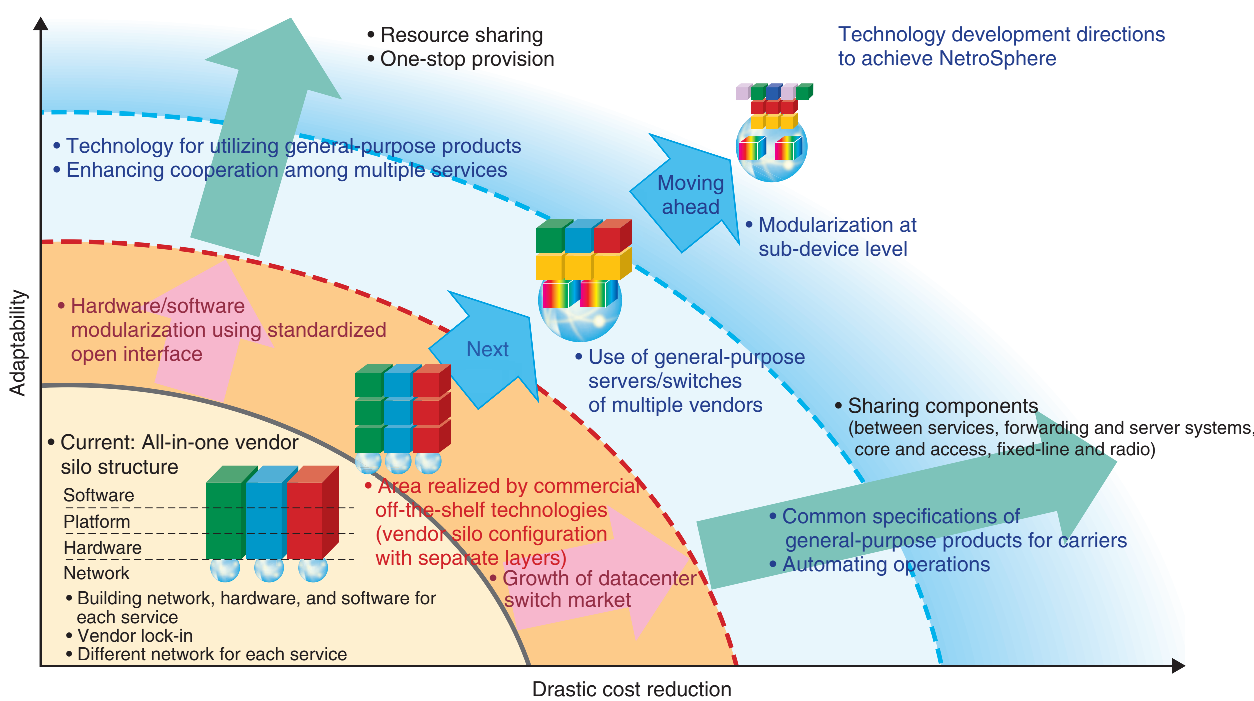
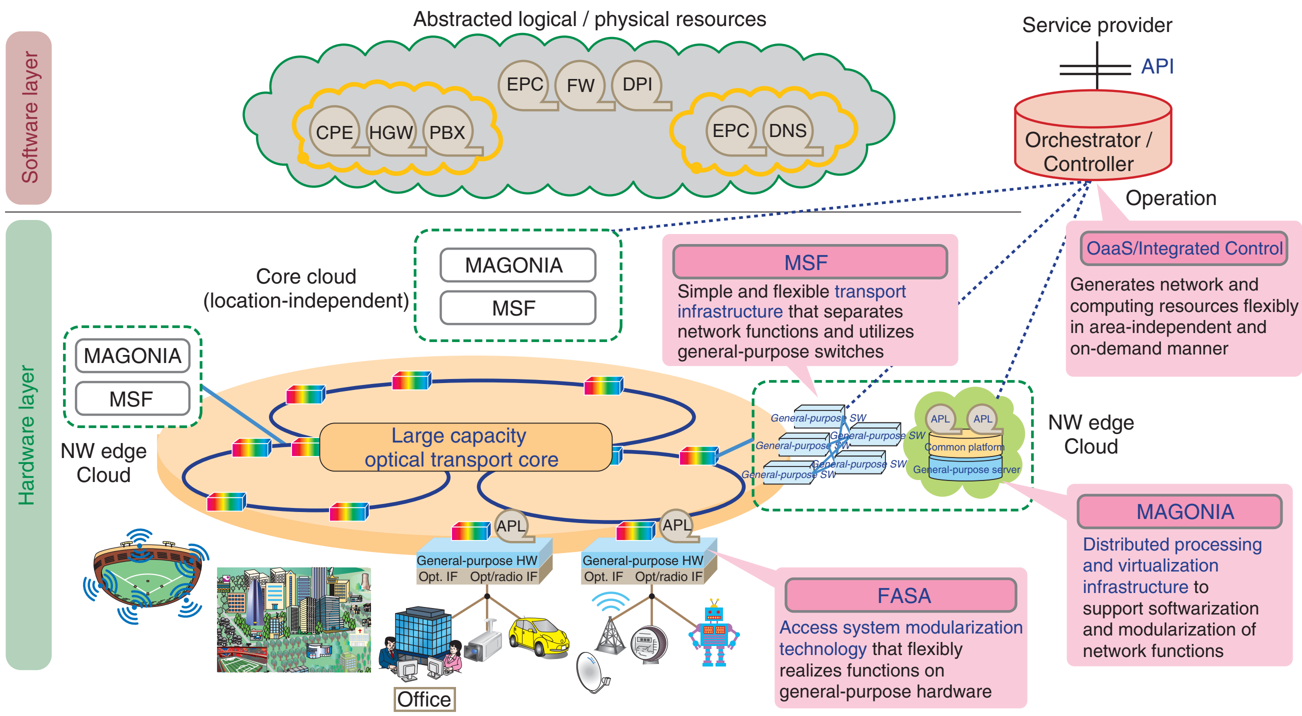


Fig. 2. Technology development directions to achieve NetroSphere concept.



API: application programming interface
APL: application
CPE: customer premises equipment
DNS: domain name system
DPI: deep packet inspection
EPC: evolved packet core
FW: firewall
HGW: home gateway
HW: hardware
IF: interface
NW: network
Opt: optical
PBX: private branch exchange
SW: switch

Fig. 3. Image of future network architecture based on NetroSphere concept.

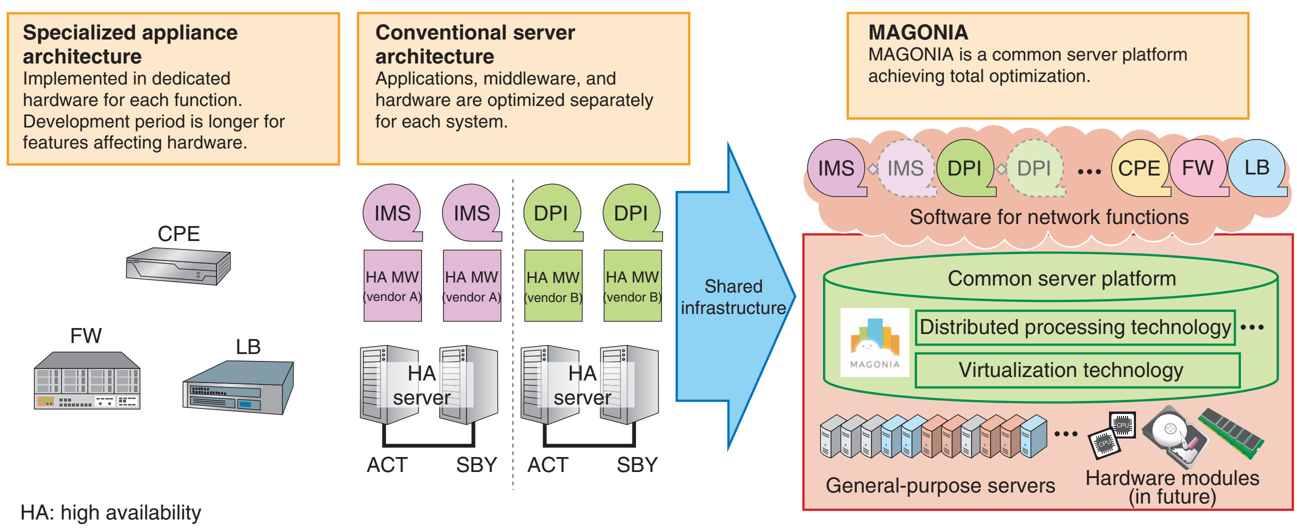
using individual components of dedicated equipment, but with MAGONIA, it is now possible to implement them as software on general-purpose hardware, with the aim of achieving flexibility and reducing costs (**Fig. 4**). In MAGONIA, application programming interface (API) specifications for distributed processing platforms that form the n-active (N-ACT) cluster mentioned below are publicly disclosed, making it possible for anyone to design API-compliant middleware and software on the basis of service logic. It should be noted that from the viewpoint of attaining carrier-grade reliability, it has been necessary to have an active and standby (ACT-SBY) redundant configuration in each piece of dedicated equipment. With MAGONIA, however, each active system takes the redundant configuration of an N-ACT cluster so that it works as the standby system for another active system that forms the cluster. This can produce the expected effect of achieving high reliability while reducing the number of equipment components.

4.2 MSF

To develop the transport system networking that MSF provides, we are studying the idea of building routers and switches based on general-purpose switches and flexibly setting the root configuration of the network. The intended purposes are to achieve optimal coordination of centralized control and equipment autonomy to compensate for the constraints of a general-purpose switch, and also to achieve economical expansion of the general-purpose switch performance, functional cooperation between different layers, and QoS (quality of service) control adapted for various services (**Fig. 5**).

4.3 FASA

Access systems have been conventionally configured with dedicated equipment, but with FASA we hope to increase flexibility by implementing functions in software on general-purpose hardware (**Fig. 6**). Since we assume that dedicated hardware remains



HA: high availability
IMS: Internet protocol multimedia subsystem
LB: load balancer
MW: middleware

Fig. 4. MAGONIA.

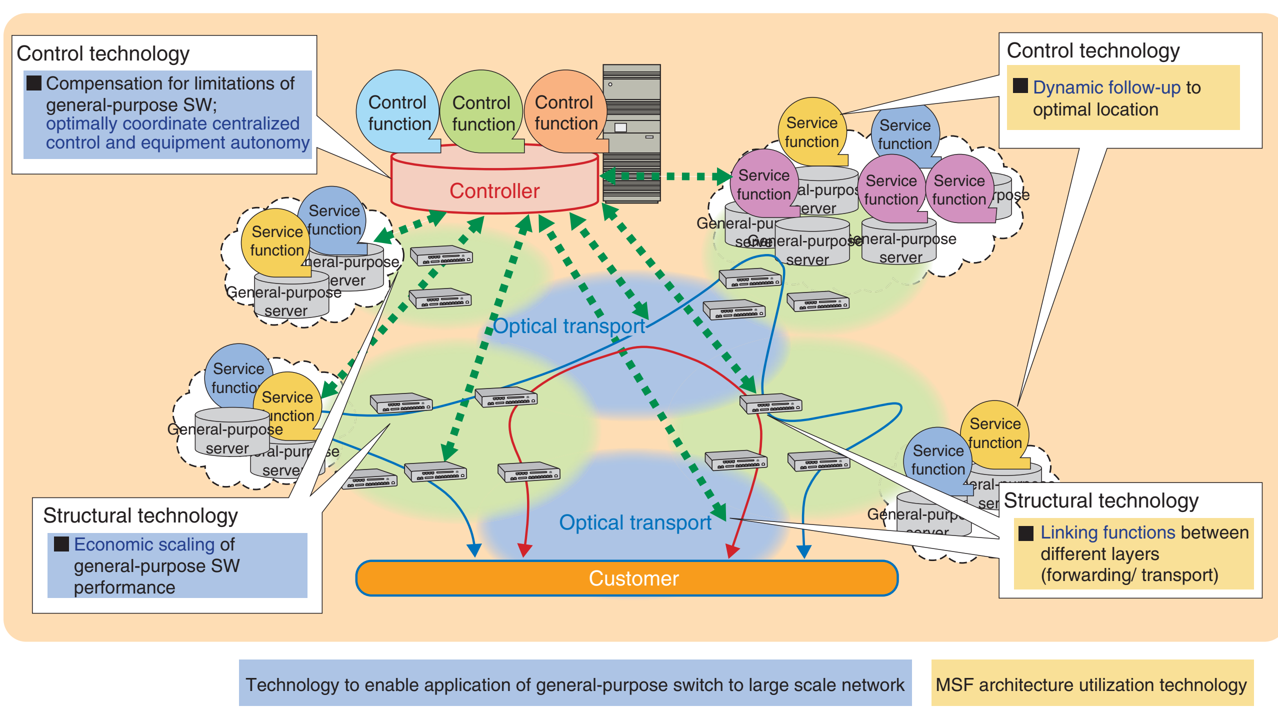


Fig. 5. MSF.

local in optical interfaces and other cases, we wish to study the degree to which general-purpose hardware can be implemented. Because a huge amount of access system equipment is distributed nationwide, reconfiguration of access systems composed of conventional dedicated equipment is a large-scale process.

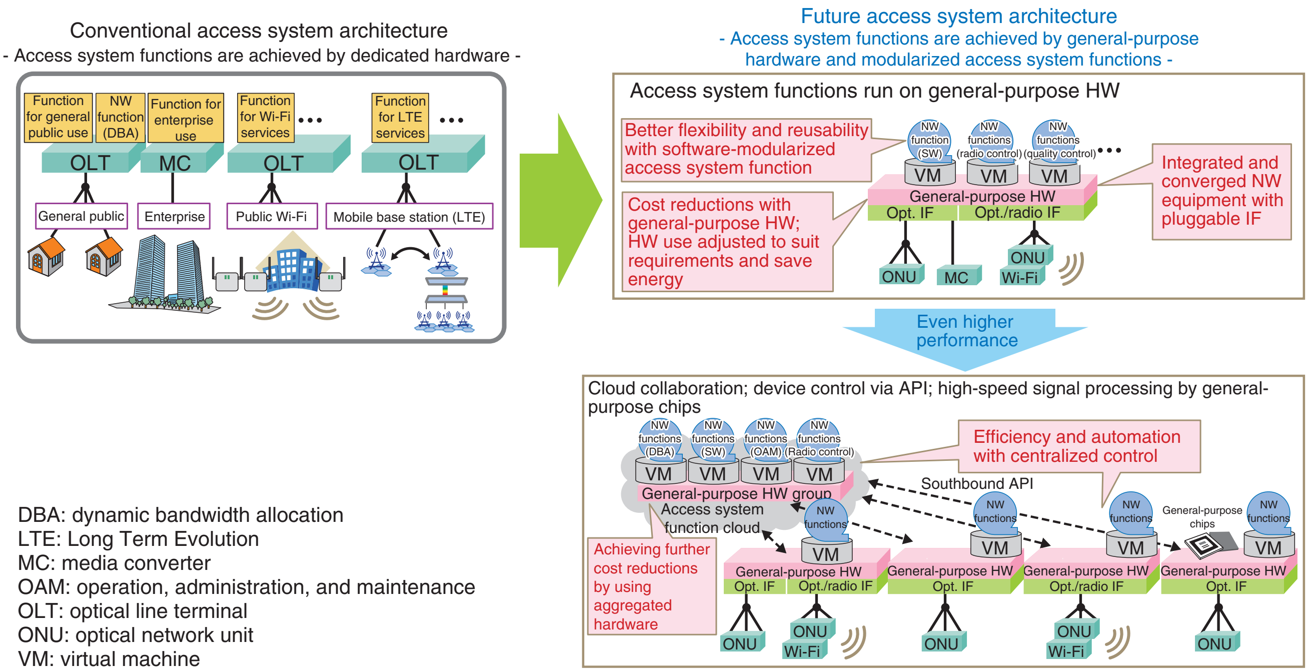


Fig. 6. FASA.

We expect that performing their functions through the use of software will enable shorter time spans and greater flexibility to be achieved.

4.4 OaaS/Integrated Control

With Integrated Control, we aim to enable configurations to be set flexibly in an on-demand manner by logically combining network functions when the network is used with a variety of service providers (**Fig. 7**). With OaaS, we aim to implement an operation that provides service providers with an API of networks, clouds, and applications in a one-stop manner.

5. Fundamental technologies supporting NetroSphere concept

One of our ultimate goals is to design networks that will not be affected by disasters. Therefore, we are developing technologies for evaluating network reliability, which involves spatially evaluating information about affected areas given on hazard maps and also evaluating network configurations (topology, redundant configurations, etc.). In the past, temporal probability has been used as a basis for evaluating and ensuring equipment reliability, in terms of factors such as physical resistance and ease of recovery. In contrast, we apply a technique called spatial information mathematics, in which the network configuration itself is evaluated in terms of the probability of its being affected by a disaster. This is a new approach to evaluate configurations that will make networks less susceptible to disasters.

Network data analysis techniques are used to analyze which actions of service providers and users lead to changes in traffic. These techniques are employed in order to predict such changes and achieve optimal resource allocation. Because network traffic fluctuates according to the actual location of users, for example, an event venue space where users are moving around, this kind of analysis can be applied to predict traffic by combining predicted people-flow data on the basis of machine learning and traffic volume prediction techniques based on user behavior models. In the same way, we are studying methods to extract network intelligence information, (e.g., congestion information and information on how factors such as failures and quality degradation affect services) that have not been obtainable using conventional analysis techniques. This network intelligence information may, for example, give users the opportunity to select services, and may also enable service providers to improve the QoE (quality of experience) of their service.

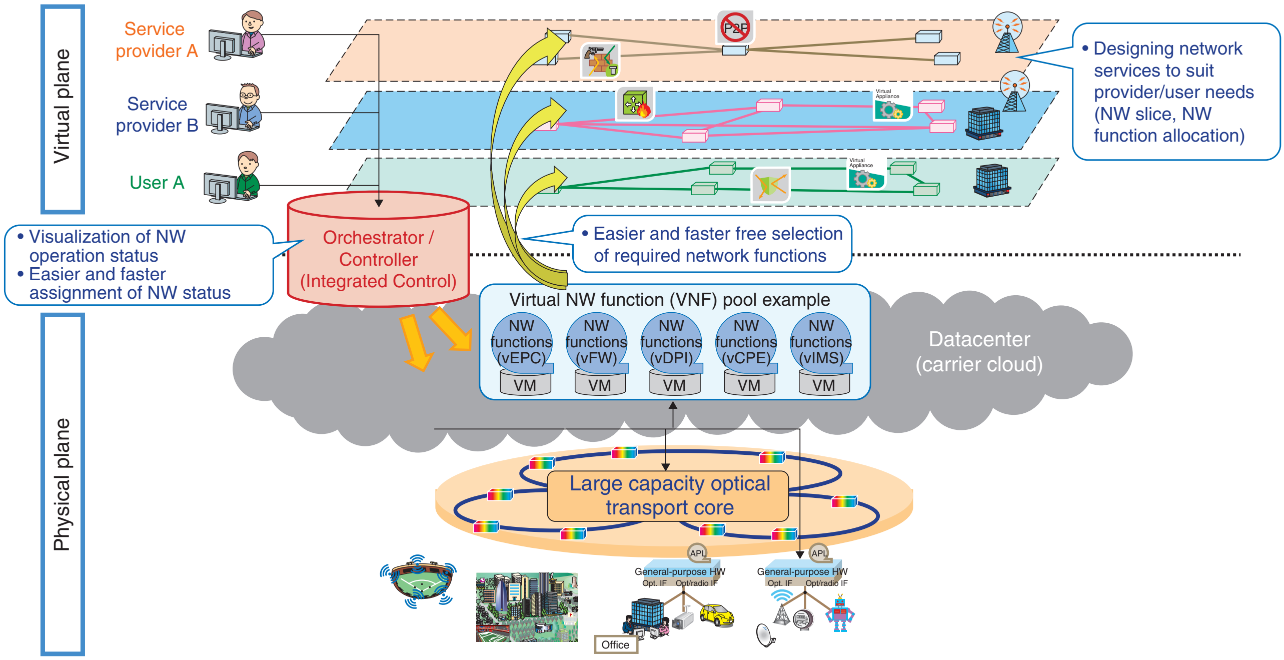


Fig. 7. Integrated Control.

6. Future prospects

We plan to adopt an open innovation approach to the study, research, development, and deployment of the NetroSphere concept from the planning and concept stages, and we will continue to work closely on this concept with a wide range of partners, including overseas carriers, vendors, and members from academia. The architecture, technology, and know-how obtained in this process will help us to develop common specifications for commercial purposes and to spread the concept globally. This will speed up the day when the revolutionary NetroSphere concept truly becomes a reality.

References

[1] NTT press release issued on November 8, 2012.
http://www.ntt.co.jp/news2012/1211ezvh/pvkf121108d_01.html

[2] NTT press release issued on May 15, 2015.
http://www.ntt.co.jp/news2015/1505eyfp/bxft150515d_01.html

[3] NTT press release issued on May 13, 2014.
http://www.ntt.co.jp/news2014/1405eznv/ndyb140513d_01.html

[4] ETSI (European Telecommunications Standards Institute) Industry Specification Group NFV, "ETSI GS (Group Specification) NFV 002," 2013.
http://www.etsi.org/deliver/etsi_gs/nfv/001_099/002/01.01.01_60/gs_nfv002v010101p.pdf

[5] NTT press release issued on February 19, 2015.
http://www.ntt.co.jp/news2015/1502e/150219a.html

■ Author profile

Yoshikatsu Okazaki

Project Manager, Network Architecture Project, NTT Network Technology Laboratories.

He received a B.E. and M.E. in applied physics from the University of Tokyo in 1989 and 1991. In 1991, he joined NTT Communication Switching Laboratories, where he was engaged in R&D of network management and NGN (Next Generation Network). From 2012 to 2015, he was with NTT WEST Network Department, where he worked on the ground design of the network. His current research includes future network architecture based on the NetroSphere concept advocated by NTT R&D.

Technology Driving FTTH and Future Developments

Kiyoharu Sasaki

Abstract

The Optical Access Network Project underway at NTT Access Network Service Systems Laboratories is a media network technology-related research and development (R&D) initiative. This article introduces the R&D that is driving FTTH (fiber-to-the-home), the latest optical access network technologies, and other future developments.

Keywords: FTTH, optical fiber, Tsukuba Forum

1. Introduction

In the short 12-year period since the FLET'S HIKARI service was launched, the NTT Group has completed the fiber-to-the-home (FTTH) rollout in Japan. This achievement has been supported by research and development (R&D) and is the result of integrated initiatives in facilities construction through to sales undertaken by both NTT EAST and NTT WEST.

The rollout can be generally divided into three phases: the initial phase, the popularization and expansion phase, and the maturity phase. Each phase has been achieved by exploiting R&D initiatives in all areas of optical access network technology.

The initial FTTH rollout phase consisted of developing technologies for building facilities economically to meet a very limited demand. In the popularization and expansion phase, demands for high-volume service commencement had to be met. This involved developing technologies to greatly reduce the time taken to provide services after customers applied for them and technologies to expand service areas efficiently and to provide services in rural areas with little capital investment.

With the FTTH rollout having finished its maturity phase, optical networks have become important not only for communications but also as a social infrastructure. Hence, with the aim of eradicating unsatisfactory services, we have continued to develop technologies to enable customization to meet customer demands for responsiveness, the aesthetic appearance of cabling, and other factors. This article introduces some of the turning points that occurred in the technical areas related to FTTH technology.

First is the general area of optical fiber cables. The coverage areas were extended by increasing the number of cable lineups in the expansion phase. Then, when the area expansion stage was nearing completion, introduction of rollable optical ribbon was a turning-point technology that greatly contributed to the final area expansion by reducing the cost of cable from wiring points to terminals.

The second area is optical closures. Closures are found in both underground and aerial locations. Here, the turning point came with the introduction of the underground TN (Triple N: non-gas, non-water, non-sealing tape) closure that brought improved water-tightness and uniform quality to construction methods that had previously depended more on the skills of individual technicians. With aerial closures, using the on-site connector with the No. 3 SFAO (subscriber facility - aerial optical) closure enabled the use of metal-like wire cores, which in turn enabled large increases in the number of services commenced as well as easier service changeovers, hence contributing to more effective utilization of facilities.

The third area is wiring in residences and other

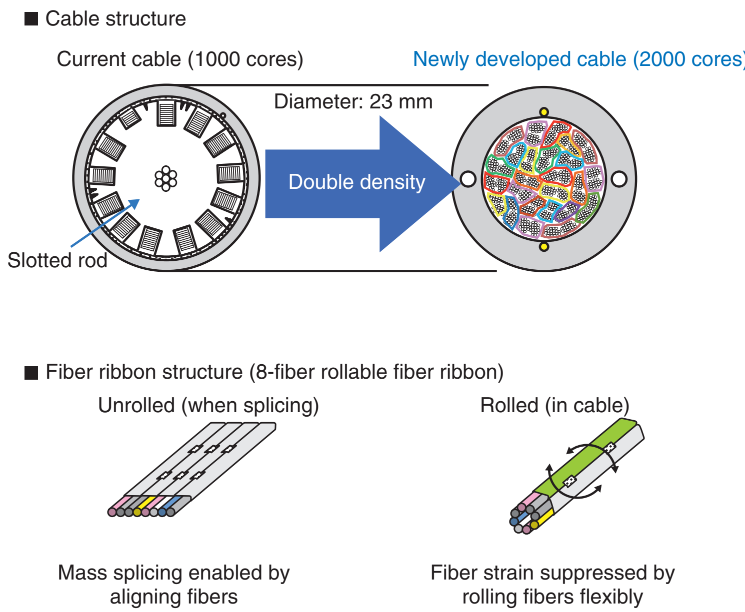


Fig. 1. Super multi-core high-density optical cables.

premises. Here, the turning point came with the introduction of small-diameter, low-friction cables that enable cable to be laid alongside wiring already installed by property developers, utility technicians, or other such personnel in situations where NTT must provide services. This technology has accelerated the provision of optical services in apartment buildings, a field in which NTT is now excelling. Also, specifications of some of the drop cables conventionally used by NTT EAST and NTT WEST have been made uniform for the introduction of VC (V-notch cicada-proof) drop cables, enabling better economy in terms of materials procurement.

The last area is that of test systems. Conventionally, large scale systems such as AURORA (Automatic Optical Fiber Operation Support System) were used, but the turning point came with the introduction of the OTM (Optical Testing Module) system specialized for core maintenance. This system helps to reduce the cost of underground facility maintenance and holds promise in disaster countermeasure applications, which have already been used to ascertain damage resulting from the Great East Japan Earthquake.

2. Recent access network technologies

2.1 Super multi-core high-density optical cables

NTT has developed the world's densest multi-core optical cable with 2000 cores. This cable has the same diameter as the conventional 1000-core version but twice the number of cores, and its structure is optimized with the application of rollable optical ribbon with the optical fibers. Optimizing the cable structure by also adjusting the sheath thickness to protect the optical fiber from external forces makes it possible to achieve stable cable characteristics without using slotted rods. Cable structures without slotted rods have also been developed for other cables. These structures are expected to become the optical fiber cable standard of the future because of their optimum bundling (**Fig. 1**) [1].

2.2 Invisible optical fiber

When exposed wiring is necessary with optical subscriptions, it is sometimes not possible to carry out the work to commence services because some customers find conspicuous wiring aesthetically problematic. To address this unsatisfactory aspect of service provision, we have developed an invisible (i.e., transparent) optical fiber that enables unobtrusive exposed wiring that does not impinge on the aesthetics of buildings [2].

NTT EAST and NTT WEST have worked together to solve issues in this project by deciding on both the form and performance to meet customer demands and service provision requirements. Deployment of this fiber is ongoing (**Fig. 2**).

Also, the NTT Group has received the Good Design

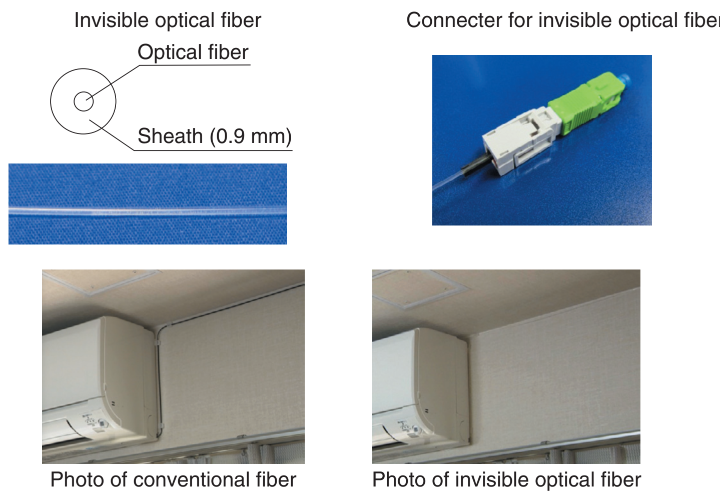


Fig. 2. Invisible optical fiber.

Award for its access components for the first time after having already received the same award hosted by the Japan Institute for Design Promotion a number of times.

2.3 Initiatives for eliminating utility poles

NTT has participated in various programs aimed at eliminating utility poles. These include the National Institute for Land and Infrastructure Management (NILIM) Pilot Program (1) (to determine a burial depth for cables that does not affect road surfaces or cable functionality); the NILIM Pilot Program (2) (to confirm the distance between communication lines and power lines), and the NILIM Pilot Program (3) (an experiment to confirm the workability of direct and small box burial). NTT is ahead of other companies with its development of direct cable burial technology for new underground schemes and will continue to participate in pilot programs planned from fiscal year 2016 onwards.

3. Future developments

Optical access network technologies start out with regional IP (Internet protocol) networks, which forms the infrastructure that supports a range of services and systems such as NGN (Next Generation Network) services and the NetroSphere concept [3]. Here, a turning point came with the start of the Hikari Collaboration Model under which service commencement work and maintenance have been commercialized. For example, ongoing research into uninterrupted switching technology is expected to result in sales tools for network reconfiguration for *hindrance migration* work*. It is also expected to result in the provision of diverse additional network services.

The demand for optical facilities, which have been central to facility construction, is showing signs of reaching saturation. Consequently, new service developments in ICT (information and communication technology) environments are expected with ongoing use. These developments may include the combined use of different services such as fixed lines and wireless, IoT (Internet of Things), and cloud computing.

The NTT Group also plans to make the most of these coming business opportunities by continuing to maintain the quality of the massive infrastructure it has built while focusing on the issue of efficiently operating these services and facilities. This entails rethinking current operating processes and proceeding with R&D to bring about operational innovations and infrastructure renovation (architecture/functionality) for the FTTH era (**Fig. 3**).

3.1 Operational innovation

The numerous operations required during the lifecycles of various facilities entail a range of service levels for both services and operators, but the ultimate aim is to achieve operations that do not require manpower. This can mean: (1) sharing functions to reduce

* Hindrance migration work: This refers to work carried out to relocate telephone or network lines to move them out of the way of newly constructed and/or installed infrastructure facilities such as roads and water pipes.

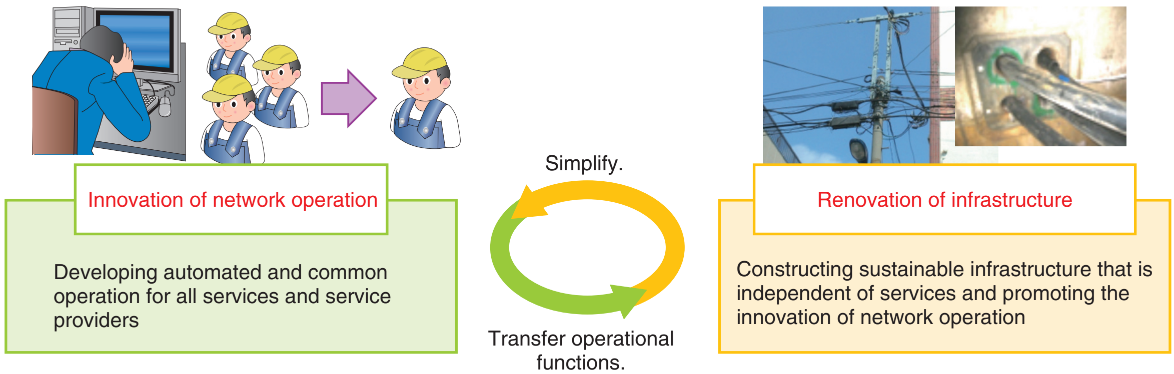


Fig. 3. Rethinking current processes to achieve innovation.

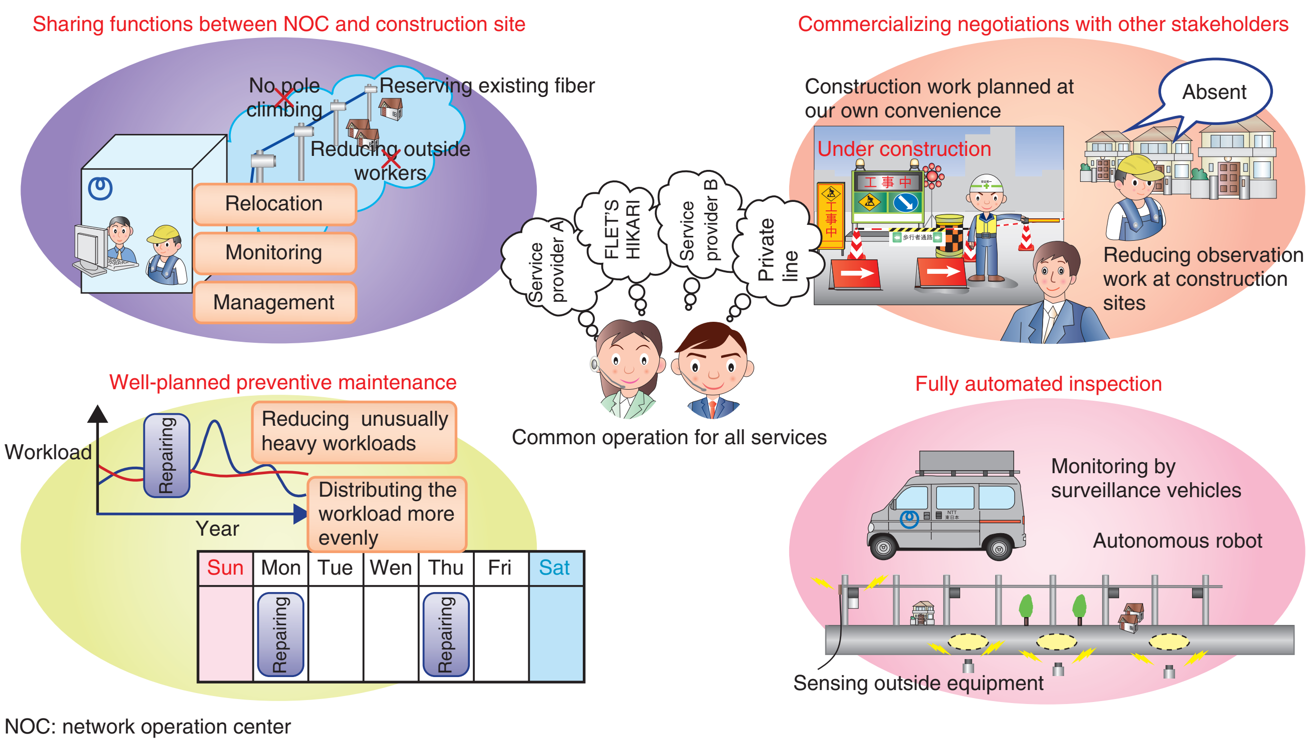


Fig. 4. Innovation of network operations.

the amount of on-site work requiring special skills and shifting such work to operation centers; (2) commercializing adjustment and negotiation tasks; (3) implementing well-planned and preventive maintenance; and (4) carrying out full non-operator facility inspections.

Key to these operational innovations is the accuracy of facility databases. Hence, we are developing technologies to transform facility management for the FTTH era with databases that are clean with non-contaminating mechanisms using three-dimensional technologies to enable data with precise location and facility information to be automatically acquired, checked, and updated (**Fig. 4**).

3.2 Infrastructure renovation

To shift to a more efficient network with facility renovation, we are building new network architecture

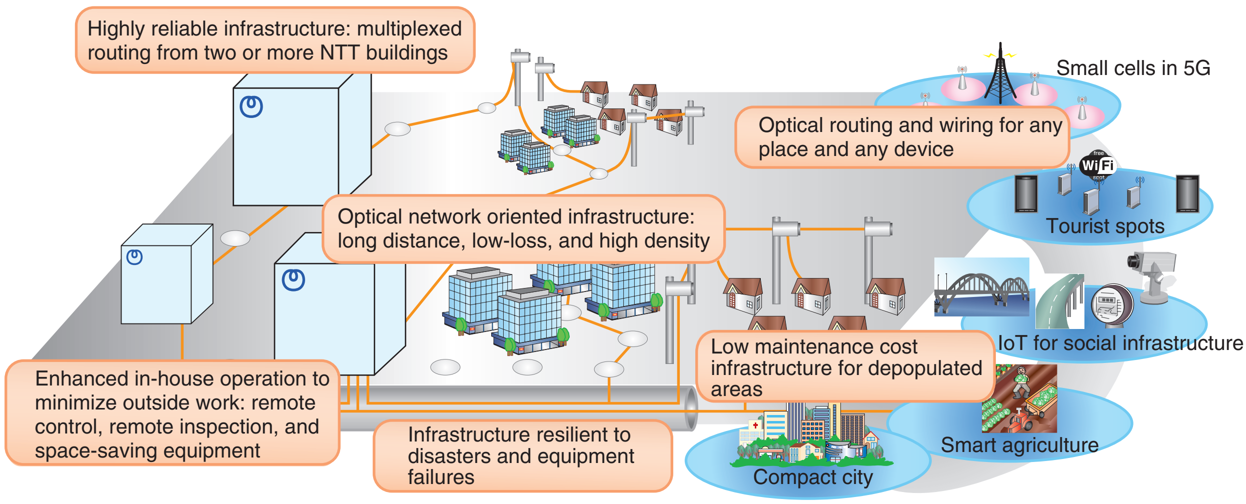


Fig. 5. Renovation of infrastructure.

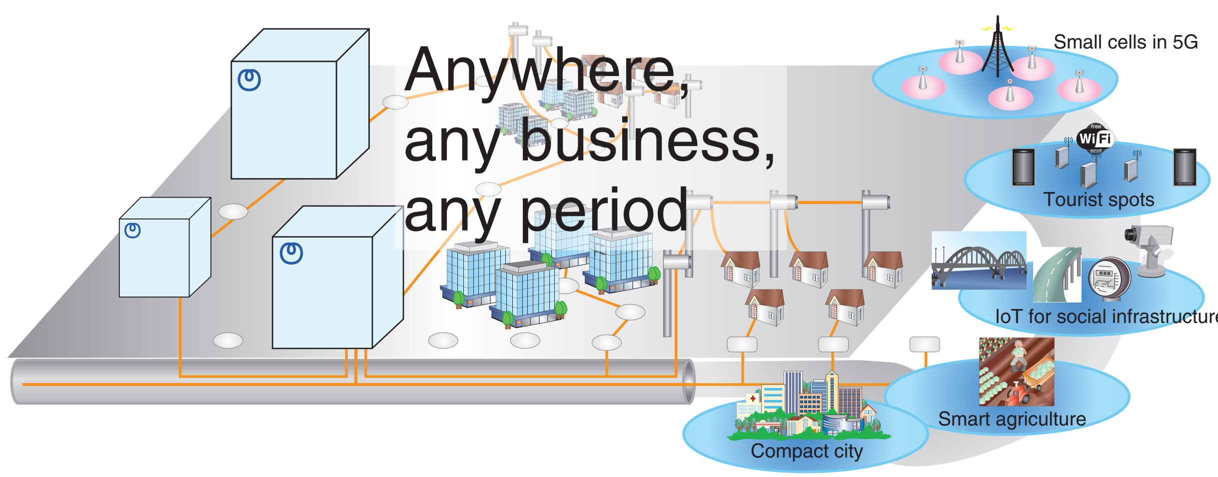


Fig. 6. Our vision.

making use of the characteristics of optical fiber with efficiencies gained from wide-area user coverage and building integration while maintaining reliability.

By aggregating active access equipment at maintenance points based on new architecture to make the most of optical fiber characteristics under the four key ideas of (1) long distance, (2) low-loss, (3) high density, and (4) high reliability, we are engaging in R&D with the intention of developing infrastructures for operational innovations with equipment that minimizes the need for on-site work and that is resilient against malfunctions and disasters (**Fig. 5**).

4. Our vision

The completed rollout of FTTH is a turning point that is prompting NTT to set the direction for and transform its networks for the future. Our vision is to spread the use of optical fiber to all kinds of people, objects, and businesses by building a safe and secure access network infrastructure for society that will span generations under the rubrics of *anywhere*, *any business*, and *any period* (**Fig. 6**). We therefore aim to deepen our cooperation and partnerships and strengthen efforts to bring about our R&D achievements in a timely manner. To this end, we look forward to the understanding and cooperation of all involved.

References

[1] N. Nakagawa, S. Hamaguchi, Y. Endo, Y. Shibata, R. Tanaka, K. Nitta, M. Nogami, K. Nishimura, T. Iwadou, and Y. Enomoto, "Development of World's Highest Density Ultra-high-count and High-density Optical Fiber Cable (2000 Cores)," NTT Technical Review, Vol. 13, No. 10, 2015.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201510ra2.html

[2] K. Yoneda, J. Onishi, T. Iwadou, H. Iino, Y. Enomoto, and K. Nakayachi, "Development of Invisible Optical Fiber for Improved Aesthetic Appearance," NTT Technical Review, Vol. 14, No. 1, 2016.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201601ra2.html

[3] R. Sumi, K. Matsumoto, I. Inoue, and Y. Kajiyama, "The NetroSphere Concept and Network Architecture," NTT Technical Review, Vol. 13, No. 10, 2015.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201510fa1.html

■ **Author profile**

Kiyoharu Sasaki

Project Manager, NTT Access Network Service Systems Laboratories.

He joined NTT in 1989. He is currently engaged in improving operations related to optical fiber paths outside telecommunication buildings.

Operations Technologies to Improve Work Efficiency and Create Value

Hideaki Harada

Abstract

The Access Operation Project of NTT Access Network Service Systems Laboratories is focused on the research and development of operations systems in access networks. This article introduces the roles that operations play in the NetroSphere concept, the environment that we seek to realize through operations, and different navigation technologies implemented to realize efficient execution of tasks without affecting existing systems.

Keywords: NetroSphere, integrated control, navigation

1. Introduction

NTT established the NetroSphere concept [1] as a new research and development (R&D) concept to transform the future of carrier networks. In this concept, functions that make up the network are treated as much as possible as small components. Service providers offer needed services by combining these components with complete freedom and control. In such a concept, the required operations functions change greatly. Operations in the NetroSphere concept require the following capabilities.

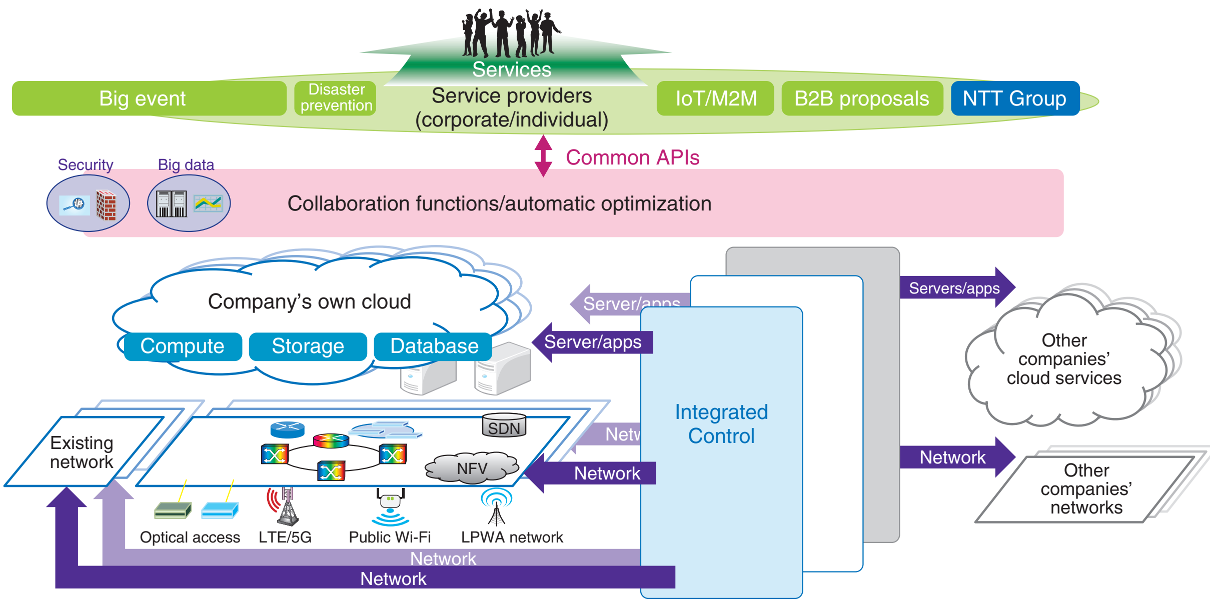
- The ability to seamlessly manage the virtual layer and the real layer
- The ability to flexibly build services that meet needs by combining componentized network functions and service functions
- The ability to provide frameworks that enable efficient and effective collaboration with service providers having diverse requirements

The vision of the computing environment we are aiming for in order to realize these abilities is presented in **Fig. 1**. This vision centers on the provision of network/cloud/applications by multiple businesses to service providers in a one-stop manner, which we refer to as *one-stop operations*. Furthermore, an approach called *Integrated Control*, described below, is necessary to provide the underlying support for one-stop operations and to improve the efficiency of end-to-end (E2E) operation tasks.

In NTT laboratories, we are currently studying five directions of future operations that will help to achieve the environment we seek to realize through operations (**Fig. 2**). In this article, we introduce the Integrated Control technologies, which are elements of Service Orchestration, a major component of one-stop operations. We also introduce the Navigation technologies, which are elements of Simple & Smart Operation, a direction of study intended to reduce the workload of operators.

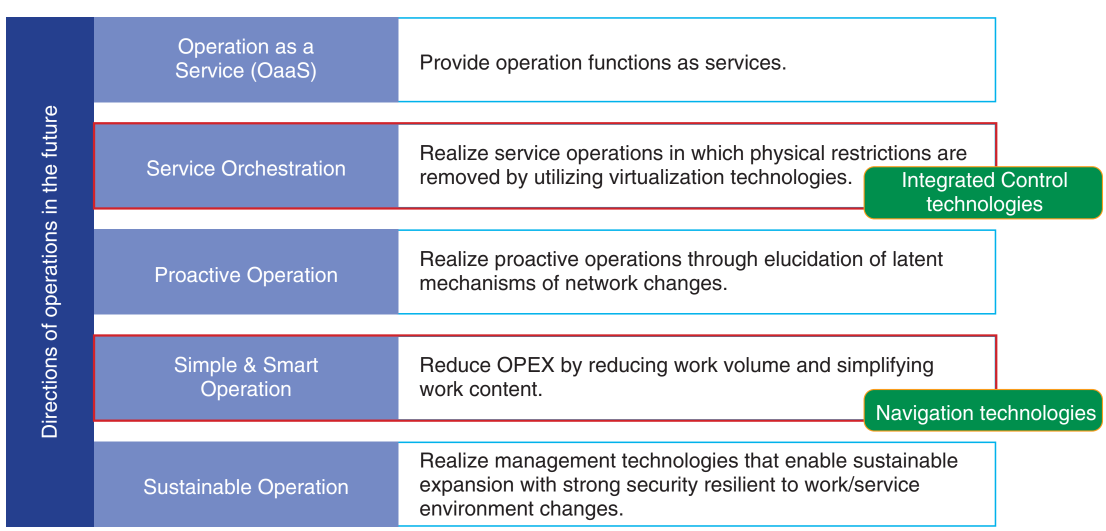
2. Integrated Control technologies

Conventional networks use dedicated equipment for each service, and therefore, specialized operations systems (OpS) are being developed for each type of dedicated equipment. Because network operations are managed by specialized OpS, silo systems arise in which services, network functions, and operations are tightly bound. Such silo architectures make it difficult to achieve collaboration that spans services. Moreover, collaboration that spans domains even within the same service requires a large amount of manual intervention, and it is difficult to provide multiple



APIs: application programming interfaces
B2B: business to business
IoT: Internet of Things
LPWA: low power wide area
LTE: Long Term Evolution
M2M: machine to machine
NFV: network functions virtualization
SDN: software-defined networking

Fig. 1. The computing environment we seek to realize through operations.



OPEX: operating expenses

Fig. 2. Directions of operations in the future.

services in a one-stop manner. Adding network functions and services also requires modifying multiple OpS. We have been conducting R&D on Integrated Control technologies as a means to resolve these

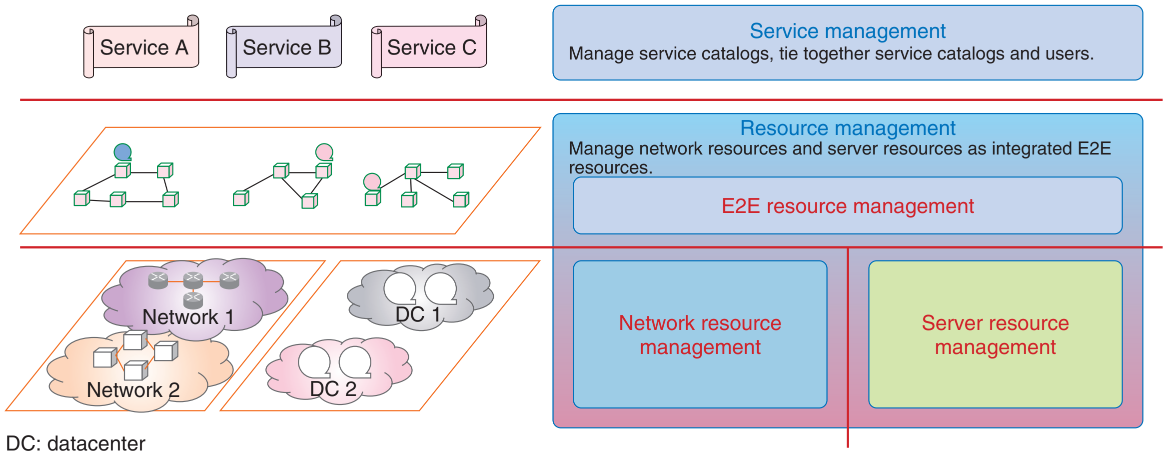


Fig. 3. Integrated Control architecture.

issues. Here, *integration* has two meanings:

- E2E management that seamlessly manages the operations of network functions implemented on access networks, transmission routes, and datacenter servers.
- Seamless operations management of the physical layer, logical layer, and service layer.

Integration does not mean making multiple operations systems into one system. It refers to providing services by organically joining the multiple systems that manage each domain. By establishing the Integrated Control technologies, we can expect to achieve benefits in the form of faster provision of services, improved network convenience, and reduced OPEX (operating expenses).

The benefits of Integrated Control technologies include the ability to start services immediately. For example, at present when a service provider applies for multiple services, it faces various challenges. For example, there is a long lead time needed to start the services, and applications have to be prepared for each service. Also, the operational conditions of the equipment used for each management domain are confirmed by the OpS of each service, and tasks such as design and configuration need to be carried out.

By contrast, in an environment in which Integrated Control technologies and one-stop operations are combined, APIs (application programming interfaces) related to the application of services by service providers are established, making it possible for service providers to apply for services with inter-system connections. The function that receives the application can carry out E2E unified management of resources and available space. It thus becomes easy to secure resources and to automatically perform batch configuration in an E2E manner. The lead time for starting services can then be greatly reduced.

An example of the architecture used to achieve Integrated Control is shown in **Fig. 3**. The first point to note is the separation of service management and resource management. To build new services by flexibly combining services, our approach is to separate and loosely couple the management of services, which tie service catalogs and their management with users, and the management of resources, which are resources for providing services.

The second point to note is the separation of network resource management and server resource management. Network systems and server systems differ greatly in terms of their management targets, for example, lifecycle. Our approach therefore is to separate management systems into network resource management and server resource management, as well as E2E resource management, which connects these two management systems.

As a use case example of automatic recovery, let us consider the role of each management function. When a piece of network equipment fails, network resource management functions are trapped inside the equipment. If new routing designs and configurations are implemented, there is no need to connect to other management functions to recover from the failure. In cases where a server installed in a datacenter fails, connections with other management functions are not necessary because services can be recovered if available resources are secured on other servers

Table 1. Integrated Control technology efforts.

Activity	Details
1. Creating specific use cases	Clarify roles of each workflow and management function and information that should be circulated for starting services, maintenance, etc.
2. Establishing resource abstraction technology based on standard management model	Clarify type and granularity of resources to be managed, and establish resource abstraction technology to minimize network methods and service dependency.
3. Studying feasibility of proposed architecture	Based on the two activities above, study consistency of proposed architecture as a commercial product, ensure there are no bottlenecks in performance, etc.
4. Transition method that takes into account migration from existing OpS	Study migration from existing OpS with special consideration of scenarios of network deployment.
5. Utilizing and proposing TMF standards	Continue efforts focusing on compatibility with international standards and upstream activities with international standards organizations.

TMF: TM Forum

within the same datacenter and necessary network functions are started up. However, if available resources cannot be secured on other servers within the same datacenter, it is necessary to recover services using a datacenter in a different location. In this case, network routes between datacenters must be combined and modified. E2E resource management functions control network resources and server resources in an integrated manner and also reconfigure new routes and change datacenters. In this way, recovery is implemented by E2E.

By realizing the Integrated Control technologies as explained above, the creation of new value can be accelerated with operations such as creating new services and promoting collaborations between service providers. The efforts planned on the Integrated Control technologies as we go forward are listed in **Table 1**.

3. Navigation technologies

We introduce here the Navigation technologies that contribute to reducing the burden of operators' tasks.

Diverse work support systems are being introduced with the aim of improving work efficiency in a wide range of fields, not just communications services. Workflows that serve as the basis of work support systems are changing rapidly due to factors such as changes in laws, the introduction of new services, changes in marketing campaigns and organizational structure of the company, and differences in individuals' skills. Changing work support systems to meet changes in such workflows usually requires a substantial expense and a lot of time, and thus is not a realistic solution. As a result, irregular tasks not covered by work support systems remain. Compared with tasks that are systematized, even when they occur with low frequency, such irregular tasks often involve issues such as complex operational procedures, a long work time, and the tendency for operational mistakes to occur. Know-how and hands-on help from experienced operators are being utilized to deal with these issues. We believe that radical measures are needed to effectively and efficiently carry out human-mediated work and are therefore carrying out R&D on Navigation technologies to resolve these problems.

Navigation technologies are technologies that achieve the implementation of operations more efficiently by reducing the number of operations and simplifying work content without affecting existing operations systems. The elemental technologies we are developing are indicated in **Fig. 4**. The horizontal axis represents the level of complexity of the required work. The vertical axis represents in general the quantity of required operations. The work on commercializing the UMS (Unified Management Support System) and the Data Bridge has already been completed. We are currently conducting R&D on three elemental technologies: system-linked integration technology, operational log acquisition/utilization technology, and annotation technology [2]. We describe here the annotation technology.

An overview of annotation technology is shown in **Fig. 5**. Annotation here means technology that provides operational support by allowing electronic

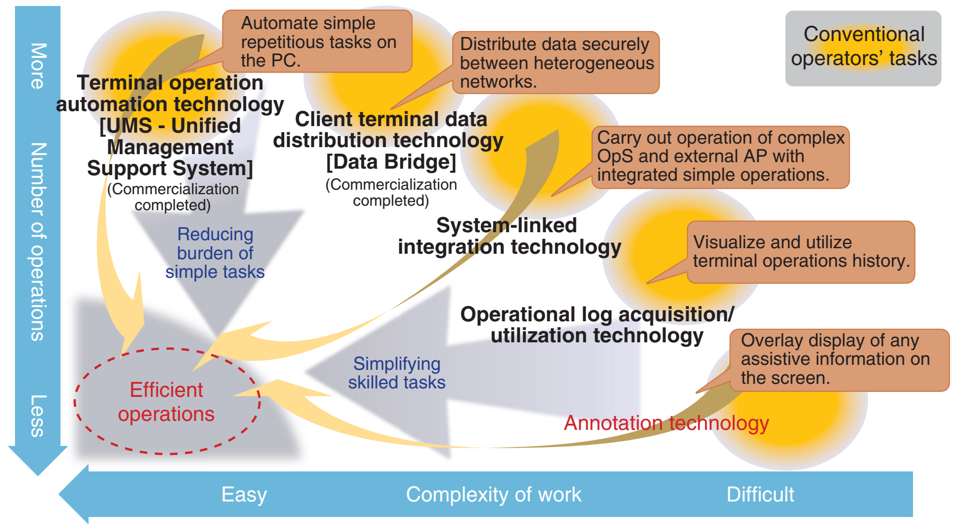


Fig. 4. Elemental Navigation technologies.

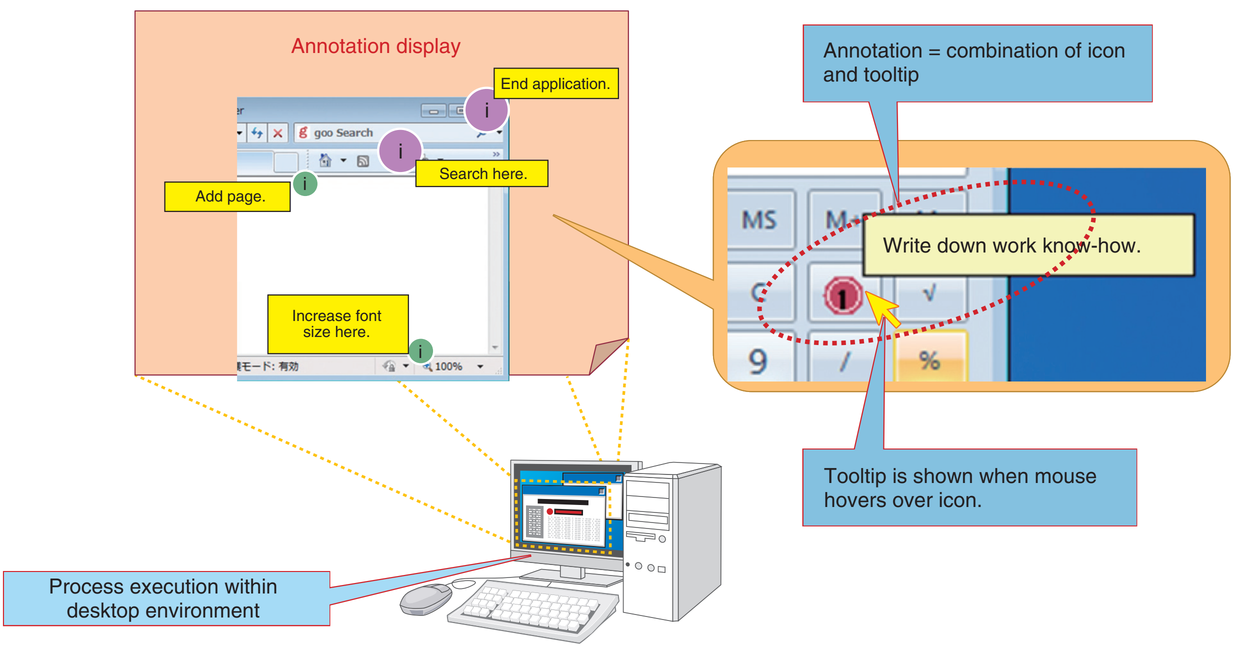


Fig. 5. Annotation technology.

sticky notes to be attached and displaying information considered necessary by the terminal operator. The features of annotation technology are as follows.

- It can be applied to numerous work scenarios thanks to its overlay display technology, which uses a versatile framework that is not dependent on particular tasks.
- Users themselves can create and edit display tools, and manage and share them as definition files.
- The technology can be used without modifying the existing system or changing the terminal's environment, enabling low-cost operation of the technology.

Table 2. Example uses of annotation technology.

Example	Overview
1. Alternative to manuals	Reduce labor involved in browsing manuals by displaying the content of manuals for input items shown on the terminal.
2. Attention pop-ups when operating	Present messages and icons that promote attention in areas where mistakes easily occur and where careful operations are needed to prevent prohibited operations and operational errors.
3. Multilingual support	Localize software and realize multilingual support by overwriting each display item on the terminal in another language.

Some examples of uses of the annotation technology are listed in **Table 2**. The following functions have already been implemented.

- A function to overlay fixed information on the operations screen based on display rules
- The ability to create display rules using a GUI (graphical user interface) rather than programming them
- Linking functions for calling external office tools

Sales of this technology by NTT Software Corporation have begun [3]. We are moving forward with efforts to continuously make these functions more advanced.

As the first stage in improving the sophistication of the annotation technology, we are studying the development of a function that switches fixed information written in advance based on the attributes and environment of the user; it then presents the selected information to the user. As a specific use scenario, we are studying the development of a system that can provide effective work support by switching the user profile based on the skills of the operator—for example, depending on whether the operator is a beginner or a veteran—and also based on the work content. We are also studying the development of a system in which multiple users cooperate to create annotations from various perspectives. The system then efficiently edits the necessary subset from the aggregated information.

Finally, we are studying the development of a system that automatically generates useful user-support information from user operation logs and displays such information appropriately based on the user's work progress and operational state. As a specific use scenario, we are seeking to create a system that provides a recommendation function. When a user has difficulty in the middle of performing an operation, the system automatically generates optimal annotation information that suits the situation from information including the operations history to date, and presents the information as a recommendation to the user.

References

[1] NTT press release issued in February 2015.
http://www.ntt.co.jp/news2015/1502e/150219a.html

[2] Y. Kawabata, T. Masuda, K. Tsuchikawa, H. Adachi, and A. Inoue, "Annotation Display/Editing Technology that Directly Presents Work Know-how on Operation Screen," NTT Technical Journal, Vol. 27, No. 7, pp. 36–39, 2015 (in Japanese).

[3] NTT press release issued in October 2015 (in Japanese).
http://www.ntt.co.jp/news2015/1510/151020a.html

■ Author profile

Hideaki Harada

Executive Manager, Access Network Operation Project, NTT Access Network Service Systems Laboratories.

He received a B.S. and M.S. in information and computer sciences from Toyohashi University of Technology, Aichi, in 1989 and 1991. He joined NTT Transmission Systems Laboratories in 1991 and engaged in research on optical access network management systems. From 2001 to 2007, he was with NTT WEST R&D Center, where he worked on optical access and wireless access technologies. After returning to NTT in 2007, he engaged in R&D of network management systems. He is a member of the Institute of Electronics, Information and Communication Engineers.

Access System Technologies for Service Diversification

Yukihiro Fujimoto

Abstract

NTT Access Service Systems Laboratories has been actively conducting research and development (R&D) of the fiber-to-the-home (FTTH) service for the access system. FTTH was commercially introduced some 20 years ago. This article reviews the technical innovations created for FTTH systems and discusses current R&D activities in access system technologies focused on the diversification of services.

Keywords: FTTH, access system technologies, access services

1. Advances in access services and system technologies

1.1 Initial commercial FTTH

The fiber-to-the-home (FTTH) service in Japan is currently being used by more than 26 million users. Its growth has followed the rapid adoption of Internet access, and it is now a key communication infrastructure. Commercial FTTH service started in Japan in 1997, and its system technologies have greatly advanced over the last 20 years or so. The initial FTTH services provided analog/ISDN (integrated services digital network) phone system communication and analog multi-channel video distribution. Two technologies dominated this period: synchronous transfer mode passive optical network (STM-PON) systems for the telephony-based services and SCM-PON (sub-carrier multiplexing PON) for the video distribution services. The access system transferred both services over the same optical fiber by using wavelength division multiplexing (WDM) [1]. A PON with a 32-branch splitter was adopted as the physical topology of the access network. The first FTTH systems were rather slow, about 16 Mbit/s, but this was acceptable since the dominant service was telephony. However, the original idea of providing access services via a WDM-based PON system carrying optical signals corresponds to the current FTTH (**Fig. 1**).

1.2 FTTH broadband access

The advent of the new millennium in 2000 saw a major change to access services. The conventional telephony service was replaced by Internet access as the dominant traffic source. In early 2000, we developed and introduced a system that could take full advantage of the STM-PON described above to realize bandwidths of up to 10 Mbit/s. This move was driven by the need to eliminate the speed restrictions of ADSL (asymmetric digital subscriber line), a high-speed metallic communication system.

In 2002, we developed the B-PON (broadband PON) based on ATM-PON (asynchronous transfer mode PON) for data communication [2]. The next advance was the introduction of the Gigabit Ethernet-PON (GE-PON) based on Ethernet technology in 2004 [3]. Consequently, access system speeds rose from 12 Mbit/s to 1 Gbit/s in just a few years. The major enabler has been the adoption of high-speed local area network (LAN) technology, which has become very cost-effective with the release of international standards such as those specified by the Institute of Electrical and Electronics Engineers (IEEE) and the Telecommunication Standardization Sector of the International Telecommunication Union (ITU-T), as well as the subsequent commercial

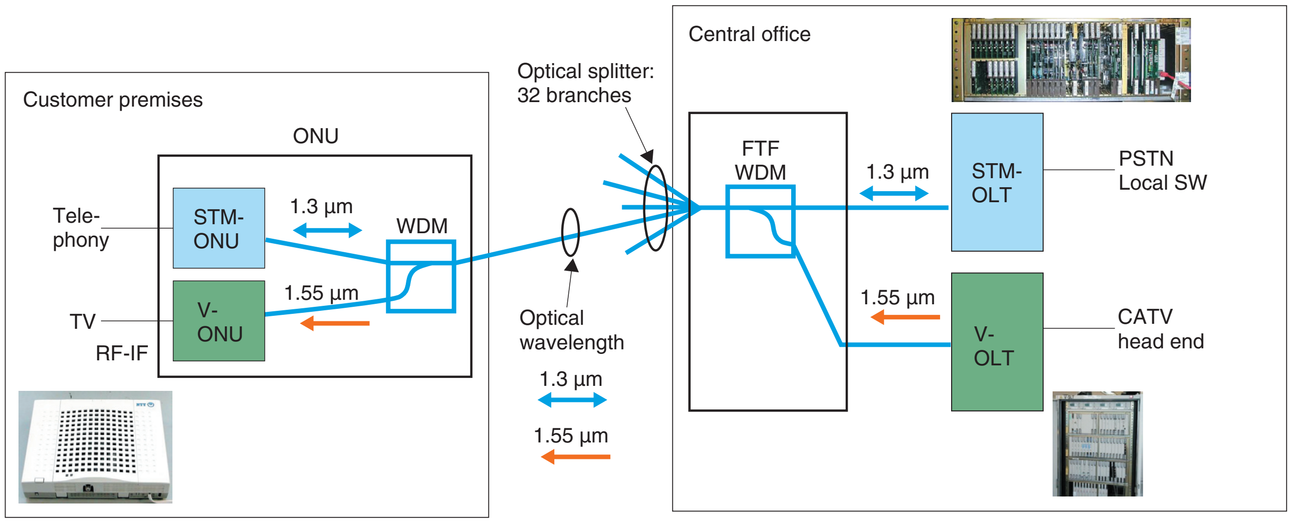


Fig. 1. Initial FTTH configurations.

development of a full spectrum of devices [4]. Prior systems largely used proprietary interfaces, and hardware was expensive and inflexible. Costs were further reduced by replacing the complex telephone system interface with Internet access, which greatly simplified the system hardware.

As the full-scale deployment of FTTH for broadband access progresses, further development has been undertaken to provide support for various services such as NGN (Next Generation Network), multicast, and BS (broadcasting satellite)/CS (communication satellite) signals, as well as the mass adoption of services thanks to DIY (do it yourself) installation and optical network unit (ONU) integration. Support has also been provided for expanding the service area (transmission coverage enhancement) and adding functions for power saving. These technological developments have enabled current services to be accepted by about 19 million users as a stable and effective communication infrastructure (**Fig. 2**).

2. Current efforts in access system technology development

2.1 Technologies to handle the increase in traffic

Over the last ten years of FTTH use, broadband traffic has increased 14-fold (**Fig. 3**). This trend is strongly expected to continue or even increase in the future with the spread of rich content services such as high-definition video. A similar trend is the continued growth in mobile communications traffic. The strong growth of 50% or more every year, driven in most part by the popularity of smartphones, has triggered significant challenges with regard to bandwidth enhancement of the backbone of the mobile network.

A recent solution is to use the optical access network as the backbone that links mobile base stations. It is obvious that continuous improvement in the access system is essential in order to continue to support broadband access and mobile communications traffic. Near-term advances in access system technologies include the PON system offering high-speed transmission at 10 Gbit/s. This system has been thoroughly studied and adopted in the IEEE802.3av and ITU-T G.987 series of standards [5]. Unfortunately, focusing only on high-speed optical access systems will not be sufficient to support the explosive diversification in access traffic; a key requirement is flexibility in system operation.

WDM/TDM-PON [6] is a system that integrates time division multiplexing PON (TDM-PON) into the conventional WDM-PON (**Fig. 4**). This technology is

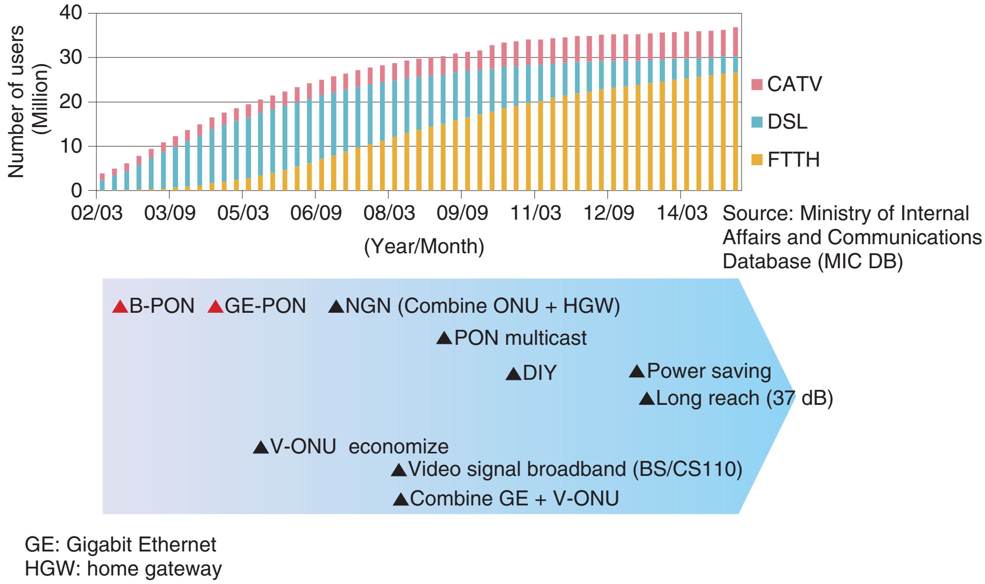


Fig. 2. FTTH service development and the growth of broadband access.

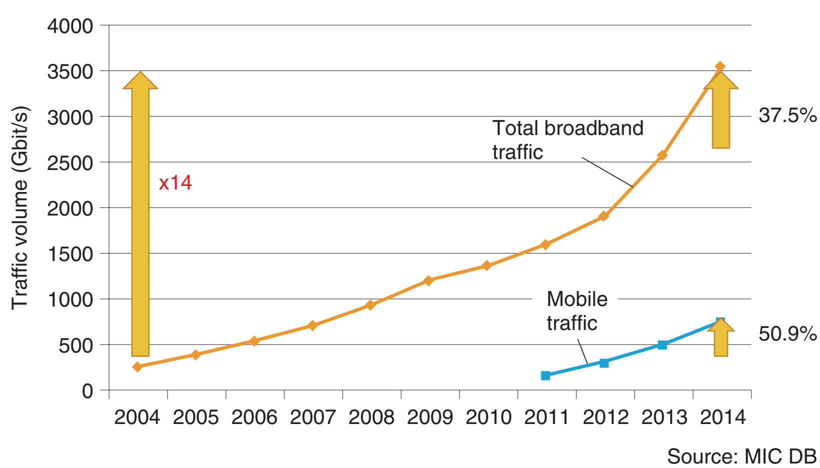


Fig. 3. Growth of Internet broadband and mobile traffic.

currently being standardized as NG-PON2 (Next Generation PON 2) in ITU-T. Each TDM-PON provides speeds of 2.5–10 Gbit/s, and PON speeds of up to 40 Gbit/s can be achieved by assigning four TDM-PONs to one service. Additionally, the dynamic allocation of the communication wavelength of any ONU-OSU (optical subscriber unit) link enables changes such as flexible speed setting and recovery after failure. Moreover, the technology of simultaneous WDM overlay point-to-point (P2P) enables this PON to establish multiple communication streams independently. This flexibility allows the access network to provide services for residences and businesses at the same time as it provides mobile communications (Fig. 4).

2.2 Technologies for mobile fronthaul

The mobile fronthaul (MFH) optically links the base band unit (BBU) in the base station to the remote antennas of the remote radio heads (RRHs). The BBU is connected to the backbone network and uses digital signal processing to generate an optical signal that

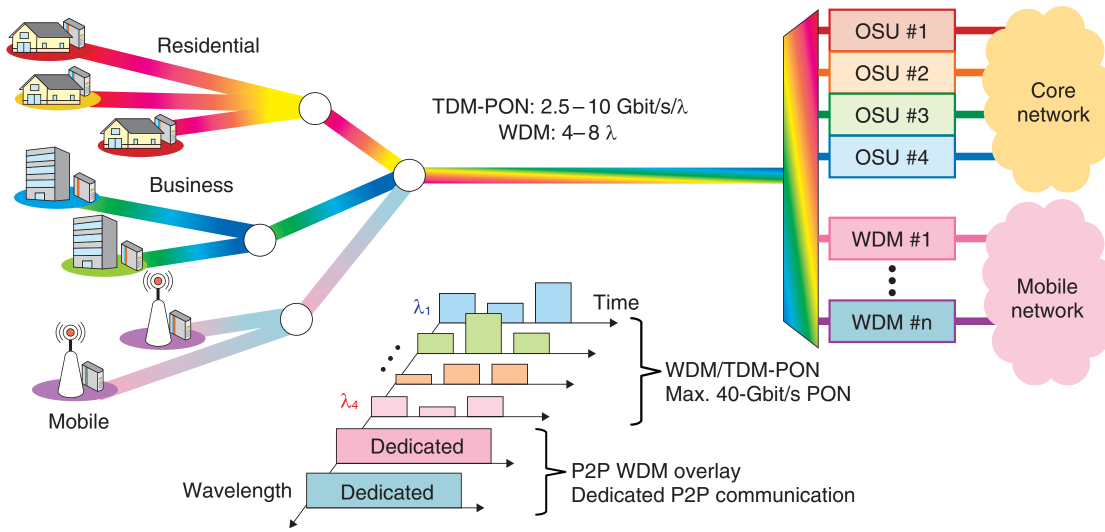


Fig. 4. WDM/TDM-PON configuration.

carries the radio signal to be transmitted.

The MFH uses the Common Public Radio Interface (CPRI), which directly digitizes the radio signal, and therefore, the required bandwidth of the optical signal is roughly 16 times that of the radio signal. CPRI is quite simple but demands very high-speed optical links. In the future, mobile communications will shift from the current LTE (Long Term Evolution) and LTE-Advanced to 5G (fifth generation), which offers up to 10 Gbit/s. This will make the current CPRI a hurdle to economical deployment of RRH, as the MFH would need access speeds in excess of 100 Gbit/s (**Fig. 5**).

Therefore, in order to achieve a cost-effective MFH that supports the traffic demands of future mobile communications, the functional configuration of the physical layer of a conventional BBU was revised so that the optical bandwidth is only slightly greater than the wireless signal speed [7]. Specifically, the new technology allows tight cooperation between base stations while reducing the interface speeds by at least 90% from the conventional CPRI demands. This advance in MFH efficiency will encourage the installation of mobile base stations. For example, even when the MFH supports 5G, the optical interface of 10 Gbit/s used in the commercial LAN or the like can be employed, which will allow low-cost commercial technology to be adopted. In addition, advances that make the MFH a better fit to PON can be expected, creating even more economical and more efficient operation.

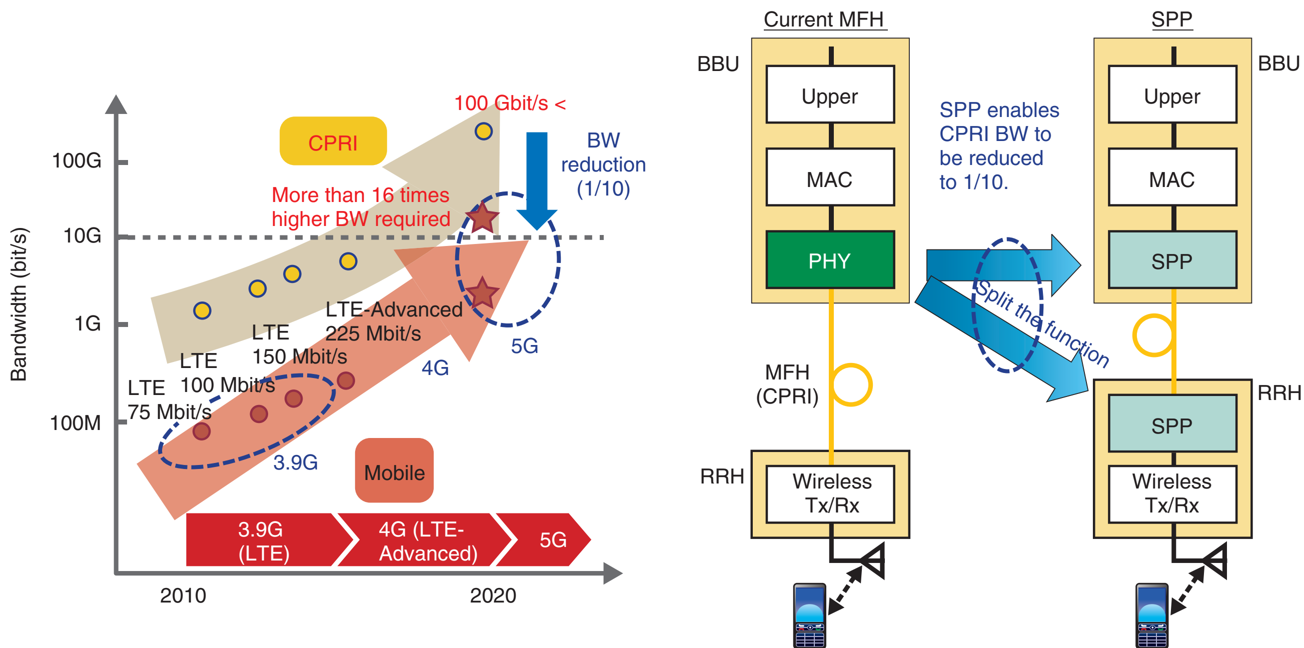
3. Towards the next research and technological development area

3.1 Emerging services and networks

Existing communication is focused on person to person communication, but the past few years have seen the rise of communication for machine to machine (M2M) and Internet of Things (IoT) applications, where the emphasis is on connecting people to things and connecting things to things. This is creating new services and business opportunities.

Research on autonomous driving is underway in many fields, but if Japanese automobiles, some 80 million units, are connected to the network, the entity of the *terminal* will rise in importance. In addition, recent predictions suggest that devices such as sensors totaling some 50 billion units or more will be connected as terminals to the network around the world by 2020, but even this number is less than the true total. In a world where such a vast number of devices/terminals are connected to the network, we must consider the possibility that the access network, currently structured for FTTH, will need to be radically altered.

For example, the M2M area network or backbone network is not likely to be layered in the same way as in the current access relay approach. Moreover, the network technologies used do not seem to suit integration (**Fig. 6**). In addition, discussions are ongoing about the actual characteristics of the information to be sent to and received by these devices.



BW: bandwidth
MAC: media access control
PHY: physical
Rx: receiver
SPP: split PHY processing
Tx: transmitter

Fig. 5. Bandwidth reduction for mobile fronthaul.

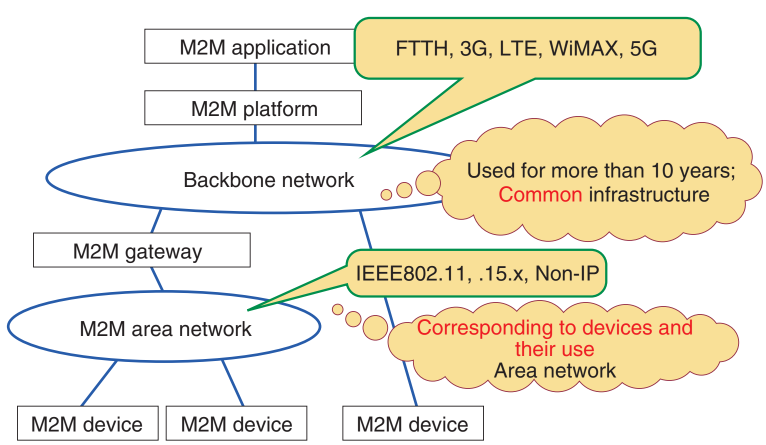


Fig. 6. Example of M2M functional architecture.

This background makes it clear that creating a network for the M2M/IoT era, assumed to be provided as an access service, is a new and very large field of research and development (R&D).

3.2 Application areas of technology

NTT Access Service Systems Laboratories has developed numerous access system technologies. A close look at each of our advances in technology is likely to reveal other areas in which they can be of benefit. For example, recently developed optical time domain reflectometry (OTDR) techniques can accurately measure the loss of optical fiber. OTDR makes it possible to not only locate faults in the optical fiber network but also to identify physical changes such as bending in the optical fiber. This makes it possible to track the status of objects that carry the fiber such as river embankments and bridges [8].

Similarly, more consideration should be given to the alternative application of the individual technologies developed for the PON as *parts*. For example, the algorithms developed to prevent optical signal collision can be used to control logistic systems. Of course, we are always alert to the possibility of adopting technology developed in other fields to rectify any problems in network technologies that may be necessary. During the Tsukuba Forum, our laboratories' core technologies are being presented under the categories of access system technology, operation technology, and network infrastructure technology. However, if we regard them as *parts* instead of being bound by these three categories, we might be able to maximize their application range. We are aggressively pursuing collaboration with partners in new areas in order to exchange viewpoints and share understandings from various quarters.

4. Future prospects

The strengthening of service diversification has led to the diversification of themes directing our R&D activities. At NTT Access Network Service Systems Laboratories, in addition to developing access system technologies to achieve goals such as high-speed, broadband, and M2M technology, our vision is to approach R&D from a new perspective that includes the IoT, involving applications that far exceed what has been thought possible. We will continue to challenge ourselves to explore the widest possible range of R&D activities.

References

[1] NTT R&D, Yearly Communications Technology Abstract (in Japanese).
http://www.ntt.co.jp/RD/OFIS/active/1998pdf/tn.pdf

[2] Website of NTT Access Service Systems Laboratories, TsuKuBa History, B-PON system (in Japanese).
http://www.ansl.ntt.co.jp/history/access/ac0109.html

[3] K. Ochiai, T. Tatsuta, T. Tanaka, O. Yoshihara, N. Oota, and N. Miki, "Development of a Gigabit Ethernet Passive Optical Network (GE-PON) System," NTT Technical Review, Vol. 3, No. 5, 2005.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr200505051.pdf

[4] Y. Fujimoto, "Application of Ethernet Technologies to FTTH Access Systems," IEICE Trans. Commun., Vol. E89-B, No. 3, pp. 661–667, 2006.

[5] J. Kani and K. Suzuki, "Standardization Trends of Next-generation 10 Gigabit-class Passive Optical Network Systems," NTT Technical Review, Vol. 7, No. 11, 2009.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr200911gls.html

[6] K. Asaka and J. Kani, "Standardization Trends for Next-Generation Passive Optical Network Stage 2 (NG-PON2)," NTT Technical Review, Vol. 13, No. 3, 2015.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201503gls.html

[7] K. Miyamoto, S. Kuwano, J. Terada, and H. Kimura, "A Study on Optical Transmission Bandwidth for Future Mobile Fronthaul Based on PON System," IEICE Tech. Rep., Vol. 114, No. 119, CS2014-18, pp. 7–12, 2014.

[8] K. Fujihashi, M. Miyamoto, K. Okutsu, and M. Okutsu, "Activities in the Area of Disaster Prevention Using Optical Fiber Sensing Technology," NTT Technical Review, Vol. 5, No. 10, 2007.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr200710le3.html

■ **Author profile**

Yukihiro Fujimoto

General Manager, Optical Access Network Service System Project, NTT Access Network Service Systems Laboratories.

He received a B.A. from Nagasaki University in 1988 and an M.S. from University of Tsukuba in 1990. He joined NTT Telecommunication Networks Laboratories in 1990 and studied fiber optic access networks including optical access systems, cables, and deployment scenarios. During 1997–1998, he was a guest researcher at Lucent Technologies Bell Lab (now a part of Nokia) in the Netherlands, where he developed the Pai-PON system, an STM-PON system for telephony services. At NTT, he has been active in writing the IEEE802.3ah specifications and in developing the GE-PON system for commercial FTTH services. He is currently studying access networks for emerging services. He is a member of the Institute of Electronics, Information and Communication Engineers and IEEE.

Gait Analysis Using a Wearable T-shirt Type Sensor

Takayuki Ogasawara, Yasuyuki Itoh, Kei Kuwabara, and Ryoichi Kasahara

Abstract

NTT has developed a T-shirt type sensor that enables continuous measurement of the heart rate of the person wearing it. The sensor links to a smartphone, with which the user can easily see the measured heart rate variation. Vital signs such as heart rate variations will be more valuable when combined with information on the situation or activity context of the user. We developed a new method to analyze the user's gait information by using a three-axis acceleration sensor built into the T-shirt type sensor. We describe in this article the gait analysis procedure and an example of the result of continuous measurement for one day. This method is easily implemented as an application in a smartphone and enables simultaneous measurement of heart rate variation and gait information.

Keywords: wearable, heart rate variation, gait analysis

1. Introduction

Wearable technology is becoming increasingly common, and many devices are now commercially available. This is making the measurement of vital data much easier [1]. Such technologies are expected to lead to the creation of new services in fields such as sports training, health and fitness, security and safety monitoring, medical care support, and entertainment. NTT has developed a wearable technology called *hitoe*, which is a conductive fabric, and a T-shirt type heart rate sensor incorporating hitoe (**Fig. 1**) [2]. Variations in the heart rate are detected as signals when the user wears the hitoe T-shirt. The signals are amplified, digitized, and wirelessly transmitted to an external device such as a smartphone via a transmitter coupled to the T-shirt. This T-shirt type fabric with built-in sensor is stretchy and comfortable, so the user can move around freely during the measurement; these features enable continuous measurement of the user's heart rate, making it possible to pick up heart rate variation.

Vital signs recorded in this way will be more valuable when they are provided with information on the activity context of the user (**Fig. 2**) [3]. It can be inferred that a change in the heart rate variation that occurs while a user is standing quietly would be different from the change that occurs while the user is running. Sending the information on the activity context of a user is helpful in inferring the reason for the change in vital signs. Our objective was to fabricate a method of simultaneously inferring the activity context of a user during the measurement of heart rate variation using hitoe.

To infer the user context, we focused on information concerning walking because walking is a basic means of moving around both indoors and outdoors. Walking information gives meaningful hints to infer the user's activity context. For example, if there is no step detection for a few hours during the daytime when the user is in an office, it can be inferred that the user stayed in the same place. If the status of *running* is detected for a few hours, it most likely indicates a period of exercise. We devised the new gait-analysis method by using the three-axis acceleration sensor installed in a transmitter attached to a T-shirt (**Fig. 3**). Unlike a GPS (Global Positioning System) sensor, an acceleration sensor works effectively even inside buildings. Therefore, it is suitable for gait analysis applications in daily life.

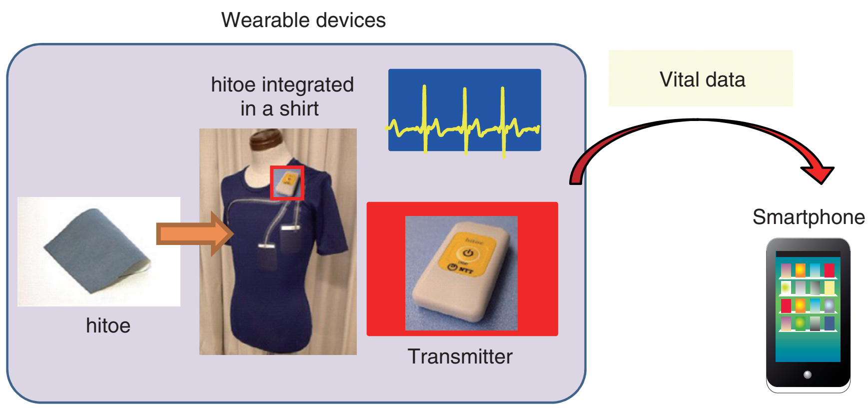


Fig. 1. T-shirt type heart rate sensor incorporating “hitoe.”

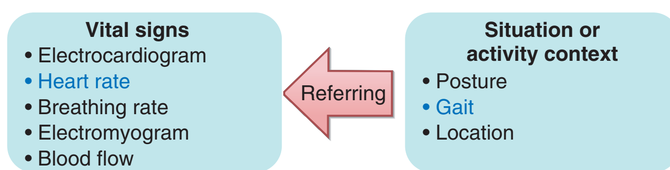


Fig. 2. Vital signs or activity context of a user.

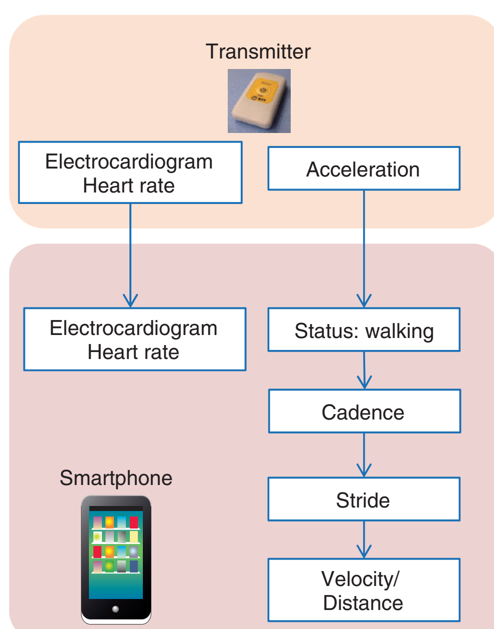


Fig. 3. Structure of gait analysis method.

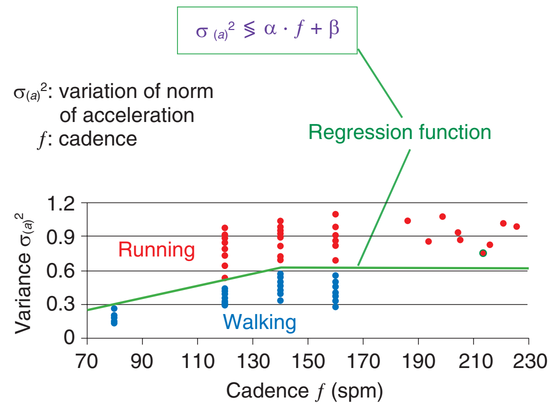


Fig. 4. Relation between variance of norm of acceleration and cadence.

This article proposes a new method to analyze exercise mode, cadence, speed, and distance by using the measured vibrations of acceleration. In the exercise mode, the method distinguishes whether a user is walking, running, or resting. Cadence means the total number of steps per minute (spm). Speed is the walking or running velocity per hour, and distance is the total length of movement. This method is based on simple mathematics and is easily implemented as a smartphone application, which makes it possible to simultaneously measure heart rate variation and gait information.

2. Method to infer the movement status of a user

We first developed a method to infer the exercise mode of a user from data provided by the three-axis acceleration sensor. We investigated the relation between exercise mode and acceleration by measuring the vibration of acceleration when 11 users were walking or running at a variety of cadences. In this experiment, each user wore a watch with an alarm that beeped at a rate of 120, 140, and 160 times per minute, and they were instructed to walk at a cadence that matched the timing of the alarm. The result is shown in **Fig. 4**. The horizontal axis is the cadence, and the vertical axis is the variance of the norm of acceleration. The graph shows that the groups of plot points for walking and running have a tendency to be separated, so we set a regression function that lies in the middle of those groups in order to distinguish them. If a measured variance is over the function, the mode is inferred as running; otherwise it is walking. If the cadence is less than 60 spm, no matter what the variance is, the status is inferred as resting because a healthy person does not walk at a cadence below 60 spm without reason [4]. As a smartphone application, the gait analysis method infers the exercise mode in real time by using the regression function, which is the function of cadence. The method used to calculate cadence is described in the next section.

3. Method for calculating cadence and step detection

As previously mentioned, cadence is defined as the total number of steps per minute. Thus, precise step detection makes it possible to calculate cadence. The main factor in detecting the number of steps and calculating cadence is the leaning angle of the upper body. When people walk or run, they generally lean forward slightly. The leaning angle affects the measurement of acceleration because the transmitter is located on the user's upper body. It is quite common to count steps by measuring the acceleration along the axis perpendicular to the horizon because it shows a distinguishing peak at the moment of a heel strike, which is when the heel touches the ground (**Fig. 5**) [5]. However, if the upper body leans forward, the axis is no longer vertical, and the amplitude of oscillation of acceleration becomes smaller. Additionally, the influence of the acceleration on horizontal axis and the motion of rotation of the upper body by swinging the arms becomes larger, making it difficult to detect the peak. Thus, a method that is not affected by the lean of the upper body is required.

We used the norm of acceleration to avoid the influence of leaning because leaning of the axis can be handled as a transformation of the Cartesian coordinate, and the norm is not changed by this. However,

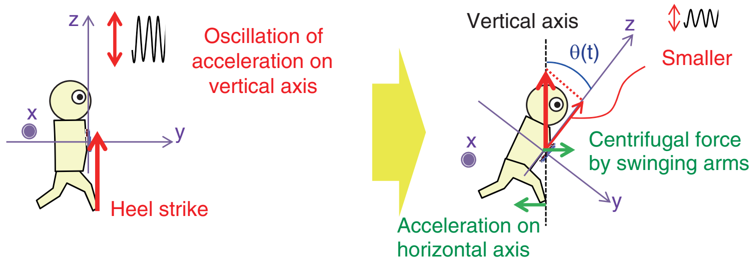


Fig. 5. Lean of axis of acceleration.

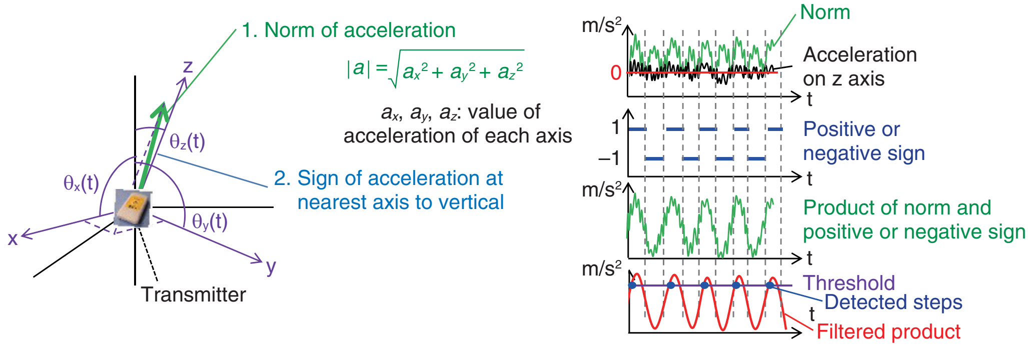


Fig. 6. Method of step detection.

acceleration along the vertical axis takes both a positive and negative value, but the norm takes only a positive value. Because of this difference, the norm often increases even if acceleration along the vertical axis decreases, and this makes it difficult to count the number of running steps. To solve this problem, we devised a method to estimate the lean of the transmitter integrated into a T-shirt by selecting the nearest axis to vertical (**Fig. 6**). If the value of acceleration measured on the nearest axis is negative, the norm is multiplied by minus one and treated as a negative value, and if it is positive, the norm is handled as a positive value. The product of the norm and a positive or negative sign cyclically changes and matches the step cycle. This product is applicable as a filter to reduce noise or a discriminator to count steps with a threshold.

We also evaluated the step detection method. Eight people walked and ran on a straight horizontal road 500 m long. They each wore a T-shirt type sensor as well as a pedometer for reference. To count the actual steps, each participant held a handy counter that they clicked every time they took a step. The results are shown in **Fig. 7**. The error rate E is defined as the following equation.

$$E = \frac{100 \cdot (S_e - S_a)}{S_a}, \quad (1)$$

where S_e is the estimated steps measured using this method, and S_a is the number of actual steps. The plot points show the median of the error rates of eight people, and the bars show the maximum errors. The length of the error bar with our method is within plus or minus 3% for both walking and running. These results reflect the stability and accuracy of our step detection method. This method also enables us to use the regression line, which is described in section 2, and to infer the exercise mode.

4. Method to estimate velocity and distance

We used the following equations to calculate walking speed and distance,

$$v = lf \quad (2)$$
$$d = \sum v \, \Delta t, \quad (3)$$

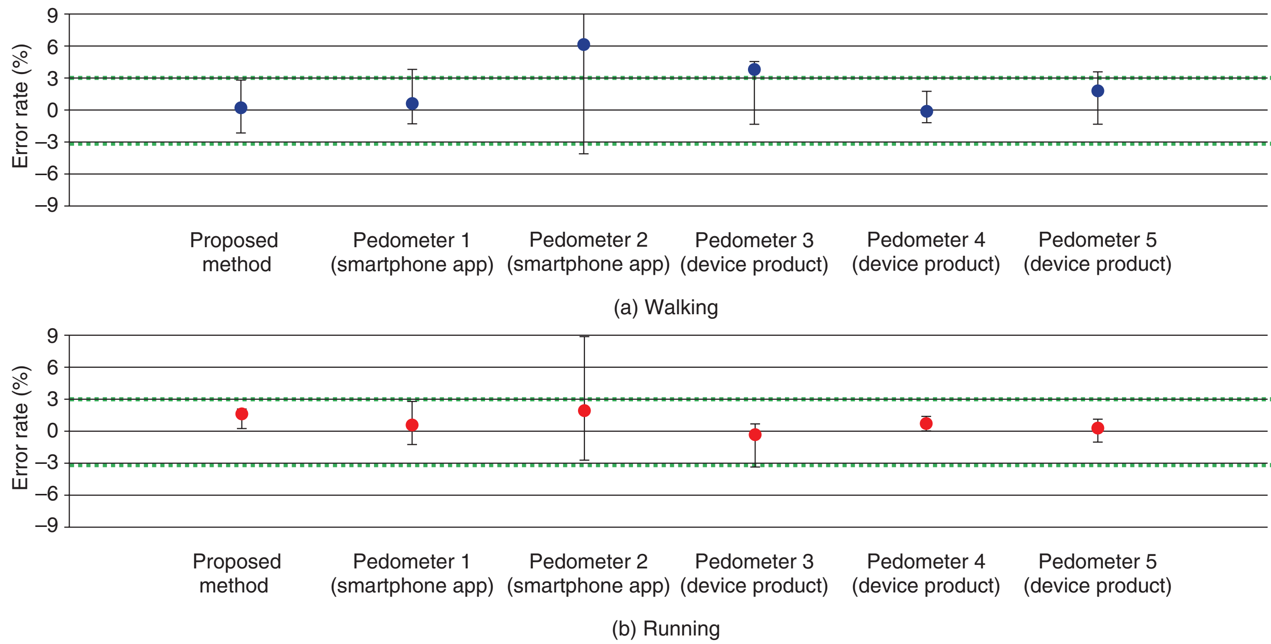


Fig. 7. Results of step detection method.

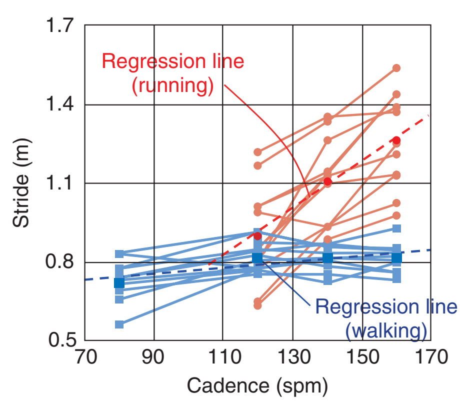


Fig. 8. Relationship between stride and cadence.

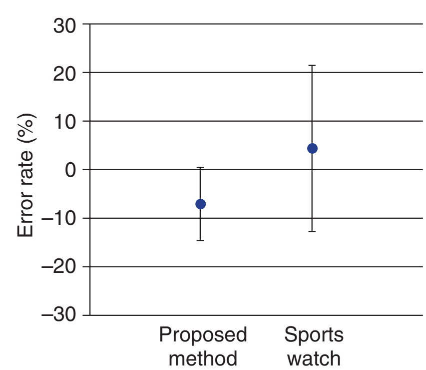


Fig. 9. Result of distance calculation method.

where v is velocity [m/min], l is stride [m], f is cadence [steps/min], d is distance [m], and Δt is measurement time interval [min]. Estimating the stride enables us to calculate the velocity and then the distance. We investigated the strides of 11 people and calculated the regression lines as a function of cadence by using the value of average cadences (**Fig. 8**).

The regression lines give the approximate values of stride for each cadence value. By using these regression lines of stride, we devised a method to estimate stride and to estimate velocity and distance with v and d in eqs. (2) and (3). The regression lines of stride while walking and running have different slopes. Therefore, first the exercise mode is inferred, and the proper line is chosen depending on the mode. Then, the distance and velocity are estimated in real time.

The result of distance calculation is shown in **Fig. 9**. In this experiment, four people walked and ran 300 m six times. They were not directed to use any particular cadence. The plot points show the average error rate, and the bars show the standard deviation. The bar using the proposed method is shorter than

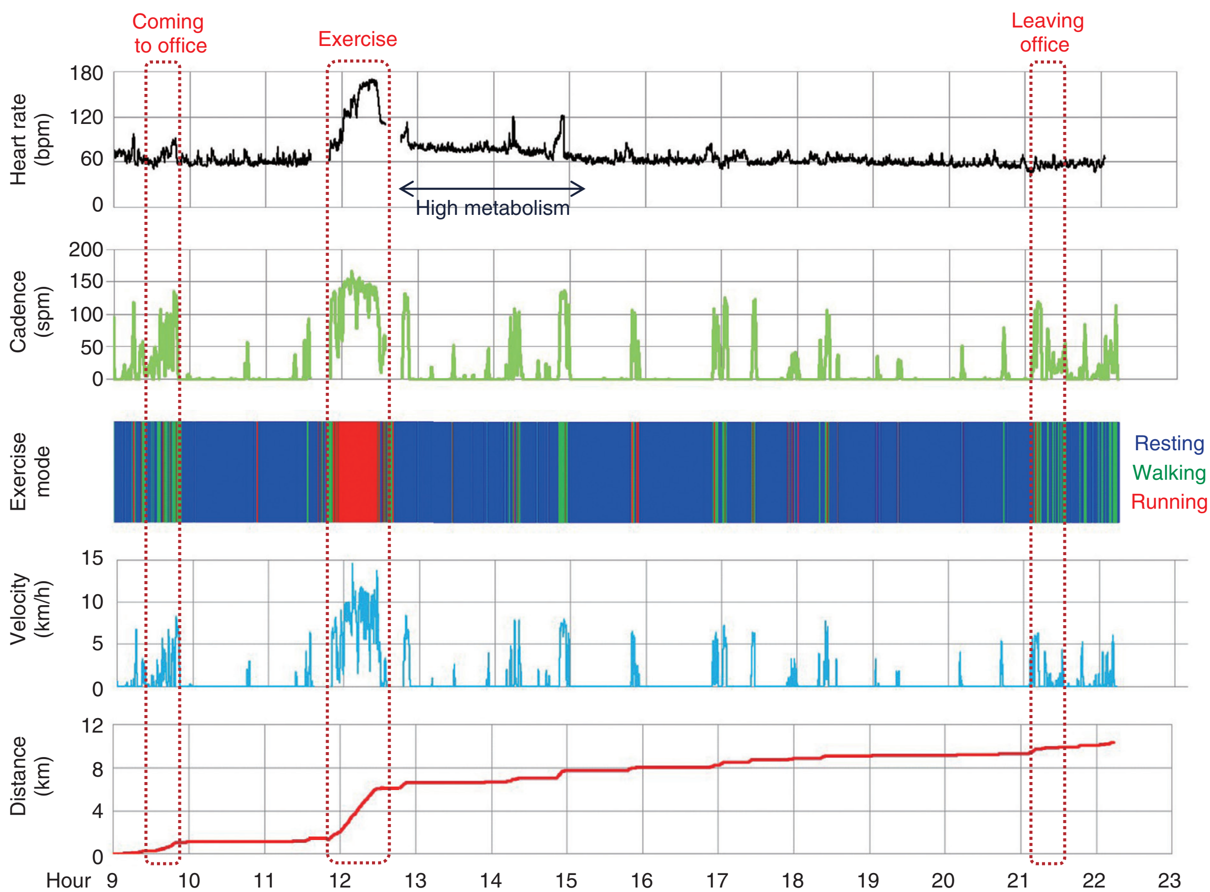


Fig. 10. Example of gait analysis and heart rate measured over one day.

that of a sports watch used as a reference, which indicates the proposed method was more accurate in calculating distance.

5. Example of heart rate referenced with gait analysis

An example of the results of gait analysis for one day is shown in **Fig. 10**. The results show that for this user, the exercise mode was primarily *resting*, indicated in blue. This participant in fact spent most of the time during the measurement sitting down and working at a computer. During the time the participant was going to work and was leaving the office later, the exercise mode indicates *walking*, and when the person exercised during lunch time, it indicates *running*. Consequently, these results indicate that our method is a feasible technique for inferring a user's activity in daily life. Interestingly, after reaching a resting state after exercising, the heart rate was higher than that of the pre-exercise resting state. This is because there is a tendency for the metabolism to remain at a higher level for several hours after exercise [6]. Multi-monitoring of heart rate and gait makes it possible to gain a better understanding of the changes in vital signs.

6. Future development

In this article, we described an example of multi-monitoring with a T-shirt type heart rate sensor and an acceleration sensor. This approach to *fusing* sensors is expected to lead to new applications or services in a variety of fields. We plan to continue our development with the aim of putting the sensor fusing approach to practical use in order to contribute to meeting social needs.

Acknowledgments

The authors would like to thank Takako Ishihara of NTT Device Innovation Center and Kenta Maruyama of Abeism Corporation for their support at experiments.

References

[1] Wearable Technology and Wearable Devices - Everything You Need to Know,
http://www.wearabledevices.com/what-is-a-wearable-device/
[2] K. Takagahara, K. Ono, N. Oda, and T. Teshigawara, "'hitoe'—A Wearable Sensor Developed through Cross-industrial Collaboration," NTT Technical Review, Vol. 12, No. 9, 2014.
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201409ra1.html
[3] Y. Kawahara, C. Sugimoto, S. Arimitsu, T. Itao, A. Morandini, H. Morikawa, and T. Aoyama, "Context Inference Techniques for a Wearable Exercise Support System," Proc. of ACM SIGGRAPH 2005 (the 32nd International Conference on Computer Graphics and Interactive Techniques), Posters Article No. 91, Los Angeles, USA, 2005.
[4] H. Kuroki, T. Morinaga, K. Suzuki, M. Sunami, and J. Takashio, "The Reproducibility of Speed in Human Level Walking Paced by a Metronome," Annual reports of the College of Medical Technology, Kyoto University, No. 6, pp. 65–72, 1986 (in Japanese).
[5] K. Tumkur and S. Subbiah, "Modeling Human Walking for Step Detection and Stride Determination by 3-axis Accelerometer Readings in Pedometer," Proc. of 2012 Fourth International Conference on Computational Intelligence, Modelling and Simulation, pp. 199–204, Kuantan, Malaysia, 2012.
[6] K. Nakayasu, K. Kitaoka, H. Matoba, S. Obara, H. Araki, M. Sato, H. Nakamura, T. Miura, H. Kuroda, and Y. Ikuta, "Influence of Moderate Intensity Exercise and a Meal Post Exercise on Heart Rate and Metabolic Substrates Level," Journal of Human Sciences and Arts, Faculty of Integrated Arts and Sciences, Tokushima University, Vol. 2, pp. 67–77, 1994 (in Japanese).

Takayuki Ogasawara
Research Engineer, Healthcare Device Development Project, NTT Device Innovation Center.

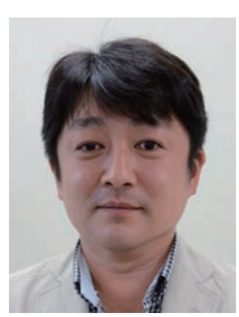
He received a B.E. and M.E. in applied physics from Hokkaido University in 2006 and 2009. He also completed the Developmental Brain Science Master's Program at the Research and Education Center for Brain Science, Hokkaido University, in 2009. He joined NTT Microsystem Integration Laboratories in 2009. His current interests include biosensors and wireless communications. He is a member of the Institute of Electrical and Electronics Engineers (IEEE) and the Institute of Electronics, Information, and Communication Engineers (IEICE).

Kei Kuwabara
Senior Research Engineer, Healthcare Device Development Project, NTT Device Innovation Center.

He received a B.E. and M.E. in electronics engineering from Keio University, Kanagawa, in 2002 and 2004. In 2004, he joined NTT. He is now with the NTT Device Innovation Center, where he is researching and developing vital sensing devices. He is a member of IEEE, JSAP, and IEICE.

Yasuyuki Itoh
Senior Research Engineer, Healthcare Device Development Project, NTT Device Innovation Center.

He received a B.S. and M.S. in physics from Hokkaido University in 1988 and 1990. He joined NTT LSI Laboratories in 1990. He has been engaged in R&D of LSI interconnection and low power technologies. He is a member of IEICE and the Japan Society of Applied Physics (JSAP).



Ryoichi Kasahara
Senior Research Engineer, Supervisor, Healthcare Device Development Project, NTT Device Innovation Center.

He received a B.E. in engineering from the University of Electro-Communications, Tokyo, in 1995 and an M.E. in engineering from Tohoku University, Miyagi, in 1997. In 1997, he joined NTT Photonics Laboratories, where he researched silica-based planar light-wave circuits. Since 2014, he has been engaged in developing vital sensing devices. He is a member of JSAP and IEICE.

Drift Transport of Helical Spin Coherence in Semiconductors

Yoji Kunihashi, Haruki Sanada, Hideki Gotoh, Koji Onomitsu, and Tetsuomi Sogawa

Abstract

Spatial transport of electron spins and their electrical manipulation are fundamental technologies in the emerging field of semiconductor spintronics, where the spin degree of freedom is used as an information carrier in a device. Images of the spatial distribution of drifting spins were obtained using Kerr rotation microscopy in a GaAs quantum well where special symmetry of the spin-orbit interaction, namely a persistent spin helix (PSH) condition, was achieved. By efficiently suppressing the spin relaxation in the PSH state, we were able to demonstrate long-distance transport of electron spins over 100 μm and electrical control of the spin precession during drift transport. In a PSH condition, the frequency of the spin precession shows significant anisotropy, reflecting the dependence of effective magnetic fields on crystal orientation. A theoretical model reproduced the spin distributions well and revealed that the spin decay length was maximized near the PSH condition. The robustness of the spin coherence with respect to the variation of transport trajectory was also confirmed by employing a time-dependent in-plane electric field perpendicular to the drift direction. Further development of this technique will advance the field of semiconductor spintronics, including the physics of spin-charge coupled systems as well as applications for future spin devices.

Keywords: spintronics, spin-orbit interaction, Kerr rotation

1. Introduction

Recent developments in electronics rely on the miniaturization and integration of electronic devices in which an electron's charge is used as an information carrier. However, device size is approaching its limit, and device performance cannot be further enhanced simply by extending existing technologies. An emerging research field known as semiconductor spintronics represents an attempt to use spin instead of charge for information processing [1–3], since this will result in lower energy consumption, higher operating speeds, and further improvement of device functionality compared with conventional charge-based devices.

The electrical control and transport of electron spins are essential techniques for realizing spintronics devices. An effective magnetic field plays an important role in controlling electron spins by electrical means. In general, the asymmetry of the system (e.g., the asymmetric layer structure of a quantum well (QW) or the lack of an inversion center in crystal structures) generates an internal electric field that is converted into effective magnetic fields for the coordinate system of a moving electron [4]. This is due to a relativistic effect called a spin-orbit interaction (SOI). However, SOI is a double-edged sword with spintronic devices. Because the direction of effective magnetic fields depends on the electron momentum, multiple scattering of electrons randomizes the effective magnetic fields, resulting in undesired spin relaxation [5]. A significant difficulty in the application of electron spins to semiconductor devices is preventing spin relaxation, which limits the transport length of electron spins to the order of 10 μm in semiconductor heterostructures [6].

Currently, much attention is being focused on the suppression of spin relaxation by balancing two

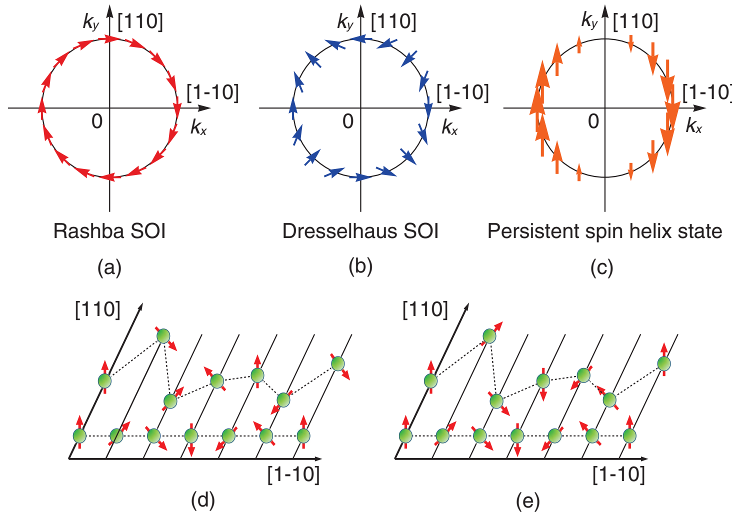


Fig. 1. Effective magnetic fields generated by (a) Rashba and (b) Dresselhaus SOIs. In (c) the persistent spin helix (PSH) state, effective magnetic fields are uniaxially oriented. Schematics of the spin relaxation caused by (d) the dependence of effective magnetic fields on momentum and (e) the coherent rotation of electron spins in the PSH state.

SOIs. In III-V semiconductor heterostructures, there are typically two kinds of SOIs. One is the Rashba SOI induced by the internal electric field in an asymmetric QW [7]. The other is the Dresselhaus SOI, which originates from the crystal field induced by the bulk inversion asymmetry in a zinc-blende crystal structure [8]. The Rashba and Dresselhaus SOIs act on electron spins as momentum-dependent magnetic fields as shown in **Figs. 1(a)** and **1(b)**. When the strengths of these two SOIs are equal, the effective magnetic field is uniaxially oriented as shown in **Fig. 1(c)**. In this condition, electron spins can precess around the same axis and do not relax even if they experience multiple scattering (**Figs. 1(d)** and **1(e)**). This special condition of SOIs is called the persistent spin helix (PSH) state, which has been theoretically predicted and experimentally confirmed [9–11]. In the PSH state, the spin transport length can be enhanced even in a system with strong SOIs.

Here, we report the spatial mapping of drifting spins in a GaAs QW where the Rashba and Dresselhaus SOIs are balanced to achieve a PSH state [12]. In the PSH state, the precession frequency of drifting spins becomes anisotropic, reflecting the crystal orientation dependence of the effective magnetic field. A comparison of experimental results and a numerical simulation based on a spin-drift diffusion model reveals that the spin decay length is maximized near the PSH condition, indicating the effective suppression of spin relaxation by the PSH state. Within the enhanced distance of the spin transport, the transport path of electron spins can be modulated by employing time-varying in-plane voltages, suggesting the robustness of the spin coherence against geometrical variations in the spin transport.

2. Experiment

To determine a suitable structure for the PSH condition, we calculated the SOIs in a GaAs single QW structure. The Hamiltonians for the Rashba and Dresselhaus SOIs in a III-V semiconductor QW are given by

$$H_R = \alpha(\sigma_x k_y - \sigma_y k_x), \quad (1)$$
$$H_D = -\beta(\sigma_x k_y + \sigma_y k_x), \quad (2)$$

where α and β indicate the strengths of the SOIs, σ_i ($i = x, y$) is the Pauli matrix, and k_i ($i = x, y$) is the electron momentum. In this article, we defined the coordinate axis with base vectors $x \parallel$ [1-10], $y \parallel$ [110], and $z \parallel$ [001]. Since the potential gradient in a QW can be modulated with an external gate voltage, the Rashba SOI parameter α is a gate-controllable value. In contrast, β is expressed by material constant γ and well thickness d in the following equation,

$$\beta = \gamma \langle k_z^2 \rangle \approx \gamma(\pi/d)^2. \quad (3)$$

According to Eq. (3), the Dresselhaus SOI is enhanced by reducing the well thickness. By solving the Poisson-Schrödinger equation, we can calculate energy

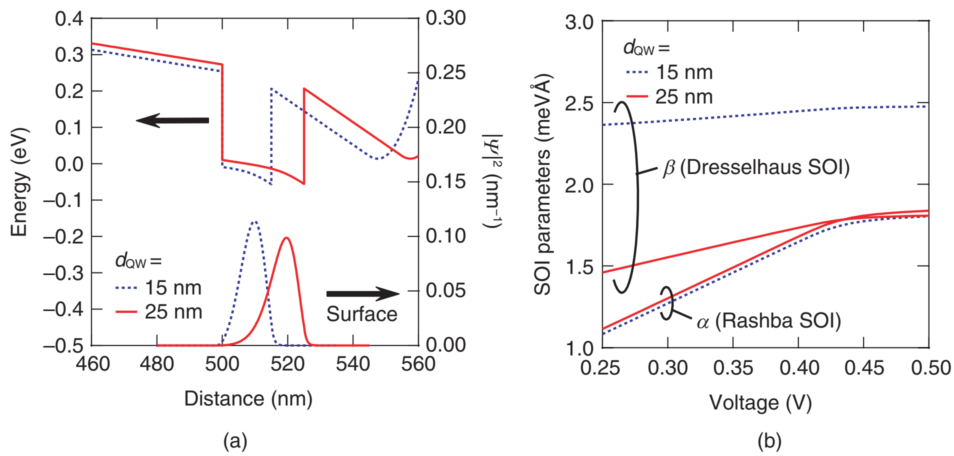


Fig. 2. (a) Energy-band profiles of the conduction band (Γ_6) in $Al_{0.3}Ga_{0.7}As$/GaAs (15, 25 nm)/$Al_{0.3}Ga_{0.7}As$ structures calculated with the Poisson-Schrödinger equation, whose energies are based on the position of the Fermi energy E_F. The normalized electron probability density $|\Psi|^2$ is also shown. (b) Calculated SOI parameters for 15- and 25-nm-thick QWs as functions of relative voltage, which is the relative difference between the substrate and surface potentials. The solid and dashed lines indicate the Rashba and Dresselhaus parameters, respectively.

band profiles and wave functions in the AlGaAs/GaAs/AlGaAs QW structures, as shown in **Fig. 2(a)**. To confirm the contribution of the Dresselhaus SOI, we assumed two different QW thicknesses of $d = 15$ and 25 nm. The gate-voltage dependences of SOI parameters calculated by using $k{\cdot}p$ perturbation are shown in **Fig. 2(b)** [13]. It should be noted that the horizontal axis in Fig. 2(b) indicates the relative difference between the potentials of the surface and the substrate, which does not correspond to the experimentally applied gate voltage. In Fig. 2(b), we found that the Dresselhaus SOI parameter β depends strongly on the well thickness, whereas the Rashba SOI parameter α can be widely modulated by applying a gate voltage rather than by varying the well thickness. According to Fig. 2(b), α can be comparable to β in a 25-nm-thick QW, which indicates the possibility of the PSH condition.

Using the theoretical calculations as a basis, we designed and grew 15- and 25-nm-thick modulation-doped $Al_{0.3}Ga_{0.7}As/GaAs/Al_{0.3}Ga_{0.7}As$ single QW structures by molecular-beam epitaxy on a (001) semi-insulating GaAs substrate. The QWs were located 120 nm below the surface, and three δ-doping layers were embedded 50, 100, and 105 nm below the surface. The epitaxial wafers were fabricated into cross-shaped structures with four ohmic contacts consisting of AuGeNi layers. The central part of the structure was covered with a semi-transparent Au gate electrode as indicated in **Fig. 3(a)**.

We employed Kerr microscopy to measure the spin dynamics of the drifting electrons (**Fig. 3(b)**). Spin-polarized electrons were generated by a circularly polarized pump light. Subsequently, the spatial distribution and dynamics of the electron spins were detected with a linearly polarized probe light via the Kerr rotation angle θ_K, which was proportional to the spin density at the focused position. For a microscopic measurement of the spin coherence, the pump and probe lights were focused on the sample with 6-µm- and 3-µm-diameter spots, respectively. The temporal development of the electron spins can be observed by using a pulse laser from a mode-locked Ti:sapphire laser, whereas the steady flow of drifting spins can be measured with a continuous wave (CW) laser. All the measurements were carried out at 8 K.

3. Results and discussion

The results of time-resolved Kerr rotation microscopy for the drifting spin in a 25-nm-thick QW with the application of an in-plane electric field $V_x = 200$ mV are shown in **Fig. 3(c)**. We can see that spin-polarized electrons generated at time $t = 0$ ns move to the drain electrode. Even in the absence of an external magnetic field, we observed a spin precession resulting from the effective magnetic field induced by the SOIs. To estimate the drift velocity of the electron spins, we performed a fitting analysis on the assumption that the spatiotemporal development of drifting

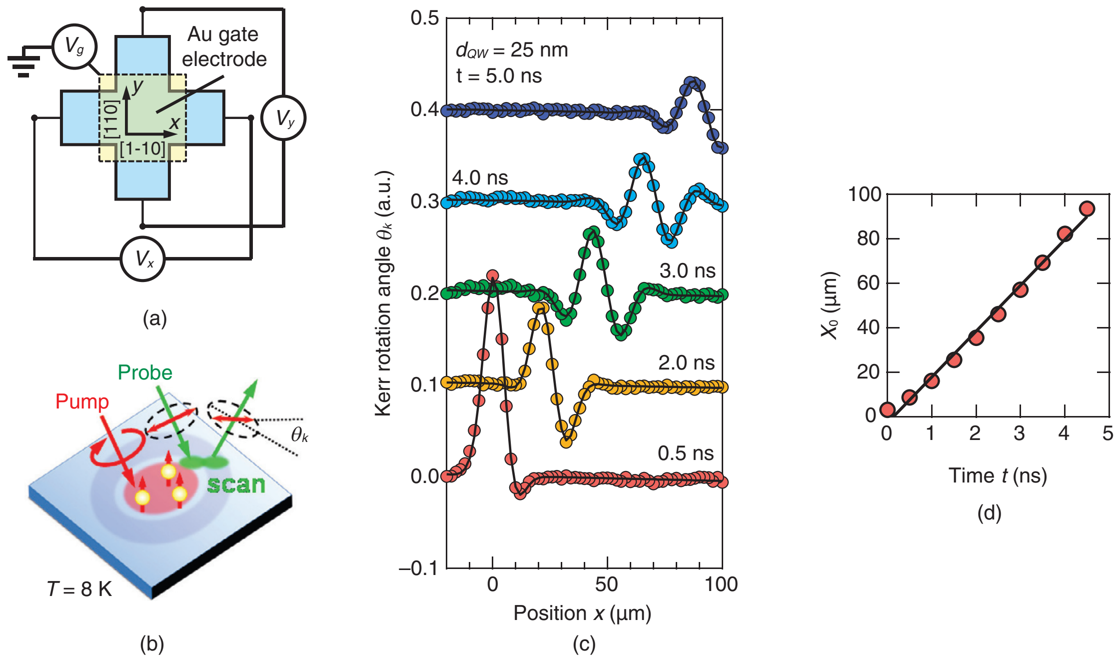


Fig. 3. (a) Schematic illustration of the top view of the sample. (b) The setup for spatially resolved Kerr rotation measurements. (c) Time-resolved Kerr rotation signal for spins drifting in a 25-nm-thick QW when applying Vx = 200 mV. The solid lines indicate the fitted results obtained with Eq. (4). (d) Time dependence of the displacement of a spin packet. The solid line is a linear function fitted to the experimental results.

spins can be explained by the model function,

$$\theta_K = A \exp(-(x-x_0)^2/w^2)\cos(k_{SO}(x-x_0)), \quad (4)$$

where A is the signal amplitude, x_0 and w are the displacement and width of the Gaussian, respectively, and k_{SO} is a spin wavenumber that represents the spatial frequency of the spin precession. We fitted Eq. (4) to the experimental result and extracted x_0, which is plotted as a function of time in **Fig. 3(d)**. We found that x_0 is proportional to time t, and the slope in Fig. 3(d) indicates the drift velocity. Thus we obtained v_d = 20.6 km/s in a 25-nm-thick QW, which is 150 times faster than the drift velocity of the electron spins observed in bulk GaAs [14].

The spatial distribution of drifting spins in a steady state is shown in **Figs. 4(a)** and **4(b)**. In a 15-nm-thick QW, spin precession due to the effective magnetic field was observed in both the x and y directions, which reflects the isotropic strength of the effective magnetic fields. This is because the Dresselhaus SOI is dominant in the 15-nm-thick QW as predicted by a theoretical calculation. In contrast, in a 25-nm-thick QW when $V_g = -4.28$ V is applied, the precession of the drifting spins in the y direction is stopped completely, although drifting spins in the x direction precess more than five cycles in 100 μm. This strong anisotropy of the spin precession originates from the dependence of the effective magnetic field on the crystal orientation, which implies that the PSH is almost realized in a 25-nm-thick QW. Furthermore, the long-distance spin transport over 100 μm observed in the 25-nm-thick QW is attributed to the suppression of spin relaxation due to the PSH state. To determine quantitatively how close this was to the PSH condition, we performed a fitting analysis of the spatial distributions of the drifting spins. On the assumption that the contribution of the drift transport of the spins is dominant compared with spin diffusion, the spatial variation of the spin flows is given by,

$$\theta_K = A \exp(-d/\lambda_{SO}) \cos(k_{SO}\, d), \quad (5)$$

where d is the distance from the origin and λ_{SO} is the spin decay length. We fitted Eq. (5) to the experimental results and extracted the spin wavenumber k_{SO}. We excluded data between d = 0 μm and 10 μm from the fitting procedure to remove the contribution of spin diffusion. If we assume simple one-dimensional transport, the SOI parameters are proportional to the spin wavenumber,

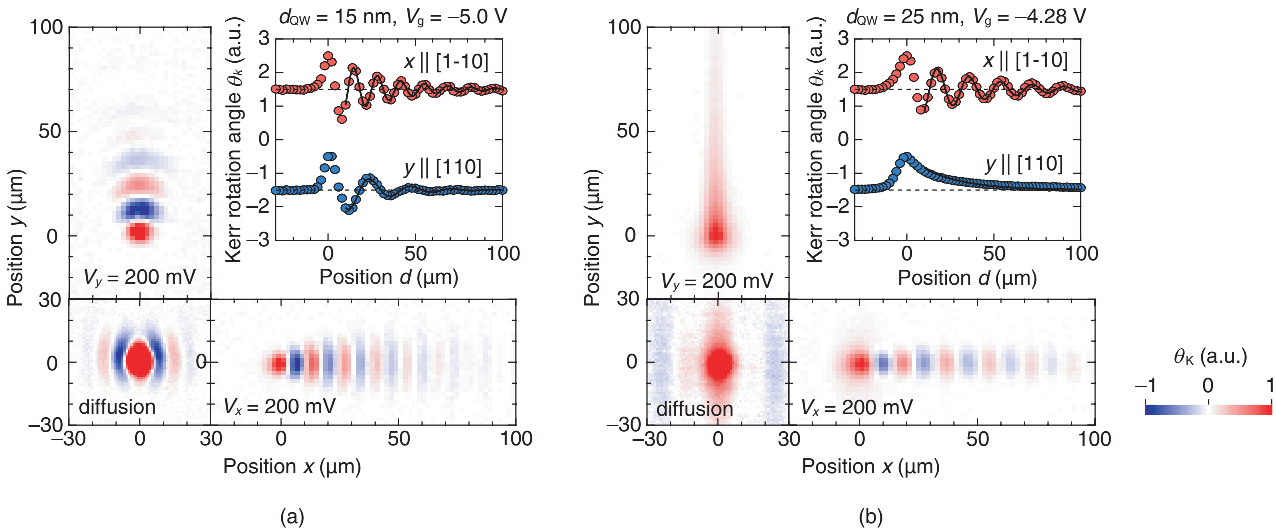


Fig. 4. (a), (b) Spatial mapping of the spin distribution for 15- and 25-nm-thick QWs. The square panels in the bottom left corners show the spin distribution for diffusive transport, while the rectangular panels are those for drift transport with in-plane electric fields. Red and blue in the maps correspond to up and down spins, respectively. The panels in the upper right corners are the cross-sectional profiles of drifting spins in the [1-10] and [110] directions. The solid lines show the fitted results obtained with Eq. (5).

$$\alpha = \frac{\hbar}{4m^*}\left(k_{SO}^{1-10} + k_{SO}^{1-10}\right), \tag{6}$$

$$\beta = \frac{\hbar}{4m^*}\left(k_{SO}^{1-10} - k_{SO}^{1-10}\right), \tag{7}$$

where m^* and $\hbar$ are the effective mass of an electron and Planck's constant, respectively. Thus, two SOI parameters, α and β, can be estimated from k_{SO} in the [1-10] and [110] directions. The estimated SOI parameters were $\alpha = 0.58$ meVÅ and $\beta = 2.10$ meVÅ for a 15-nm-thick QW and $\alpha = \beta = 0.99$ meVÅ for a 25-nm-thick QW. From these results, we confirmed that the PSH state is realized in a 25-nm-thick QW.

The spatial frequency of the spin precession during drift transport is electrically controlled by the gate modulation of the Rashba SOI. The gate voltage (V_g) dependence of θ_K scanned along the [1-10] direction for $V_x = 50$ mV and $V_y = 0$ mV is shown in **Fig. 5(a)**. By varying the gate voltage, we were able to continuously modulate the spatial frequency of the drifting spin precession via gate control of the Rashba SOI. This behavior was well reproduced by a simulation based on a spin-drift-diffusion model, as shown in **Fig. 5(b)**. Assuming that the precession period in Fig. 5(a) depends only on α, we can compare the effect of α on the transport length by plotting spin decay length λ_{SO} versus spin wavenumber k_{SO}, where both parameters can be extracted by the fitting procedure used in Fig. 4. The obtained λ_{SO} values are plotted as a function of k_{SO} in **Fig. 5(c)**. In both the experiment and the simulation, λ_{SO} decreases as k_{SO} diverges from the balanced condition $\alpha = \beta$, indicating that the suppression of the D'yakonov-Perel spin relaxation caused by the PSH also appears in the spin transport length.

We can transport the helical spin state along arbitrary trajectories by using a time-dependent in-plane electric field. We applied a sinusoidal ac voltage V_y^{ac} with frequency f in the y direction and dc voltages V_x^{dc} in the x direction. To excite spins at the timing of a certain phase of V_y^{ac}, the initial spins were excited with a pulsed pump light from a mode-locked laser whose repetition frequency was synchronized with f or $f/2$, whereas the Kerr signal was detected with a probe light from a CW laser. When a sinusoidal voltage was applied in a transverse direction to the drift spin transport, a clear spin flow along a winding path was observed (**Fig. 6**). The stripe patterns in the spin packet are maintained regardless of the transport trajectories. This is because in a PSH condition, spins always precess in an x-z plane, and the precession phase depends only on x [9, 10]. For all transport paths, the spin phase was conserved even at distances much longer than the precession periods, and thus, the technique will be beneficial for further exploitation of the SOI in drift spin manipulation.

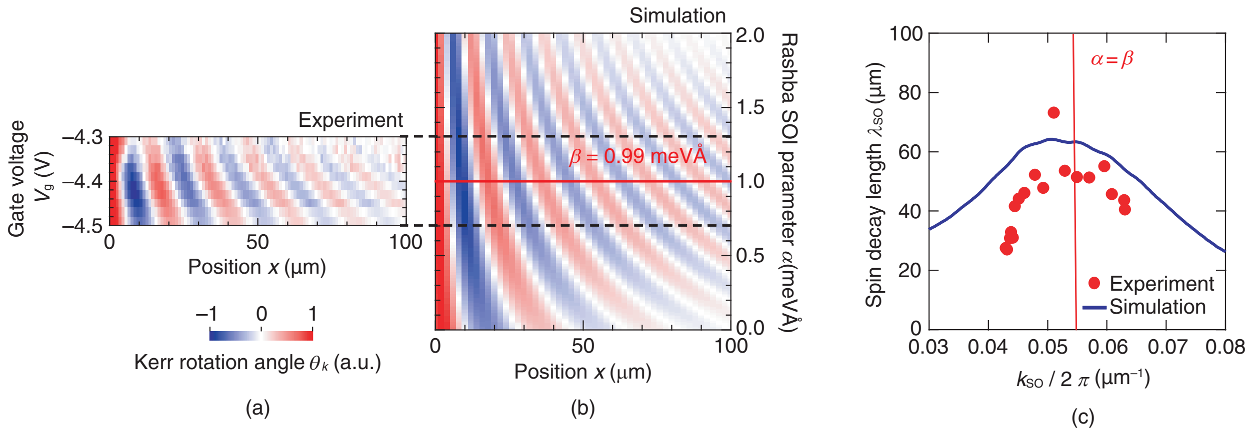


Fig. 5. SOI dependence of spin dynamics of drifting spins. (a), (b) Comparison of experimental and simulated spin distribution driven by V_x = 50 mV in the x direction. In the simulation, we directly varied the Rashba SOI parameters α, and the spin distribution is shown as a function of α, whereas the experimental data are plotted as a function of the gate voltage, which modulates the Rashba SOI. Note that the gate voltage shown in this figure does not correspond to that in Fig. 2. (c) Spin decay length as a function of spin wavenumber.

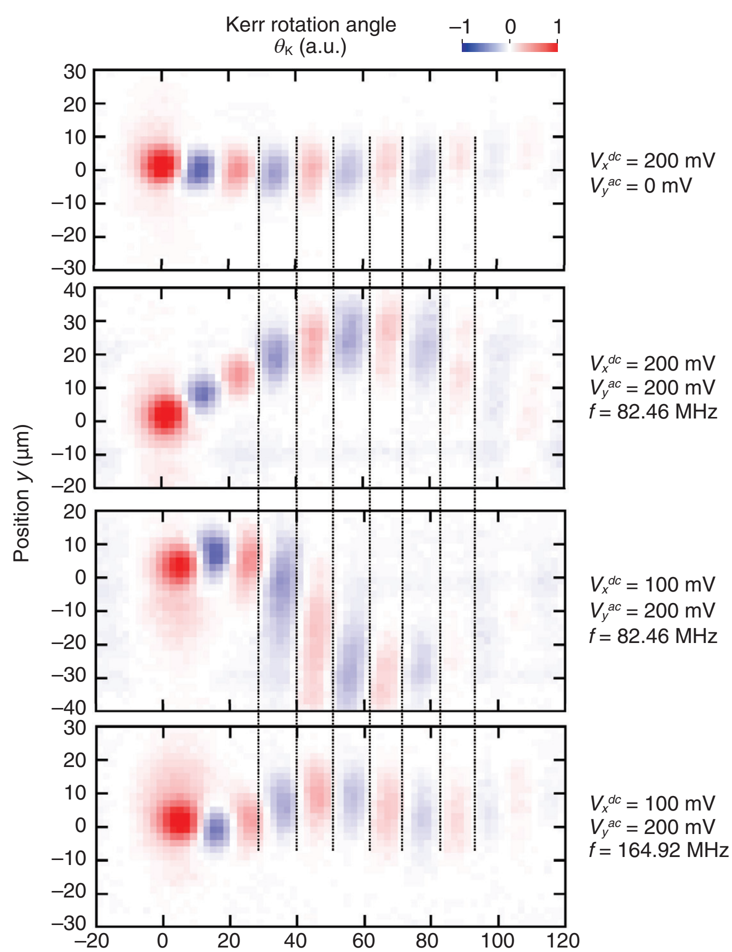


Fig. 6. Dynamic modulation of the transport path of drifting spins. Drift spin transport with a sinusoidal voltage applied in the y direction. The dc voltage V_x^{dc} and the sinusoidal voltage V_y^{ac} are specified in each figure.

4. Conclusion

The spatial distribution of drifting spins in a GaAs QW where two types of SOI, namely the Rashba and Dresselhaus SOIs, are balanced to realize a PSH state, was mapped by using temporally and spatially resolved Kerr rotation microscopy. In the PSH state, spins drifting in a direction where there are strong effective magnetic fields exhibit a fast spin precession, whereas the spin precession of spins drifting in an orthogonal direction is completely stopped. The spin decay length is maximized near the PSH condition, indicating the effective suppression of spin relaxation by the PSH state. Furthermore, we demonstrated drift spin transport over 100 μm, where the precession frequency was controlled by an external gate voltage. The results presented here show that spin coherence with a balanced SOI can be efficiently transferred to a distant place. We confirmed the robustness of the spin phase for the variation of transport paths in the PSH state. If the PSH condition is sufficiently maintained, we may also manipulate the spin states by using the gate bias voltage or a trajectory-controlled quantum operation. Further development of this technique will advance the field of semiconductor spintronics, including the physics of spin-charge coupled systems as well as applications for future spin devices.

Acknowledgments

We thank P. V. Santos of Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany, and J. Nitta and M. Kohda of the Department of Materials Science, Tohoku University, Sendai, for their useful technical advice. This work was partly supported by the Japan Society for the Promotion of Science (JSPS).

References

[1] S. Datta and B. Das, "Electronic Analog of the Electro-optic Modulator," Appl. Phys. Lett., Vol. 56, No. 7, p. 665, 1990.
[2] S. A. Wolf, D. D. Awschalom, R. A. Buhrman, J. M. Daughton, S. von Molnár, M. L. Roukes, A. Y. Chtchelkanova, and D. M. Treger, "Spintronics: A Spin-based Electronics Vision for the Future," Science, Vol. 294, pp. 1488–1495, 2001.
[3] J. Wunderlich, B.-G. Park, A. C. Irvine, L. P. Zârbo, E. Rozkotová, P. Nemec, V. Novák, J. Sinova, and T. Jungwirth, "Spin Hall Effect Transistor," Science, Vol. 330, pp. 1801–1804, 2010.
[4] R. Winkler, "Spin-orbit Coupling Effects in Two-dimensional Electron and Hole Systems," Springer Tracts in Modern Physics, Vol. 191, Springer, Berlin, 2003.
[5] M. I. D'yakonov and V. I. Perel', "Spin Relaxation of Conduction Electrons in Noncentrosymmetric Semiconductors," Sov. Phys. Solid State, Vol. 13, pp. 3023–3026, 1972.
[6] L. Yang, J. D. Koralek, J. Orenstein, D. R. Tibbetts, J. L. Reno, and M. P. Lilly, "Doppler Velocimetry of Spin Propagation in a Two-dimensional Electron Gas," Nature Phys., Vol. 8, pp. 153–157, 2012.
[7] Y. A. Bychkov and E. I. Rashba, "Oscillatory Effects and the Magnetic Susceptibility of Carriers in Inversion Layers," J. of Physics C: Solid State Physics, Vol. 17, No. 33, pp. 6039–6045, 1984.
[8] G. Dresselhaus, "Spin-orbit Coupling Effects in Zinc Blende Structures," Phys. Rev., Vol. 100, No. 2, pp. 580–586, 1955.
[9] J. Schliemann and D. Loss, "Anisotropic Transport in a Two-dimensional Electron Gas in the Presence of Spin-orbit Coupling," Phys. Rev. B, Vol. 68, p. 165311, 2003.
[10] B. A. Bernevig, J. Orenstein, and S.-C. Zhang, "Exact SU(2) Symmetry and Persistent Spin Helix in a Spin-orbit Coupled System," Phys. Rev. Lett., Vol. 97, p. 236601, 2006.
[11] J. D. Koralek, C. P. Weber, J. Orenstein, B. A. Bernevig, S.-C. Zhang, S. Mack, and D. D. Awschalom, "Emergence of the Persistent Spin Helix in Semiconductor Quantum Wells," Nature, Vol. 458, pp. 610–613, 2009.
[12] Y. Kunihashi, H. Sanada, H. Gotoh, K. Onomitsu, M. Kohda, J. Nitta, and T. Sogawa, "Drift Transport of Helical Spin Coherence with Tailored Spin-orbit Interactions," Nature Communications, Vol. 7, p. 10722, 2016.
[13] Th. Schäpers, G. Engels, J. Lange, Th. Klocke, M. Hollfelder, and H. Lüth, "Effect of the Heterointerface on the Spin Splitting in Modulation Doped $In_xGa_{1-x}As$/InP Quantum Wells for $B\rightarrow 0$," J. Appl. Phys., Vol. 83, p. 4324, 1998.
[14] J. M. Kikkawa and D. D. Awschalom, "Lateral Drag of Spin Coherence in Gallium Arsenide," Nature, Vol. 397, pp. 139–141, 1999.

Yoji Kunihashi
Research Scientist, Quantum Optical Physics Research Group, Optical Science Laboratory, NTT Basic Research Laboratories.

He received a B.E., M.E., and Ph.D.in electrical engineering from Tohoku University, Miyagi, in 2007, 2009, and 2012. He joined NTT Basic Research Laboratories in 2012. His research interests include the optical and electrical properties of low-dimensional semiconductor nanostructures, spin-related phenomena in solid-state materials, and fabrication technology of semiconductor/insulator/metal hybrid nanostructures. He is a member of the Japan Society of Applied Physics (JSAP).

Haruki Sanada
Research Scientist, Distinguished Researchers, Quantum Optical Physics Research Group, Optical Science Laboratory, NTT Basic Research Laboratories.

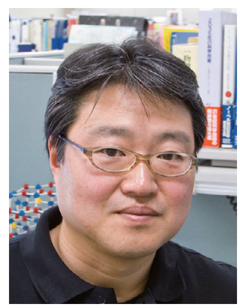
He received a B.E., M.E., and Ph.D. in electrical engineering from Tohoku University, Miyagi, in 2001, 2002, and 2005. He joined NTT Basic Research Laboratories in 2005. His research interests include the optical properties of low-dimensional semiconductor nanostructures and carrier spin dynamics modulated by surface acoustic waves and their application to solid-state quantum information processing. He is a member of JSAP.

Hideki Gotoh
Executive Manager of Research Planning Section, General Manager of Optical Science Laboratory, and Group Leader of Quantum Optical Physics Research Group, NTT Basic Research Laboratories.

He received a B.E., M.E., and Ph.D. in engineering from Hiroshima University in 1991, 1993, and 2000. Since joining NTT Basic Research Laboratories in 1993, he has been working on optical physics and device applications of semiconductor nanostructures. He is a member of JSAP and the Optical Society of America.

Koji Onomitsu
Senior Research Scientist, Low-Dimensional Nanomaterials Research Group, Materials Science Laboratory, NTT Basic Research Laboratories.

He received a B.E. and M.E. in electrical engineering from Aoyama Gakuin University, Tokyo, in 1998 and 2000, and a Ph.D. in electrical engineering from Waseda University, Tokyo, in 2004. He joined NTT Basic Research Laboratories in 2006. His current interests are crystal growth and device applications of two-dimensional layered materials such as $MoSe_2$. He is a member of JSAP.



Tetsuomi Sogawa
Director of NTT Basic Research Laboratories.

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

Report on ITU Telecom World 2015

Hideyuki Iwata

Abstract

ITU Telecom World 2015, which is sponsored by the International Telecommunication Union (ITU), was held at HUNGEXPO, an international exhibition hall, in Budapest, Hungary, October 12–15, 2015. Approximately 4000 people from 129 countries took part in the event. The Japanese presence included exhibits in the Japan Pavilion organized by the Ministry of Internal Affairs and Communications, and a Japan Session, in which a lecture was given on the topic *Society Construction with a Sense of Security - Making Full Use of "IoT" for Future Progress*. This article presents an overview of the exhibition and the lectures.

Keywords: ITU Telecom World, IoT, SME

1. Introduction

ITU Telecom World is a combined conference and exhibition that is held for International Telecommunication Union (ITU) member countries. It is aimed at sharing the latest technologies and services in the information and communications field and discussing policy trends in the information and communication technology (ICT) field. This event brings together people working in the information and communications industry, and also those working in the public administration of the industry worldwide. Until 2011, the event was held every four years. Since then, the event has been integrated with Telecom World, Telecom Asia, and other regional Telecom events and is now held annually. ITU Telecom World was held in Dubai, United Arab Emirates, in 2012, in Bangkok, Thailand, in 2013, and in Doha, Qatar, in 2014. The 2015 event was the first time in three years it was held in Europe.

ITU Telecom World 2015 was held at HUNGEXPO in Budapest, the capital of Hungary, October 12–15, 2015. The main theme centered on assisting small- and medium-sized enterprises (SMEs) in emerging countries. There were SME-focused exhibits, and awards were presented to outstanding SMEs. Some 4000 persons from 129 countries took part in the event, including 239 prominent people in the public administration field or ICT industry, 247 lecturers from 62 countries, and 142 members of the press from 21 countries. There were 238 exhibits from 54 countries, 23 pavilions from 23 countries, and 49 sponsor enterprises.

About 30 Japanese members attended the event, including Mr. Yasuo Sakamoto, Vice-Minister for Policy Coordination, Ministry of Internal Affairs and Communications. A report issued by ITU stated that representatives of regulatory and other administrative organizations made up 27% of all participants, while those from telecommunications operators totaled only 8%. Ten percent of the participants were from software and application developers, and only 5% were from the telecommunications equipment industry. In terms of regions, 60% of the participants were from Europe—the host region—and the CIS (Commonwealth of Independent States), 23% from Asia-Pacific, 8% from Africa, and 6% from the Middle East.

2. Overview of exhibition and lectures

2.1 Opening ceremony

An opening speech by Houlin Zhao, ITU Secretary-General, was followed by a video message from Ban Ki-moon, Secretary-General of the United Nations, a greeting from the vice president of Deutsche Telecom, and a welcome address from the Prime Minister of Hungary.

Photo 1. Japan Pavilion.

Photo 3. South Korean enterprise pavilion.

Photo 2. China Pavilion.

Photo 4. Smart City pavilion.

2.2 Exhibition

Four organizations (Fujitsu, National Institute of Information and Communications Technology, Internet Initiative Japan, and Japan Battery Regeneration, Inc.) participated in the Japan Pavilion (**Photo 1**), where they exhibited environmental solutions, data-oriented networking technology, Dagik Earth—an educational project and multi-layer image display system, a portable datacenter, and technology for regenerating and extending the life of lead-acid batteries.

The pavilion of Hungary, the host country, had an exhibit on Magyar Telekom, which is a subsidiary of Deutsche Telecom. The China Pavilion presented exhibits from China Mobile, China Telecom, and China Unicom (**Photo 2**). Korea Telecom (now, KT Corporation) had its own pavilion (**Photo 3**). A large percentage of the 23 country pavilions were from African nations such as Rwanda, Uganda, Gabon, Kenya, Zimbabwe, Tanzania, and Senegal. These pavilions introduced the respective countries' ICT policies. Countries that had their own pavilions included Hungary, Saudi Arabia (Middle East), Argentina (South America), Azerbaijan (CIS), and Japan, Thailand, and South Korea (Asia).

Huawei, ZTE, and Intel were among the enterprises that had their own pavilions. In addition, some pavilions were dedicated to specific concepts such as Smart City and SME (**Photo 4**).

2.3 Lecture in the Japan Session

On the afternoon of the 12th, a Japan Session was held under the theme of *Society Construction with a Sense of Security - Making full use of "IoT" for Future Progress*, sponsored by the Ministry of Internal Affairs and Communications. After Mr. Sakamoto of the Ministry greeted the audience and introduced the participating enterprises, lectures were given on behalf of those enterprises. One lecturer was Dr. Ryutaro Kawamura, Director of NTT Network Innovation Laboratories, who gave a talk entitled "IoT 2.0." He spoke about the key technologies and their significance in realizing IoT 2.0, the next stage of Internet of Things, which is a revolution that is already underway, with everything in a variety of fields becoming interconnected via networking.

There were several other sessions, including one on agriculture given by FAO (Food and Agriculture Organization of the United Nations), a session on medical care given by WHO (World Health Organization), and a session focusing on development of ICT engineers.

2.4 Topics related to SMEs

SMEs were the focus of this event, and therefore, exhibits, SME presentations, and a dialog session with the industry were held with a view to building a platform for supporting the formation of SMEs. Awards were also conferred on SMEs, including the firm Japan Battery Regeneration, Inc., which is developing technology for regenerating lead-acid batteries. Additionally, outstanding SMEs were selected from among the award recipients and given commendations. They included two South Korean companies working on Braille and iris recognition, two Kenyan companies working in the respective areas of agriculture and medical care, and a Saudi Arabian company involved in medical care. In addition, three Hungarian companies received commendations, and a South Korean supplier of three-dimensional sound systems was selected as the most outstanding company.

3. Next event

The organizers of ITU Telecom World 2015 tried out a new initiative of encouraging participation by SMEs. There were many participants from Africa, suggesting that emerging countries have high expectations of ITU. The next event, ITU Telecom World 2016, is scheduled to be held in Bangkok, Thailand in November 2016.

Hideyuki Iwata

Senior Research Engineer, Supervisor, Research and Development Planning Department, NTT.

He received a Ph.D. in electrical engineering from Yamagata University in 2011. From 1993 to 2000, he was engaged in research on high-density and aerial optical fiber cable at NTT Access Network Service Systems Laboratories. Since 2000, he has been responsible for the standardization strategy planning for NTT R&D. He has been a delegate of the International Electrotechnical Commission (IEC) SC (Subcommittee) 86A (optical fiber and cable) since 1998 and of ITU-T Telecommunication Standardization Advisory Group since 2003. He is a vice chair of the Expert Group of Bridging the Standardization Gap in Asia-Pacific Telecommunity Standardization Program Forum. In 2004, the IEC Activities Promotion Committee of Japan gave him an award for his contribution to standardization work in IEC.

Long-term Durability of Humidity-controlling Polymer

Abstract

This article describes an evaluation of humidity-controlling polymer that was tested for use in telecommunication facilities. This is the thirty-fourth article in a bimonthly series on telecommunication technologies. This month's contribution is from the Materials Engineering Group, Technical Assistance and Support Center, Maintenance and Service Operations Department, Network Business Headquarters, NTT EAST.

Keywords: humidity control, CCP cable, insulation failure

1. Introduction

Insulation failure in core wires of color coded polyethylene (CCP) cable within terminal closures and surge protectors can occur when there is contact between wires or condensation of moisture on cracks in the wire covering. Solving the former problem requires maintaining an appropriate distance between wires or using additional insulation, while solving the latter problem requires removing the moisture. Humidity-controlling polymer is a product that can prevent water condensation. It can absorb moisture (humidity) in the installation space and release moisture during dry periods so as to maintain a fixed level of humidity. Installing this product can reduce the probability of insulation failures occurring in metal wires. However, because CCP cable must have long-term and stable use to provide customers with uninterrupted service, humidity-controlling polymer must likewise maintain long-term performance.

2. Reduction of insulation failures in metal wires by installing humidity-controlling polymer

Condensation often occurs in No. 6 surge protectors in regions with high rainfall or where dense fog occurs frequently, so insulation failures accompanying cracks in the wire covering can easily occur in such situations. When humidity-controlling polymer was installed for experimental purposes inside No. 6 surge protectors in regions with relatively frequent occurrences of insulation failures, it was found that the number of failures that occurred dropped to as low as one-tenth that before installation. Although insulation failures cannot be completely eliminated by installing humidity-controlling polymer, it can greatly reduce the frequency of their occurrence. In this capacity, it is a useful product for reducing maintenance operations and maintaining the quality of communication services.

3. Humidity-controlling polymer evaluated for long-term durability

Humidity-controlling polymer has properties enabling it to absorb ambient moisture (water vapor) in high-humidity environments and to release moisture in low-humidity environments in order to maintain a fixed level of humidity in an installation space (**Fig. 1**). It uses a sodium-polyacrylate super absorbent polymer (SAP), a material also used in disposable diapers. Several types of humidity-controlling polymer have come into use since the initial introduction of SAP. We evaluated two such products for long-term durability, as summarized in **Table 1**. These consisted of humidity-controlling polymer for use in special-environment terminal closures and humidity-controlling polymer for use in surge protectors. These two products were installed in terminal closures and No. 6 surge protectors (with and without

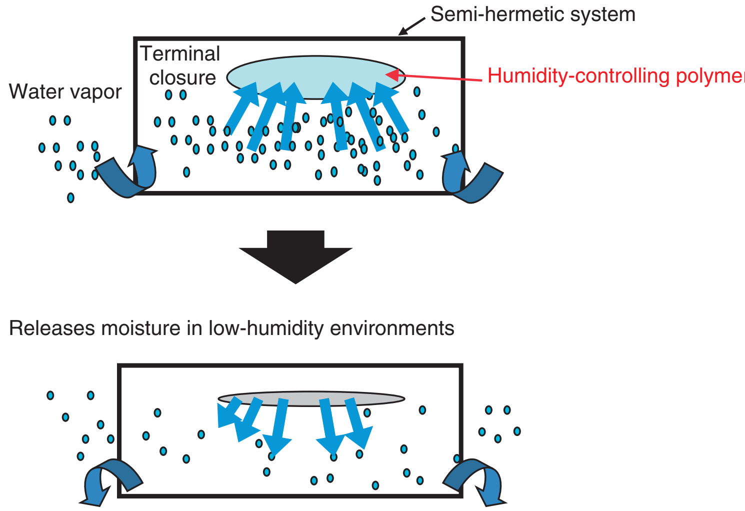
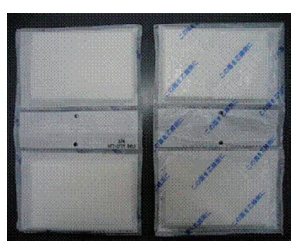


Fig. 1. Function of humidity-controlling polymer.

Table 1. Humidity-controlling polymer products.

Terminal closure use	Surge protector use
 Size: 150 × 230 mm^2	 Size: 35 × 50 mm^2
• Former specifications (wrap type) • Used in special-environment terminal closures • Current specifications (strong/weak) • Condensation-prevention material for communication facilities (large area)	• Used in No. 6 surge protectors • Condensation-prevention material for communication facilities (small area)

sealing the feed-through apertures) for about 9 years and 7.5 years, respectively, and then recovered for evaluation (**Photo 1**). The equipment the products were used in was installed in an area with a relatively high occurrence of strong winds caused, for example, by typhoons.

4. Humidity absorption/release performance test

As described above, humidity-controlling polymer absorbs ambient moisture in high-humidity environments, as on rainy or foggy days, and releases the absorbed moisture in low-humidity environments, as on sunny days, in order to maintain a fixed level of humidity in the installation environment. We therefore

Photo 1. Facility using humidity-controlling polymer (foreground: No. 6 surge protectors; background: terminal closures).

Table 2. Temperature/humidity conditions in moisture absorption/release performance test.

Product	Test method	Stabilizing conditions	100% RH holding time (hours)
Special-environment terminal closure use	Hold under stabilizing conditions. ⬇ Change RH and measure weight change.	25°C 75% RH	240
No. 6 surge protector use			168

decided to test this absorption/release function in the product that had been targeted for evaluation of long-term durability. In particular, we wanted to assess whether the product's performance was equal to or better than the performance at the time of its manufacture.

During the test, the relative humidity (RH) was changed using the three-step procedure described below, and the weight of the product was measured at each step to evaluate the amount of moisture absorption (**Table 2**).

Step 1: The humidity-controlling polymer was held under fixed temperature/humidity conditions in a state of little weight change over time (stabilizing conditions: temperature = 25°C, RH = 75%).

Step 2: The RH was increased to 100% and held there for a fixed time (holding time: 240 h for special-environment terminal closure, 168 h for No. 6 surge protector).

Step 3: On completion of the 100% RH holding time, the product was held under the same stabilizing conditions as in step 1.

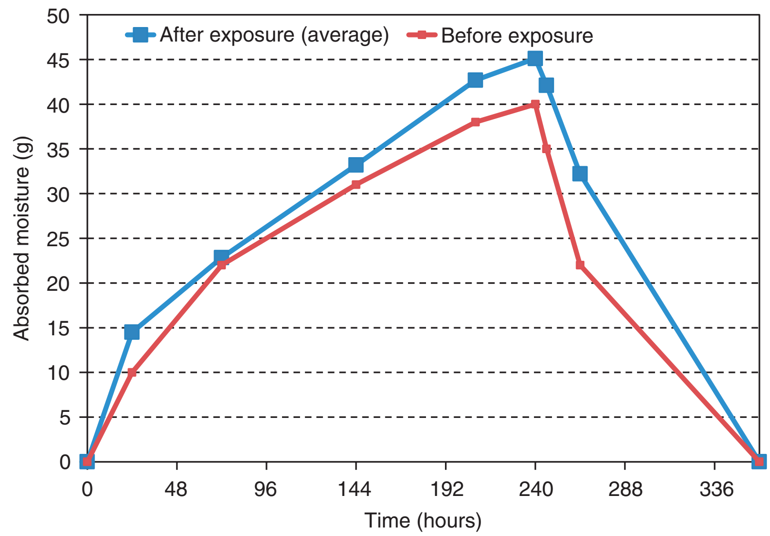


Fig. 2. Comparison of moisture absorption/release performance (special-environment terminal closure use).

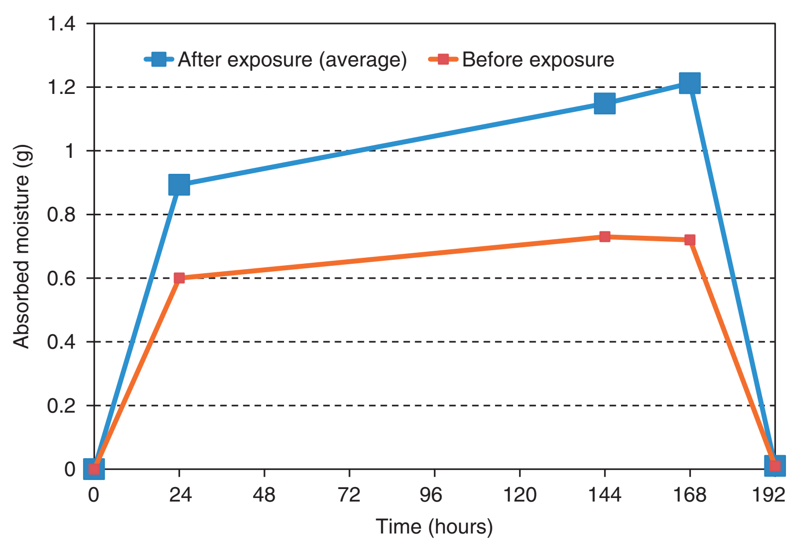


Fig. 3. Comparison of moisture absorption/release performance (No. 6 surge protector use).

The test results showed that the moisture absorption/release performance of both the humidity-controlling polymer for special-environment terminal closures and that for No. 6 surge protectors after long-term installation was equivalent to that at the time of manufacture. Results of this moisture absorb/release test are shown in **Figs. 2** and **3**.

On the basis of these results, we can say that the humidity-controlling polymer continues to exhibit the same function as that when first installed even after long-term use, and that it has a long-term effect in countering insulation failures in metal wires caused by condensation of moisture on cracks in wire covering.

5. Conclusion

It has been more than ten years since humidity-controlling polymer was first introduced. This article provided information as to whether they are still effective in preventing insulation failures by testing products actually installed—not those used in special test environments. It is our sincere hope that this information will prove useful to those in charge of maintenance operations in the field.

Going forward, the Technical Assistance and Support Center is committed to performing more tests and surveys to uncover information that can be of great use in field operations.

External Awards

The Surface Science Society of Japan Young Scientist Award

Winner: Manabu Ohtomo, Yoshiaki Sekine, Hiroki Hibino, and Hideki Yamamoto, NTT Basic Research Laboratories
Date: February 8, 2016
Organization: The Surface Science Society of Japan (SSSJ)

For "Etching-free Transfer of Highly-ordered Bottom-up Graphene Nanoribbon."

We report on a novel etching-free transfer method for a highly-aligned bottom-up graphene nanoribbon array grown on a Au(788) surface. This method will pave the way for the device application of ultra-narrow graphene nanoribbons with well-defined edge structures.

Published as: M. Ohtomo, Y. Sekine, H. Hibino, and H. Yamamoto, "Etching-free Transfer of Highly-ordered Bottom-up Graphene Nanoribbon," Abstract of the 2015 Joint Symposium of the Surface Science Society of Japan and the Vacuum Society of Japan (SSSJ's 35th Annual Meeting and VSJ's 56th Annual Symposium), 1Gp07R, Tsukuba, Ibaraki, Japan, Dec. 2015.

IN Research Award

Winner: Ginga Kawaguti, Rie Tagyo, and Fumiya Kobayashi, NTT Network Technology Laboratories
Date: March 3, 2016
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE) Technical Committee on Information Network (IN)

For "Estimation of Web Waiting Time from Network Observation."

Published as: G. Kawaguti, R. Tagyo, and F. Kobayashi, "Estimation of Web Waiting Time from Network Observation," IEICE Tech. Rep., Vol. 115, No. 310, IN-2015-69, pp. 47–50, Nov. 2015.

IN Young Researchers Award

Winner: Tetsuya Hishiki, NTT Network Technology Laboratories
Date: March 3, 2016
Organization: IEICE Technical Committee on Information Network (IN)

For "A Study on Network Architecture based on Architecture Evolution of the Internet."

We focus on the "middle entity," which provides value to applications in the middle of end-to-end communication. We discuss its disposition from the viewpoint of architecture based on the recent evolution of the Internet. The architecture of the Internet has been evolving to adapt to changes in the Internet application usage. Recently, it has tended to use the existing IP protocol stack as a basis of tunnels. This ensures deployment of new protocols or technologies on the tunnels. It may, however, cause side effects such as unoptimized routing. In this paper, we first study the evolution of the Internet from an architecture point of view and then discuss how to improve the architecture empowered by middle entities.

Published as: T. Hishiki, H. Waki, T. Ohba, and A. Koike, "A Study on Network Architecture based on Architecture Evolution of the Internet," IEICE Tech. Rep., Vol. 115, No. 210, IN-2015-52, pp. 69–74, Sept. 2015.

ICM Research Award

Winner: Takafumi Fujita, Nobuhiro Azuma, Takumi Ohba, Masao Aihara, NTT Network Innovation Laboratories; Hiroyuki Morikawa, The University of Tokyo
Date: March 10, 2016
Organization: IEICE Technical Committee on Information and Communication Management (ICM)

For "A Framework for Multiple M2M Service Sharing on M2M Area Networks."

To provide connectivity for machine-to-machine (M2M) devices in an easy and inexpensive way, we propose the concept of "Shared M2M area networks," which enables multiple M2M service providers to share M2M gateways. This paper analyzes characteristics of M2M communications based on a lot of M2M use-cases, and also derives requirements and technical challenges for "Shared M2M area networks." Furthermore, this paper also proposes an access cost evaluation model for "Shared M2M area networks," which can be applied for system design from a cost analysis viewpoint.

Published as: T. Fujita, N. Azuma, T. Ohba, M. Aihara, and H. Morikawa, "A Framework for Multiple M2M Service Sharing on M2M Area Networks," IEICE Tech. Rep., Vol. 115, No. 45, ICM-2015-6, pp. 165–170, May 2015.

Papers Published in Technical Journals and Conference Proceedings

A Citizen-centric Approach towards Global-scale Smart City Platform

T. Yonezawa, J. A. Galache, L. Gurgen, I. Matranga, H. Maeomichi, and T. Shibuya

Proc. of the 2015 International Conference on Recent Advances in Internet of Things, Singapore, April 2015.

In order to help smart cities provide responsive services to improve the quality of life of their citizens, a global-scale platform relying on cloud computing as an enabler to bridge the Internet of Things with Internet of People via Internet of Services, is presented in this paper. This platform will focus on a citizen-centric approach, offering end-users the possibility of creating their own cloud services and sharing them with other citizens, as well as involving other city stakeholders ranging from municipalities to service developers and application integrators. The definition, design, and development of the aforementioned platform has been carried out within the ClouT project (ongoing), framed into a joint European-Japanese initiative, where different field trials developed on top of the developed platform have been deployed in the four cities taking part in the project: Mitaka and Fujisawa in Japan, and Santander and Genova in Europe.

Pupillometric Evidence for the Locus Coeruleus-noradrenaline System Facilitating Attentional Processing of Action-triggered Visual Stimuli

K. Kihara, T. Takeuchi, S. Yoshimoto, H. M. Kondo, and J. I. Kawahara

Frontiers in Psychology, Vol. 6, Article 827, June 2015.

The present study investigated whether the locus coeruleus-noradrenaline (LC-NA) system is involved in the attentional facilitation effect. A rapid serial visual presentation paradigm was used to assess the dynamics of transient attention in humans. Participants were instructed to change a digit stream to a letter stream by pressing a button and specifying successive targets of four letters. Pupil dilation was measured as an index of LC-NA function. These results indicate that target identification in the visual task is closely linked to pupil dilation. We conclude that the LC-NA system plays an important role in the facilitation of transient attention driven by voluntary action.

First Experimental Demonstration of Signal Performance Improvement by Walsh-Hadamard Transform for Super-channel Transmission

A. Masuda, K. Shibahara, S. Kawai, and M. Fukutoku

Proc. of 2015 Opto-Electronics and Communications Conference (OECC), Shanghai, China, June/July 2015.

We show application schemes of the Walsh-Hadamard transform method to mitigate optical filtering and polarization-dependent loss effects. The conducted experiments demonstrate for the first time that the method effectively improves overall performance of super-channel transmission.

Sensory-perceptual Transformations for Auditory Scene Analysis

H. M. Kondo

Proc. of CME 2015 (the 9th International Conference on Complex Medical Engineering), Okayama, Japan, June 2015.

An essential function of perceptual systems is to structure the incoming flow of sensory inputs into a coherent scene. Multistability in perception provides us with clues to investigate sensory-perceptual transformations because it produces dissociations between physical information and subjective experience. For instance, spontaneous switching between different percepts is caused by prolonged listening to a sequence of triplet tones and a word, which are called auditory streaming and verbal transformations, respectively.

Transferring Positioning Model for Device-free Passive Indoor Localization

K. Ohara, T. Maekawa, Y. Kishino, Y. Shirai, and F. Naya

Proc. of UbiComp2015 (the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing), pp. 885–896, Osaka, Japan, September 2015.

This paper proposes a method that transfers a signal strength model used for locating a person obtained in another environment (source environment) to the end user environment. With the transferred models, we can construct a positioning model for the end user environment inexpensively. Our evaluation showed that our method achieved almost the same positioning performance as a supervised method that requires labeled training data obtained in an end user's environment.

Multicore Space Division Multiplexed Unrepeatered Transmission beyond 100-Tb/s Capacity

H. Takara, T. Mizuno, A. Sano, and Y. Miyamoto

Proc. of Frontiers in Optics 2015, FM1E.1, San Jose, CA, USA, October 2015.

The paper describes high capacity unrepeatered transmission using a multicore-fiber based remote optically pumped amplifier. Recent development on transmission technologies based on multicore space-division-multiplexing is also reviewed.

Evaluation of Importance of Treating Free-style Information in Disaster Information System, and Proposal for Effective Utilization Method

F. Ichinose, H. Hayashi, T. Yamamoto, T. Kokogawa, M. Sugiyama, and Y. Maeda

Journal of Institute of Social Safety Science, No. 27, pp. 179–188, November 2015 (in Japanese).

In most cases, activity logs are not recorded properly. In a conventional disaster information system, we record certain kinds of digital information such as the damage situation in order to prepare documents for meetings at the headquarters, but the activity log that affects the management is not recorded. The disaster information system (WebEOC®) can record the activity logs of the disaster control headquarters. At the Kashihara city office, it has been used for training from the year H23 (2011). We clarify the actual information processing situation in a disaster control headquarters by analyzing its activity log, and we point out the importance of the free-style information and suggest a policy for carrying out activities effectively.

Dispersion Insensitive Demodulation Using Spectral Symmetry of Real-valued Signals

M. Yoshida, K. Yonenaga, and A. Hirano

Electronics Letters, Vol. 51, No. 24, pp. 2024–2026, November 2015.

A chromatic dispersion insensitive demodulation for real-valued signals (e.g. binary shift keying and 4 amplitude shift keying) is proposed. This method utilizes the symmetric spectrum of signals and can be implemented simply in a feed-forward manner. Its feasibility is confirmed through simulations and experiments.

On the White Turbidity Phenomena in the Drying Process of Nanoporous Vycor Glass

S. Ogawa and J. Nakamura

Journal of the Spectroscopical Research of Japan, Vol. 64, No. 6, pp. 549–558, December 2015 (in Japanese).

The transient white turbidity phenomena observed in drying transparent nanoporous composites are reviewed with reference to experimental results, including their transmission spectrum changes, wavelength dependence, and correlation with the amount of an imbibed wetting fluid. These results are analyzed from both the particle-scattering and Einstein's fluctuation viewpoint. The former permits us to interpret the observed λ-4 dependence as random Rayleigh scatterers embedded in a homogeneous matrix. The scatterers have a variable effective radius, which is a measure of optical imhomogeneities that cause the strong scattering. The latter permits us to directly extract the spatial correlations in the pore space of the composites from the transmission spectrum of forward-scattered light. The agreement between the radius and the correlation length that characterizes optical inhomogeneites implies that the phenomena can be explained by a fractal-like percolation of a wetting fluid.

Estimating Human Visual Attention Based on Visual Saliency

A. Kimura

Japanese Journal of Optics, Vol. 45, No. 1, pp. 22–28, January 2016 (in Japanese).

We humans are easily able to instantaneously detect the regions in a visual scene that are most likely to obtain something of interest. Exploiting this pre-selection mechanism called visual attention for image and video processing systems would make them more sophisticated and thus more useful. This paper briefly describes various computational models of human visual attention and their development. In particular, this paper introduces visual attention models based on visual saliency that can be regarded as a measure of visual attractiveness.

Bringing Movable and Deployable Networks to Disaster Areas: Development and Field Test of MDRU

T. Sakano, S. Kotabe, T. Komukai, T. Kumagai, Y. Shimizu, A. Takahara, T. Ngo, Z. M. Fadlullah, H. Nishiyama, and N. Kato

IEEE Network, Vol. 30, No. 1, pp. 86–91, January 2016.

Communication demand is paramount for disaster-affected people to confirm safety, seek help, and gather evacuation information. However, the communication infrastructure is likely to be crippled due to a natural disaster, which makes disaster response excruciatingly difficult. Although traditional approaches can partially fulfill the most important requirements from the user perspective, including prompt deployment, high capacity, large coverage, useful disaster-time application, and carrier-free usability, a complete solution that provides all those features is still required. Our collaborative research and development group has developed the Movable and Deployable Resource Unit, which is referred to as the MDRU and has been proven to have all those required features. Via extensive field tests using a compact version of an MDRU (i.e., the van-type MDRU), we verify the effectiveness of the MDRU-based disaster recovery network. Moreover, we demonstrate the further improvement of the MDRU's performance when it is complemented by other technologies such as relay-by-smartphone or satellites.

Dense Space-division Multiplexed Transmission Systems Using Multi-core and Multi-mode Fiber

T. Mizuno, H. Takara, A. Sano, and Y. Miyamoto

Journal of Lightwave Technology, Vol. 34, No. 2, pp. 582–592, January 2016.

In this paper, we describe recent progress in space-division multiplexed (SDM) transmission, and our proposal and demonstration of dense space-division multiplexing (DSDM), which offers the possibility of ultra-high capacity SDM transmission systems with high spatial density and spatial channel count of over 30 per fiber. We introduce the SDM transmission matrix, which cross-indexes the various types of multi-core multi-mode transmissions according to the type of light propagation in optical fibers, and discuss how the spatial channels are handled in the network. For each category in the matrix, we present the latest advances in transmission studies and evaluate their transmission performance by spectral and spatial efficiencies. We also expound on technologies for multi-core and/or multi-mode transmission including optical fiber, signal processing, spatial multi/demultiplexer, and amplifier, which will play key roles in configuring DSDM transmission systems, and we review the first DSDM transmission experiment over a 12 core × 3 mode fiber.

Optimized Canonical Labeling Algorithm for Graph Rewriting Systems

K. Miyahara and K. Ueda

Computer Software, Vol. 33, No. 1, pp. 126–149, February 2016 (in Japanese).

In graph-base model checking, systems are modeled with graph structures which are highly expressive and feature a symmetry reduction mechanism. However, it involves frequent isomorphism checking of graphs generated in the course of model checking. Canonical labeling of graphs, which gives a unique representation to isomorphic graphs, is expected to be an effective method to check isomorphism among many graphs efficiently. It is therefore important to efficiently compute canonical forms of graphs in graph rewriting systems. For this purpose, we propose an optimization technique for McKay's canonical labeling algorithm that reuses information of graph structures that does not change by rewriting. To enable reuse, we reformulated McKay's algorithm to clarify what substructures of graphs are utilized in its execution, and designed an algorithm for successive graph canonicalization that organizes graph information in such a way that recomputation may be minimized. We evaluated the performance of the proposed algorithm and found that it achieved sublinear time complexity with respect to the number of vertices for many cases of re-canonicalization.

Integrated Photonic Devices and Applications for 100GbE-and-beyond Datacom

Y. Doi, T. Ohyama, T. Yoshimatsu, T. Ohno, Y. Nakanishi, S. Soma, H. Yamazaki, M. Oguma, T. Hashimoto, and H. Sanjoh

IEICE Transactions on Electronics, Vol. E99-C, No. 2, pp. 157–164, February 2016.

We review recent progress in integrated photonics devices and their applications for data communications. In addition to current technology used in 100-Gigabit Ethernet (100GbE) with compact form-factor of a transceiver, the next-generation technology for 400GbE seeks a larger number of wavelengths with a more sophisticated modulation format and higher bit rate per wavelength. For wavelength scalability and functionality, planar lightwave circuits (PLCs) such as arrayed waveguide gratings (AWGs) will be important, as well higher-order-modulation to ramp up the total bit rate per wavelength. We introduce integration technology for a 100GbE optical sub-assembly that has a 4λ x 25-Gb/s non-return-to-zero (NRZ) modulation format. For beyond 100GbE, we also discuss applications of 100GbE sub-assemblies that provide a 400-Gb/s throughput with 16λ x 25-Gb/s NRZ and bidirectional 8λ x 50-Gb/s four-level pulse amplitude modulation (PAM4) using PLC cyclic AWGs.

Transferring Positioning Model for Device-free Passive Positioning based on Wi-Fi Signals

K. Ohara, T Maekawa, Y. Kishino, Y. Shirai, and F. Naya

IPSJ Journal, Vol. 57, No. 2, pp. 406–415, February 2016 (in Japanese).

The widespread use of smartphones equipped with Wi-Fi modules has led to studies of Wi-Fi based indoor positioning techniques. However, many Wi-Fi indoor positioning methods assume that an end user to be tracked always possesses a signal receiver such as a smartphone, and this assumption places a large burden on end users. Recently, to alleviate the burden, device-free indoor positioning techniques have been studied, which enable us to locate an end user who does not possess a smartphone based on RSSI attenuation caused by the human body. However, device-free indoor positioning techniques require a lot of training data in a target environment. In this study, we propose a device-free positioning method that transfers training data collected in other environments to a target environment in order to reduce the training cost of positioning systems.
