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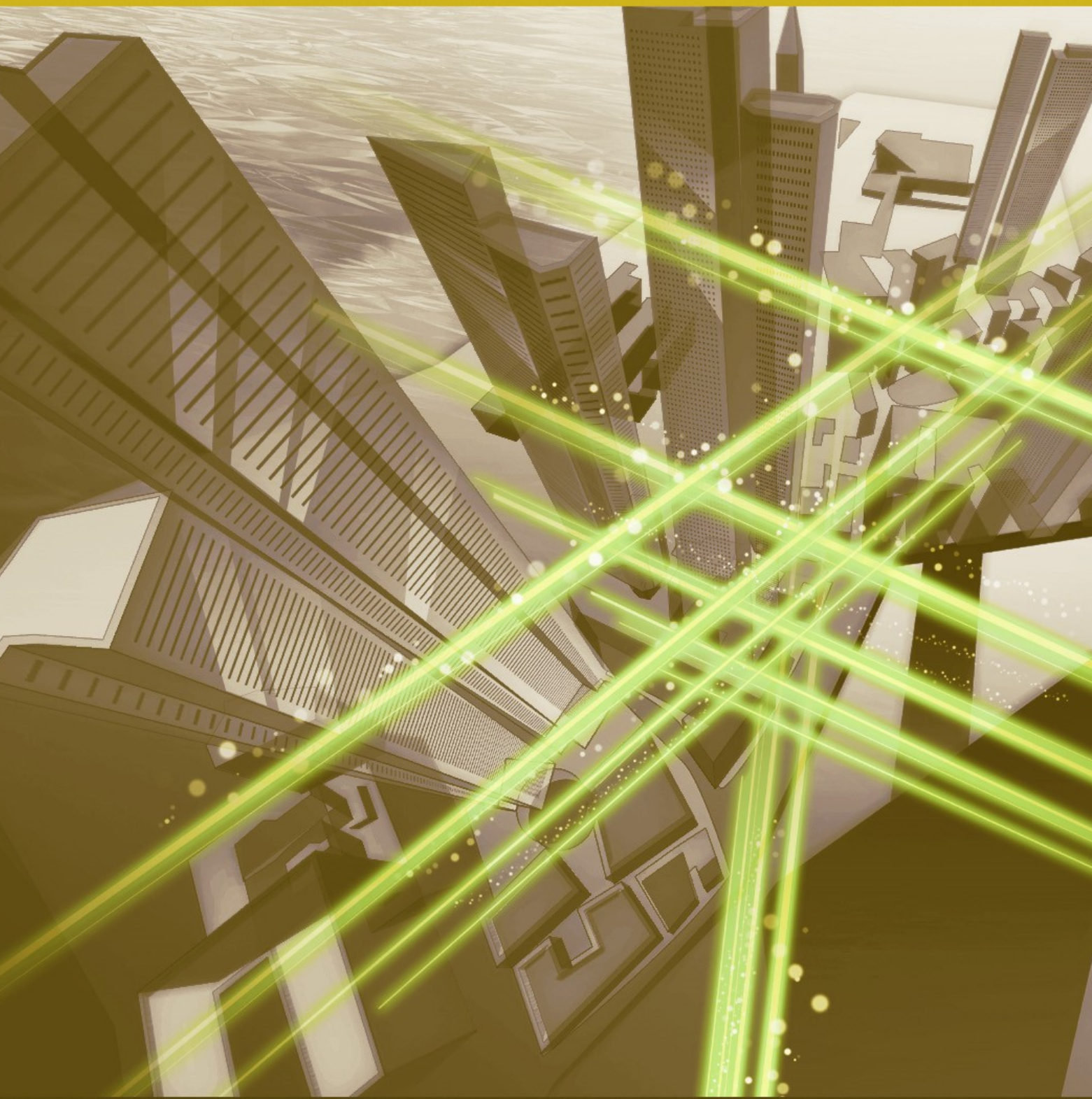

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My Responsibility Is to Continue Researching Speech/Audio Coding to Provide Highest Quality Services and High Reliability

Takehiro Moriya
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Overview

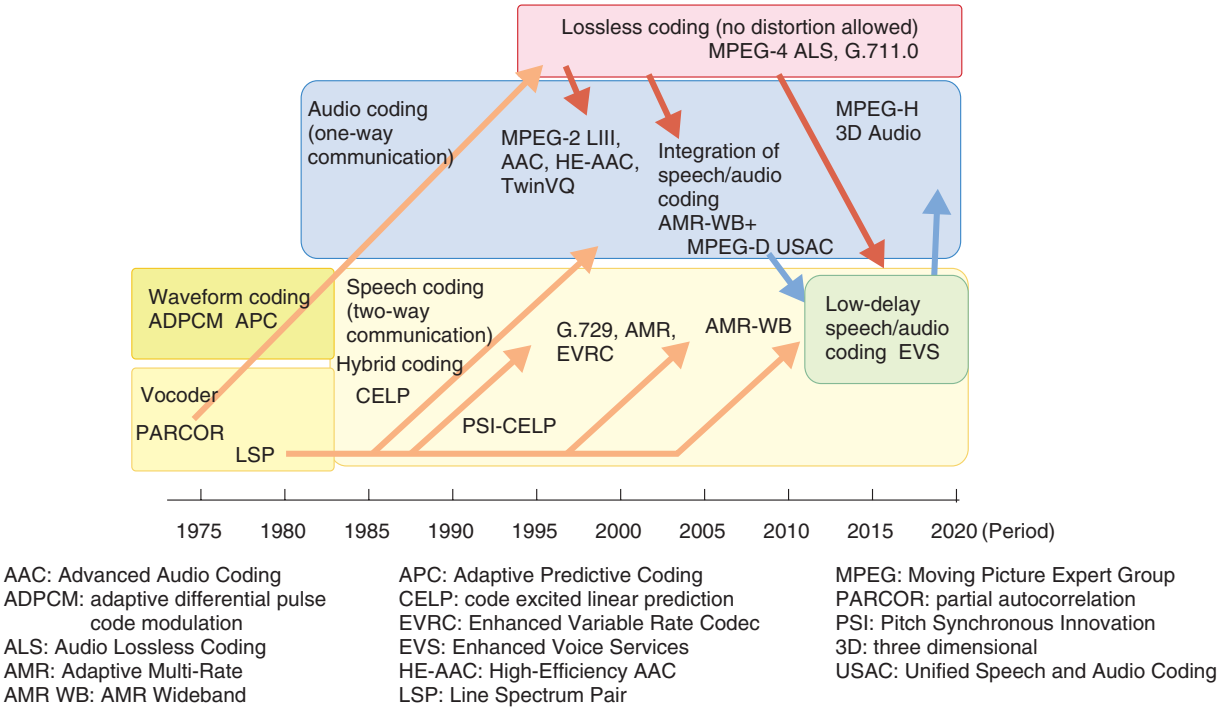
Performing business tasks and holding meetings using personal computers, the Internet, and phones is accelerating the trend toward more efficient work processes and diverse work styles. It is generally agreed that sound quality can greatly influence the sense of presence in videoconferencing, and the results of NTT research have long been making major contributions on a global scale toward high-quality speech in fixed-line phones and mobile phones as well as in videoconferencing and video calls, as used in teleworking. NTT Fellow Dr. Takehiro Moriya of NTT Communication Science Laboratories has been involved in the research of speech/audio coding for about 40 years. We asked him about his current areas of research and his mindset as a researcher.

Keywords: speech and audio coding, telephone, standardization

Our goal is to meet our customers' needs in the fastest way possible

—Dr. Moriya, please tell us about your research thus far.

I have been involved for about 40 years in the research of speech and audio coding to digitize speech and music and to compress that information efficiently with high reproducibility at playback. For example, the music that we can hear from portable music players or digital broadcasts is not the original signal but rather a compressed signal in which the amount of information has been reduced to about one-tenth its original size. In short, this is research related to methods of compressing and reproducing signals while maintaining sound quality. Speech and audio coding technologies based on digital signal processing have been progressing over the past 50 years (**Fig. 1**). I will omit a detailed description of this history, but I'll say that these technologies were developed through the dedicated efforts of many researchers and engineers throughout the world. From the 1990s onward, these technologies have



AAC: Advanced Audio Coding
ADPCM: adaptive differential pulse code modulation
ALS: Audio Lossless Coding
AMR: Adaptive Multi-Rate
AMR WB: AMR Wideband
APC: Adaptive Predictive Coding
CELP: code excited linear prediction
EVRC: Enhanced Variable Rate Codec
EVS: Enhanced Voice Services
HE-AAC: High-Efficiency AAC
LSP: Line Spectrum Pair
MPEG: Moving Picture Expert Group
PARCOR: partial autocorrelation
PSI: Pitch Synchronous Innovation
3D: three dimensional
USAC: Unified Speech and Audio Coding

Fig. 1. Progress in the development of speech/audio coding.

been making significant contributions to everyday life and business in the form of telephones, broadcasts, etc. Among the many speech and audio technology fields, I believe that data compression/coding technology has made the most significant contribution to commercial services.

In the first half of the 1980s, the mainstream technologies were high-speed optical fiber in the fixed-line network and analog transmission in the mobile network (mobile phones) and the possibility of digitization was unclear. As a result, technologies for digital compression/coding of speech was losing sight of any uses or applications. However, in the 1990s, the worldwide trend shifted to the digitization of mobile phones with the result that digital compression/coding technologies suddenly became important. During this period, our research achievements in meeting certain conditions such as guaranteeing sound quality at low bit rates even with transmission error codes were adopted in Japan's standard system following a competitive process and used in second-generation (2G) mobile phones. Our elemental technologies were also adopted in 3G mobile phones and Internet protocol (IP) phones, contributing to the improvement of speech quality in mobile telephony throughout the world.

Around 2010, there was a strong desire in the 3rd Generation Partnership Project (3GPP), an international standardization organization targeting mobile communications systems, for establishing new coding protocols toward Voice over Long-Term Evolution (VoLTE), the worldwide 4G mobile communications network. In response to this need, Enhanced Voice Services (EVS) became internationally standardized as a speech/audio coding system through competition and collaboration among many expert parties around the world including the NTT Group.

Up to that point, speech coding systems for mobile phones used Code Excited Linear Prediction (CELP) emulating the human vocalizing mechanism to transmit the human voice with high quality at a low bit rate. The EVS codec combined CELP with newly developed low-delay music-oriented coding that made it possible to transmit speech including background noise and background music or music itself with low delay and high quality that had not been previously possible. During the standardization process, EVS was shown to have a level of quality significantly higher than current systems through large-scale subjective quality evaluation tests conducted by third-party institutions under a variety of conditions, sound sources, and languages. As a result, the EVS

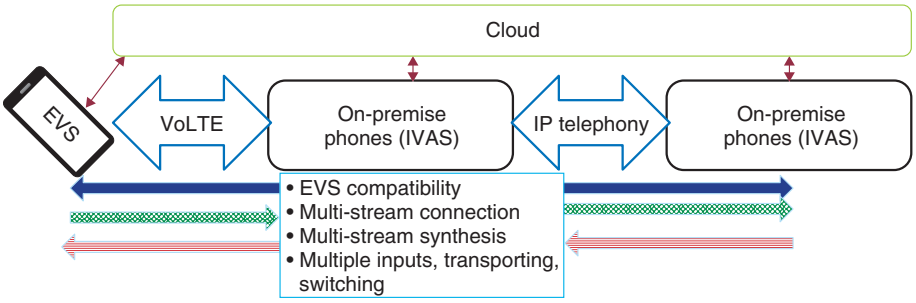


Fig. 2. Example of an extension-phone configuration using IVAS.

codec was adopted in unison by telecom companies, telephone equipment manufacturers, and chip manufacturers worldwide, and in Japan, calls between smartphones that had already come into use achieved a high level of quality with wideband transmission not previously possible in telephones.

—Those were certainly major achievements.

For about 40 years, the NTT team together with leading researchers and engineers throughout the world has been working to improve the quality of telephone calls through a process of trial and error. It's been a great joy to see the results of this hard work being used by people around the world.

We are currently working to standardize an extension of EVS called EVS extension for Immersive Voice and Audio Services (IVAS). The aim is to develop telephone services that maintain a sense of immersion in an interactive manner using multiple microphones and speakers such as for virtual reality and videoconferencing applications.

As a researcher at NTT, a global information-communications company with a profound history particularly in the research of telephone speech, my desire is to create services that can be applied to a variety of business scenarios. For example, immersion-related technology that makes participants of teleconferencing feel as if they were all in the same room is desirable, and video may also be necessary, but I would like to place priority on achieving calls with good audio quality irrespective of the medium. Teleconferencing applications using paid-for or free software have recently been gaining in popularity, but the networks used for running such applications are best-effort types with the result that quality degradation due to delay or packet loss cannot be avoided. In addition, using fixed-line phones has been assumed with teleconferencing systems for business applications, and connecting to such systems from smartphones or IP extension phones can significantly degrade quality. I therefore believe that we should develop IVAS so that EVS codec can be used without degradation in high-reliability networks applicable to voice calls such as Hikari Denwa (IP telephony using optical fibers) and VoLTE networks constructed by network specialists (**Fig. 2**).

Research laboratories of leading telecom companies throughout the world conventionally possessed a considerable amount of influence, but today, this is no longer the case as the service field and industry players have changed. Amid this trend, NTT and NTT DOCOMO as companies providing fixed-line phone and mobile phone services attach great importance to improving speech-related technologies as a matter of responsibility. This is exactly the domain that I am in.

Imagining the smiling faces of people who use one's research achievements

—Looking back at more than 40 years of research activities, what lessons have you learned?

It is important that a researcher think for himself or herself, find a variety of issues, and make his or her ideas into a reality. Half of the motivation here comes from thinking that something would be interesting to research. It's also very important to consider whether the research activities themselves would be interesting. In other words, can those research activities be thought of as exciting and worthwhile? This could not be the case if there were no people that would one day enjoy the results of one's research, so the attitude to take is to devote oneself continually to research while imagining people who use your research results and thinking about ways to make them happy. The point

at which this idea came to me dates back to my student days when I began researching. At that time, I was involved in research completely different from what I'm doing today. I enjoyed thinking about this and that and making something concrete that I would like many people to use. However, no matter how hard I tried, I could not escape from the limits of self-contentment, and when asking other people what they thought, I would only get an indifferent reaction such as "What is the point?" I felt a vague sadness thinking that I could not be useful to anyone or contribute to society. Therefore, I wanted to work at a place in which whatever action I take, the world would respond to it, and I knocked at NTT's gate.

After joining the company, Nippon Telegraph and Telephone Public Corporation was privatized in 1985 as Nippon Telegraph and Telephone Corporation, now commonly known as NTT. At that time, the corporate philosophy was established as "We shall strive to provide highest quality services and high reliability based on technology development with a global vision and contribute to the creation of an affluent life and culture." I was very encouraged by these words as they underscored the importance of being an NTT researcher, and to this day, I still have the paper inscribed with these words on the back of my NTT security pass. These are words that I treasure. They constitute the philosophy that I have always adhered to, and as an employee of a company espousing such a philosophy, I have pursued my research while thinking whether my current work is based on and consistent with this philosophy. These words have provided daily support in my research life, especially when faced with a difficult problem or hardship such as when I could not achieve a consensus on standardization. Perhaps a bit of an exaggeration, but these words truly give worth to my role as a researcher.

It is unbelievable that I researched the same theme continuously for about 40 years. Given that the world changes rapidly, most researchers have to take up a new problem or change research fields after about five years, so sticking with the same theme for a 40-year period is extremely rare. As a researcher, it is important to discover or invent new things and write papers about them so that society will come to use them. For this reason, it frequently happens that a researcher cannot help but change research fields after achieving certain results. Under such conditions, I believe that a researcher in a subject area near practical use, even if at a stage at which final results have not yet been achieved, should discover a different viewpoint or skillfully find another issue to address. Fortunately, in my case, I have been able to expand upon my research over a 40-year period. For example, in the 1990s, many mobile phone users expressed dissatisfaction with sound quality, and during research on this problem, the idea (new issue) came to me that the same technology for improving sound quality could be used to achieve high-quality playback of music. In this manner, I was able to find new issues one after another based on the same theme of "communications and sound." Of course, 40 years of research activities have also included failures and cases of losing out to the competition.

Pursuing multiple research themes and viewpoints with a balanced approach

—Can you offer some advice to young researchers on how to lead a better research life?

My advice would be to work on multiple research themes in parallel. My research team, for example, is currently working on two themes. One is to improve the sound quality and functions of smartphones and other devices as a telecom company and the other is to measure sound and other signals using light. I'm not sure if such light-based measurement would be immediately useful, but I believe that it could contribute to developing services using NTT's high-speed networks in a totally new way by conducting repeated trials. I also would like young researchers to have multiple viewpoints with different dimensions (such as theoretical and experimental and short-term and long-term problems). This is because social trends and conditions are dynamic and if external conditions should change, research results no matter how superior may turn into technology that won't be used. Papers describing one's research results can be written, but it may happen that they will never be used if not matching current conditions or if failing to be competitive in a field with many competitors. It is important to keep an eye on world trends and technological advances and continue researching over a long period while maintaining a balanced approach, and it's better to be prepared to throw out one or another research theme if necessary.

I expect our young researchers to continue in their research efforts over the next 20 years. Research activities have many peaks and valleys, so I think it is good to take on multiple themes having different timeframes and techniques, such as by concentrating on one theme for several years and taking up another over the long term. It is rare to be able to concentrate

on one theme in research or elsewhere and you may spend some time supervising subordinates and dealing with an increasing number of stakeholders. Even so, a researcher should devote his or her efforts to a primary theme while maintaining an interest in peripheral areas because one's primary theme may unfortunately disappear one day.

Promoting the significance of one's research with conviction and winning supporters

—How should research themes be selected?

To begin with, you should avoid research themes that are currently in fashion. Entering an area that many researchers are already pursuing means that you will always be behind someone. When joining in on the competition, it is difficult to promote your own achievements to society. It would be better to select an original theme in which you can integrate your knowledge and skills with social needs.

As a researcher in a company that provides telephone services, I am always thinking about ways of bringing joy to the billions of people on Earth when they use their telephones. I don't think it's a good idea to compete while not knowing who might use the results of one's research. This is the same as running without the finish line in mind. However, each research field has its own characteristics. In the case of basic research, results obtained in the present may become useful in years to come or reflected in textbooks, so the goal here is to improve future society.

Additionally, to drive research forward, a budget is needed for facilities, team formation, etc., but securing that budget is not easy if there is no one who understands the significance of that research. In particular, given the relatively long research span of basic research, people who can understand the importance of that research into the future must be found. It is therefore important to promote the significance of one's research with conviction and winning supporters.

There have been times in which I too have had much difficulty in finding supporters of my research efforts. Around 2000, it was recognized around the world that technology for compressing music signals at a low bit rate was nearly completed and that coding was no longer important. I was convinced, however, that "no matter how large transmission capacity becomes, technology for reducing the amount of information under conditions that strictly prohibit degradation in sound quality will still be useful and should therefore be standardized." However, this belief was met with some resistance even within the NTT laboratories and was rejected by standards organizations as well. Nevertheless, I pointed out the importance of this technology in collaboration with overseas specialists and gradually won support from both inside NTT and from participants of standards organizations. As a result of this and incorporating requirements from the music industry, we were able at long last to establish an international standard in 2005.

Today, 15 years since establishing that standard, this technology has finally found widespread use in the NTT Group's high-quality music delivery business and other areas. As a researcher, the competitive arena is the world. Representatives of the United States, Europe, and China can be quite assertive and have at times disagreed with my opinions. Yet, technology speaks the truth, and it comes down to competing with technology and having strong convictions about it. In addition, whenever I find myself in troubled times, I return to and follow NTT's corporate philosophy, the base point of my research activity, which also provides me with emotional support.

—Dr. Moriya, please tell us about your future aspirations.

Telephone services including mobile phones have reached a state of saturation, but video services and services based on artificial intelligence and other new technologies are attracting attention not only from the world of information communications but also from platformers such as Google, Amazon, Facebook, and Apple (GAFA) and many other fields. These new fields include many research issues, and NTT as well is actively promoting research in these fields. Within this environment, the number of telephone-related research issues are decreasing, but there are still some solutions that would be useful to society. For example, since different types of telephone networks, such as mobile phones, fixed-line phones, and extension phones, still exist, measures are needed to deal with degraded sound quality in teleconferencing using many and varied terminals. As someone who has been a researcher in this field and an employee of a telecom company for about 40 years, I believe that it's my responsibility to research speech and audio coding through to the end.

Finally, opportunities for giving advice to young researchers have recently been increasing, but many of the experiences that I have accumulated over these

past 40 years are not necessarily helpful at present. Therefore, rather than simply giving out instruction, I speak about the need to take on new challenges that are now appearing in our society.

■ **Interviewee profile**
Takehiro Moriya
NTT Fellow, Head of Moriya Research Laboratory, NTT Communication Science Laboratories.

He received a B.S., M.S., and Ph.D. in mathematical engineering and instrumentation physics from the University of Tokyo in 1978, 1980, and 1989. Since joining the Nippon Telegraph and Telephone Public Corporation (now NTT) in 1980, he has been engaged in research on medium to low bitrate speech and audio coding. In 1989, he worked at AT&T Bell Laboratories, NJ, USA, as a visiting researcher. Since 1990, he has contributed to the standardization of coding schemes for the Japanese Personal Digital Cellular system, ITU-T (International Telecommunication Union - Telecommunication Standardization Sector) G.729, G.711.0, ISO/IEC (International Organization for Standardization/International Electrotechnical Commission) MPEG, MPEG-4 General Audio Coding, MPEG-4 ALS, and 3GPP EVS. He is an IEICE (Institute of Electronics, Information and Communication Engineers) Fellow, an IEEE (Institute of Electrical and Electronics Engineers) Fellow, and a member of the Information Processing Society of Japan and the Acoustical Society of Japan.

Smart Energy Targeted by NTT Anode Energy

Shinya Date and Naoyuki Suzuki

Abstract

Established as a wholly owned subsidiary of NTT on June 3, 2019, NTT Anode Energy aims to contribute to solving social issues related to the environment and energy by leveraging NTT's technologies and assets. This article introduces the projects that are being undertaken at NTT Anode Energy.

Keywords: energy policy, power supply for telecommunication, renewable energy

1. Energy situation and policy in Japan

Japan has small reserves of fossil fuels, so its energy-self-sufficiency ratio* is low. Under an energy policy to reduce geopolitical risks such as high dependence on fuel imported from overseas, construction of nuclear-power plants, and introduction of renewable energies, such as hydroelectric-power generation and solar-power generation that use the rich natural environment, have been promoted. As a result, the energy-self-sufficiency ratio has increased, contributing to a stable energy supply. However, large-scale natural disasters are increasingly threatening stable supplies. Some examples of power outages are (i) the implementation of planned power outages in the Tokyo metropolitan area triggered by the accident at the Fukushima Daini Nuclear Power Station due to the aftermath of the Great East Japan Earthquake on March 11, 2011; (ii) a prefecture-wide power outage triggered by the Hokkaido Eastern Iburi Earthquake on September 6, 2018; and (iii) long-term power outages due to problems with power transmission and distribution networks caused by Typhoon No. 21 (Jebi), which struck Japan's Kansai region (southcentral region of the main island of Honshu) in September 2018, and Typhoons Nos. 15 and 19 (Faxai and Hagibis), which caused significant damage to the Boso Peninsula in Chiba (southeastern Honshu), in September and October 2019, respectively.

The Japanese government decided on the Fifth Energy Basic Plan on July 3, 2018 with the aim of reforming the energy supply-and-demand structure. Specifically, a policy was established called 3E+S, where "S" means *safety* (a prerequisite), and "3E" stands for stable *energy supply* (a top priority), secure energy supply at low cost by improving *economic efficiency*, and ensuring *environmental compatibility*.

Regarding the Paris Agreement, Japan declares that it will reduce its greenhouse-gas emissions by 26% by 2030 compared to 2013 levels. To achieve this goal, the basic policy is to carry out thorough energy saving and increase the ratio of zero-emission power sources such as renewable energy. In particular, renewable energy accounted for about 11% of the total amount of power generation in 2013, and the target for 2030 has been set to 44%, including nuclear-power generation.

In some cases, however, the introduction of solar-power generation or wind-power generation, which have high potential but are unstable means of power generation, is restricted due to constraints on the power grid system. In the worst case, if the electricity supply and demand are out of balance, large-scale power outages will occur, so it is necessary to always match supply and demand. To balance supply and demand, the amount of power generation is controlled according to fluctuations in demand. If this

* Energy-self-sufficiency ratio: The ratio of energy that can be secured within one's country to primary energies required for life and economic activity.

controllable capacity is exceeded, connection between the new power plant to the power grid system is limited, or it becomes necessary to suppress the output of solar power plants. This is a bottleneck to introducing a large amount of renewable energy and turning that energy into the main power source.

To solve this problem and promote the spread of renewable energy, it is necessary to adjust fluctuations in the supply-and-demand balance in combination with supply from storage batteries and achieve locally produced and locally consumed energy in a small area to strengthen the regional energy supply. This requires incorporating power from electric vehicles (EVs) and storage batteries into distributed energy systems, supplying the power to multiple facilities, and controlling energy consumption and consumption patterns with an energy management system. To satisfy these requirements, storage batteries that can charge and discharge electric power will become key.

2. The NTT Group's efforts thus far

From operating approximately 7300 telecom central offices nationwide, NTT has accumulated knowledge on a power-supply system for over 100 years with the purpose of continuously providing telecommunications services without interruption. Alternating current (AC) power received from power companies is converted to direct current (DC) power with rectifiers and supplied to communication equipment. These central offices are also equipped with storage batteries and emergency power generators as backup-power sources as well as mobile power-supply vehicles in case of long-term power outages or failure of emergency power generators.

DC power supply has the advantages of reliability and high efficiency. For an uninterruptible power supply (UPS) commonly used in datacenters, three-stage power conversion is normally required: (i) AC power is converted to DC, (ii) the DC power is converted to AC and supplied to information and communication technology (ICT) equipment, and (iii) AC is converted to DC again in the ICT equipment. In a DC power supply, one-step conversion is sufficient, and the failure rate of ICT equipment is reduced due to the small number of conversions, reliability of the power supply is increased approximately 10 times, and conversion loss is reduced by up to 20%. For these reasons, the telecommunications industry, which requires continuous power supply 24 hours a day, 365 days a year, has selected DC power supply as standard.

NTT's first initiative concerning renewable energy was the introduction of a 32-W solar-power generation system in Oronoshima, Fukuoka Prefecture in 1962 with the aim of enhancing disaster countermeasures involving public telephones. In 1989, Japan's then-largest (10 kW) solar-power generation system was installed in a public telephone box at Konpoku Pass in Hokkaido. Since then, to promote the use of natural energy, NTT has installed solar-power generation systems providing more than 5 MW of power centered on NTT Group office buildings and research laboratories. In addition, NTT FACILITIES is working on the construction of large-scale solar power plants. As of the end of 2017, the company owns 80 solar power plants providing 269,000 kW of power. Using its construction and operation expertise, NTT FACILITIES is engaged in the construction, maintenance, and operation of solar power plants providing approximately 880,000 KW of power at about 1400 locations nationwide.

In 1999, following the liberalization of the electricity market, Ennet was established as a retail electricity business through joint investment by Tokyo Gas, Osaka Gas, and NTT FACILITIES. For over 20 years, Ennet has been a leader among newly entered power producers and suppliers and is currently supplying electricity to approximately 90,000 customers. In 2011, NTT Smile Energy was established as a joint venture with OMRON and NTT WEST to sell remote-monitoring equipment ("eco-glasses") for solar-power generation systems and develop a small-scale renewable-energy power-generation business. It has gained a large market share in visualization services for solar-power generation.

3. Smart energy targeted by NTT Anode Energy

NTT Anode Energy is developing a smart energy business that complements existing power grids by leveraging the NTT Group's renewable energy and DC power supply technologies and expertise as well as using its ICT assets. It plans to provide backup-power supply, virtual power plants, green power generation, and power retailing businesses as well as data utilization services for these businesses. This will be enabled by ensuring power reserves using power storage and digital technology, making renewable energy the main power source, and building a distributed energy system integrating renewable energy, EVs, micro grids, etc.

To facilitate the development of the smart energy business, NTT Smile Energy and Ennet were

respectively made subsidiary companies of NTT Anode Energy in September and October 2019. In the future, we will provide services using the B2B2X (business-to-business-to-X) model in collaboration with other partners.

Considering recent large-scale disasters and the growing worldwide need for backup-power supplies, we want to contribute to strengthening regional disaster resilience by providing backup-power-supply services. The number of long-term blackouts due to disasters of an unexpected scale is increasing. In line with this trend, it is becoming important—from the perspective of self-preservation—to own independent power sources (self-help) and help one another in the local community (co-help) rather than waiting for restoration of power supplies by power companies and government support (public assistance). During typhoons Nos. 15 (Faxai) and 19 (Hagibis) that struck Japan in 2019, for example, the solar-power generation systems installed at roadside charging stations supplied power to local facilities during power outages, and electricity was supplied to the local evacuation shelters by using EVs.

In the future, we plan to make proposals for installing solar-power generation systems, storage batteries, and EVs as distributed energy sources in, for example, evacuation shelters of local governments. We aim to provide a system to control these distributed energy sources across areas and deliver limited energy to the appropriate places in the event of emergencies. We also plan to use the technologies of Cognitive Foundation® and Digital Twin Computing to create a mechanism for precisely controlling energy and supporting power supplies during emergencies.

Current electric devices generally use AC power, but personal computers, smartphones, and other devices support USB (universal serial bus) and use DC power internally, and such devices are becoming widespread. Solar-power generation systems and storage batteries also use DC power. Accordingly, we will study services that use DC power that effectively use the affinity between devices.

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He joined NTT WEST in 2000 and developed virtual private network services and planned the transportation layer for the grand design of next-generation optical networks. He is currently responsible for managing a smart-energy infrastructure project.

Naoyuki Suzuki
Senior Manager, Planning Division, Smart Energy Business Department, NTT Anode Energy Corporation.
He joined NTT FACILITIES in 2003 and planned the maintenance of electric power facilities and energy conservation measures. He is currently responsible for managing a smart-energy infrastructure project.

Services Undertaken by NTT Anode Energy

Takeshi Arai, Shigemichi Watanabe, Yu Miyazaki, Noriaki Kikuchi, and Yuko Inoue

Abstract

Major power outages due to large-scale natural disasters have been frequently occurring. As a countermeasure against them, NTT Anode Energy provides a backup-power-supply service that adopts a distributed energy system. In Europe, there is a trend toward integrating multiple distributed energy systems to build a single virtual power plant (VPP). In Japan, players such as electric-power companies are participating in the VPP Construction and Demonstration Project, which is a subsidy project of the Agency for Natural Resources and Energy of the Ministry of Economy, Trade and Industry. In this article, the energy services that NTT Anode Energy is working on to address the recent issues surrounding energy are introduced.

Keywords: distributed energy, backup power, virtual power plant

1. Introduction

Major power outages due to large-scale natural disasters, including the Hokkaido Eastern Iburi Earthquake in 2018, have been occurring frequently in Japan (**Fig. 1**). Typhoons Nos. 15 (Faxai) and 19 (Hagibis) that struck Japan in 2019 caused widespread damage in many places, and the power outages due to these typhoons lasted for a considerable amount of time and severely impacted daily life. One of the causes of those power outages was that the power-transmission and distribution equipment for the energy supply from the electric-power company was damaged and/or disconnected by fallen trees and flying debris caused by the strong winds brought by the typhoons. Since the conventional energy-supply system is centralized using large-scale power-generation facilities, the power-transmission and distribution equipment for delivering generated energy to customers is indispensable. However, if the power-transmission and distribution equipment becomes damaged, energy will not be available; it is thus necessary to build an environment in which customers can use energy without being affected by damage to such equipment. To address this issue, NTT Anode Energy will provide a backup-power-supply service that adopts a distributed energy system to supply energy to customers without dependence on the status of power-transmission and distribution equipment (**Fig. 2**). This distributed energy system is an energy-supply system that uses small-scale power-generation facilities that are deployed in a distributed manner. This backup-power-supply service will make it possible to improve regional power-supply resilience.

With the recent increase in environmental awareness, renewable energy is becoming more widespread. Even so, it is difficult for power-generation equipment based on renewable energy to adjust energy supply and demand because it is affected by natural phenomena. Consequently, renewable energy cannot easily be deemed the main power source for stably supplying energy such as existing thermal-power generation and hydroelectric-power generation.

Virtual power plants (VPPs) are expected to solve this problem. A VPP is a new energy-supply system that controls power-generation equipment, storage batteries, and demand-side equipment to function as if they were a single power plant (**Fig. 3**). A VPP is expected to make it not only possible to coordinate

[Earthquake]

June 2018	Northern Osaka Earthquake	Approximately 170,000 households in Osaka and Hyogo prefectures suffered power outages.
September 2018	Hokkaido Iburi Eastern Earthquake	Power outages affected approximately 2.95 million households throughout Hokkaido.

[Storm and flood damage]

September 2018	Typhoon No. 21 (Jebi)	Approximately 2.4 million households, mainly in the Kansai and Chubu (central Honshu) regions, suffered power outages (recovery time: approximately 120 hours).
September 2018	Typhoon No. 24 (Trami)	Approximately 1.8 million households, mainly in the Chubu region, suffered power outages (recovery time: about 70 hours).
September 2019	Typhoon No.15 (Faxai)	Approximately 900,000 households in Chiba prefecture suffered power outages (recovery time: about 280 hours).
October 2019	Typhoon No. 19 (Hagibis)	Approximately 500,000 households, mainly in the Kanto, Chubu, and Tohoku (northeast Honshu) regions, suffered power outages.

Source: Energy White Paper 2018

Fig. 1. Status of power-outage damage due to large-scale disasters.

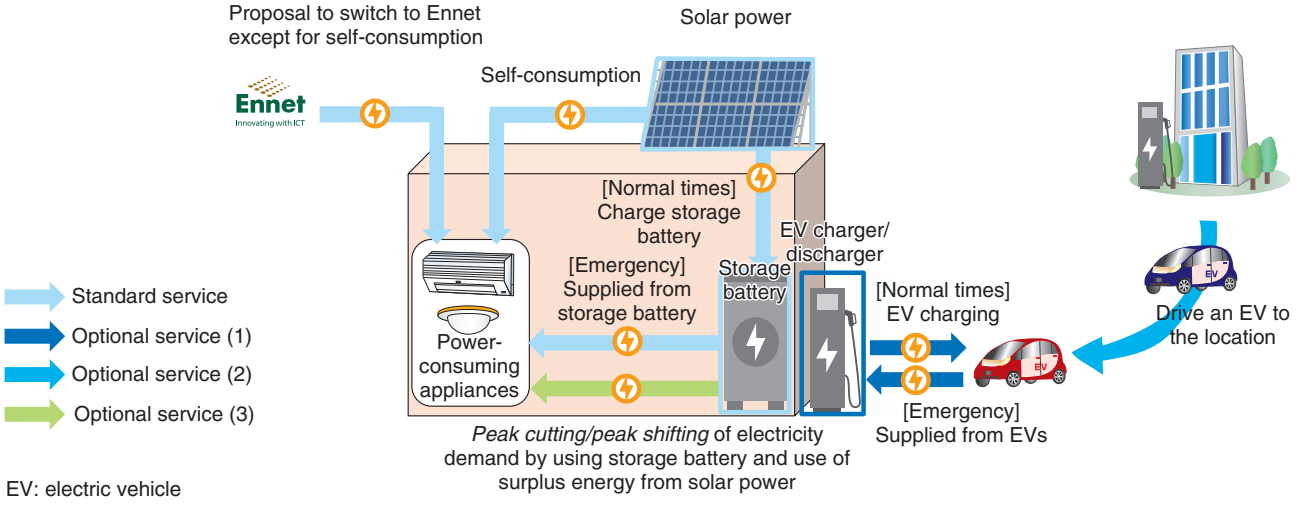
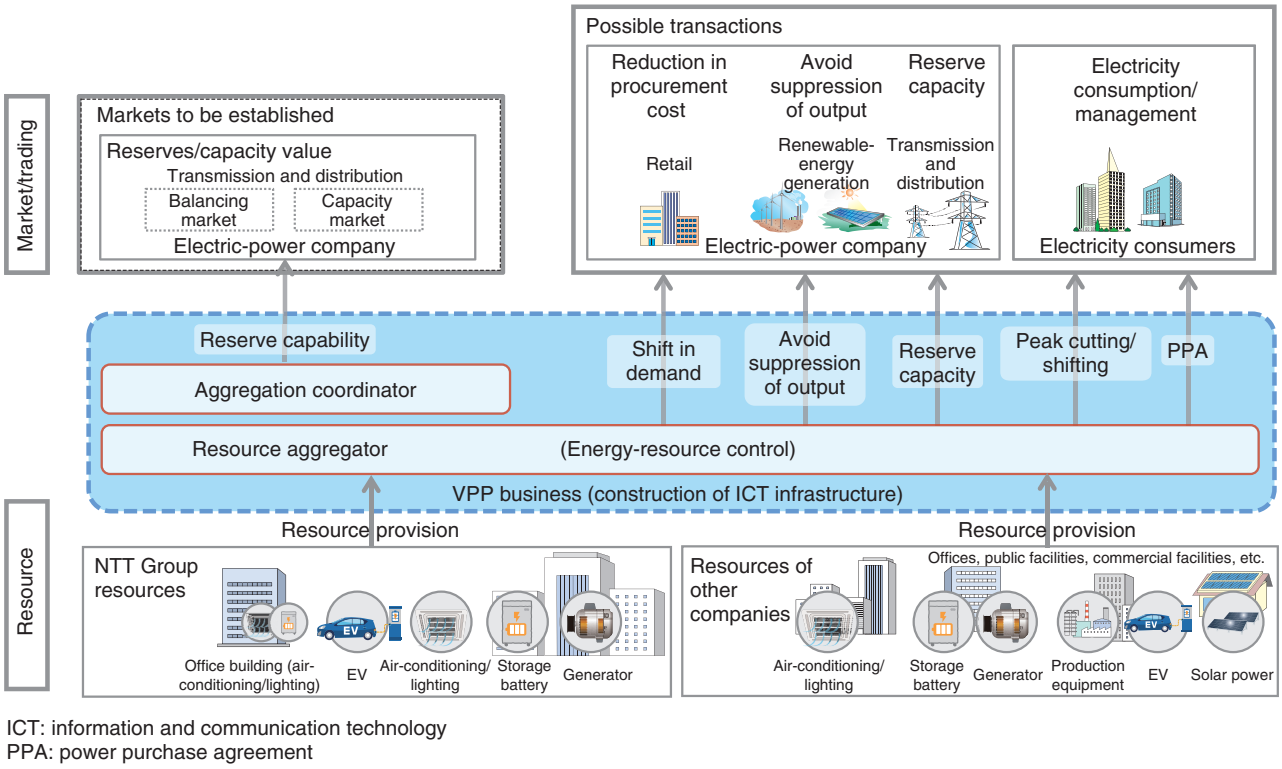


Fig. 2. Illustration of backup-power-supply services.

energy supply and demand but also replace existing thermal-power plants by increasing the capacity of energy handled. Among thermal-power plants, coal-fired power plants in Japan were mostly constructed in the 1960s and will come up for renewal sometime within the next ten years. Since coal-fired power plants are exposed to international criticism, it is expected to be difficult to upgrade them. Toward *decarbonization*, which was set as a goal of the Paris Agreement (the international framework for global-warming countermeasures), Japan's Ministry of Economy, Trade and Industry (METI) has set a goal of increasing the ratio of renewable energy from 16% in 2017 to 22–24% by 2030. Accordingly, NTT Anode Energy is creating a new system for supplying energy in a different manner from the existing energy-supply system by constructing a VPP, which is crucial for making renewable energy into the main power source. NTT Anode Energy will facilitate the spread of renewable energy and help create an environmentally friendly society.



ICT: information and communication technology
PPA: power purchase agreement

Fig. 3. VPP business.

2. Backup-power-supply service

NTT Anode Energy will provide backup-power-supply services to customers, such as local governments, having needs concerning business continuity planning to improve regional power-supply resilience. The backup-power-supply service provided by NTT Anode Energy is based on the following two approaches.

The first approach is to introduce a distributed energy system to buildings that require enhanced power-supply resilience. Establishing a distributed energy system makes it possible to avoid power outages by supplying energy from the system even if the power-transmission and distribution equipment owned by the electric-power company is damaged due to disasters, etc. Specifically, NTT Anode Energy will install solar panels on the roofs of customer buildings, and the energy generated by the solar panels will be used by the customer. By installing storage batteries to store excess energy, the customer will also be able to use energy even when electricity cannot be generated. Since the number of solar panels installed depends on the size of a building's roof, it may not be possible to cover the full amount of electricity required by customers. Therefore, NTT Anode Energy will secure against insufficient amount of electricity by supplying electricity from the electric-power company. This backup-power-supply service adopts a mechanism called a power purchase agreement (PPA) model. With the PPA model, a third party installs power-generation equipment, such as solar panels, while the customer signs a contract to purchase the electricity. Therefore, customers do not have to pay the initial cost of installing the power-generation equipment or its maintenance costs. The cost of the power-generation equipment will be collected as part of the cost of the long-term electricity purchased by the customer. From the customer viewpoint, it is possible to build an environment that secures two sources, namely, the energy supply from the electric-power company and the distributed energy system installed in the customer's building. With the distributed energy system acting as a backup, it will therefore be possible to improve power-supply resilience.

However, the issue is the cost of supplying energy via a distributed energy system. This is because if that

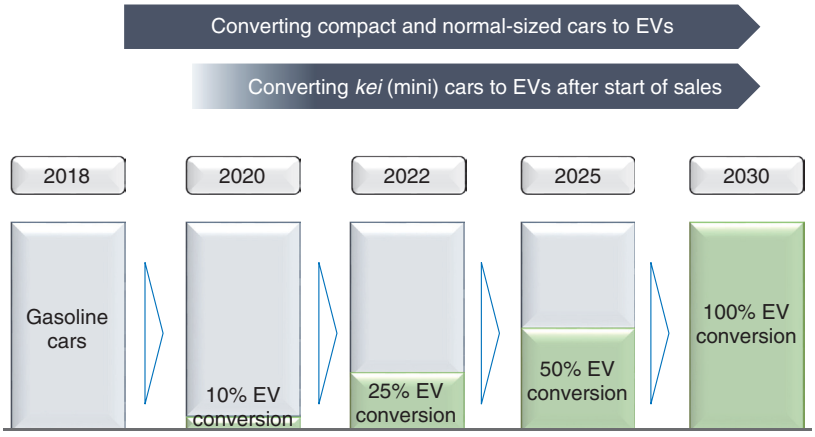


Fig. 4. Plan for converting company-owned cars to EVs.

energy-supply cost is high, customers are likely to continue to use only the energy supplied from the electric-power company as usual. Currently, *grid parity*, namely, the cost of power generation from solar panels is equal to or lower than the cost of energy supply from electric-power companies, has been achieved. However, the power-generation cost of the combination of solar panels and storage batteries has not reached the level of *storage parity*, that is, equal to or lower than the cost of energy supply from electric-power companies. Grid parity was achieved as a result of the expansion of the solar-panel market, which brought about economies of scale due to cheaper, mainly overseas-made, products. As with grid parity, expanding the market is essential for achieving storage parity. Therefore, it is necessary to further reduce the cost of storage batteries and peripheral equipment such as power-conditioning systems (PCSs).

The second approach is to deliver energy to important bases that have lost power due to disasters. Specifically, an electric vehicle (EV) rushes to an important base where a power outage has occurred. Then, by supplying energy from the storage battery installed in the EV, it is possible for customers to use energy in the event of a disaster. However, even if an EV rushes to the important base with the power outage, it cannot directly supply energy to the buildings at that base as is. A PCS is required to supply energy from EVs to these buildings.

With that problem in mind and for the time being, NTT Anode Energy will provide a service that receives the energy supplied from EVs via a portable PCS (carried by the EV) and directly connects customer devices that require power supply to the PCS. In the future, we will install vehicle-to-everything (V2X)-compatible EV stations at important base buildings so that the energy stored in EVs can be directly supplied to those buildings. The popularization of EVs is indispensable to provide backup-power-supply services that use them. Accordingly, the NTT Group has announced a plan to join the EV100 initiative and replace all 10,000 company cars it owns with EVs by 2030 and plans to introduce them at a rate of about 1000 vehicles a year nationwide (**Fig. 4**). NTT Anode Energy will continue establishing EV stations to charge EVs in line with the initiative. By developing EV stations not only for company cars but also for important customer bases, NTT Anode Energy hopes to contribute to the further expansion of EVs.

3. VPPs

With the widespread use of storage batteries and EVs capable of storing electricity, there is a trend in Europe towards building VPPs that connect renewable energy and storage batteries via a network and treating it like a single power plant. With a VPP, the equipment on the power-generation side and that on the demand side can be bundled (aggregated) and remotely controlled in an integrated manner that allows the power supply-and-demand balance to be adjusted. We introduce three initiatives by NTT Anode Energy for building a VPP focusing on demand-side controls.

3.1 Participation in VPP Construction and Demonstration Project

NTT Anode Energy provided business support to the VPP Construction and Demonstration Project, which is a subsidy project of the Agency for Natural Resources and Energy of METI, in which NTT FACILITIES is participating. The demonstration project NTT Anode Energy worked on is aimed at examining the implementation of a VPP and *demand response*[*1] in electricity markets. Specifically, in collaboration with an aggregation coordinator[*2], the NTT Group acted as a resource aggregator[*3] by controlling air-conditioners and storage batteries and suppressing demand on the demand side to provide the amount of electricity (reserve capability (ΔkW)) specified by the directive (from Waseda University). The challenge is to increase the amount of equipment on the demand side that can be controlled remotely, shorten the time from receiving an order to responding to it, and improve the control accuracy of demand-side equipment so that the ordered reserve capability can be appropriately provided. The more equipment that can be controlled, the more it is possible to increase the reserve capability. If response time can be shortened and control accuracy can be improved, reserve capability can be provided as a reserve power source that can respond to supply and demand more efficiently. In 2021, a "balancing market" will be opened as one of the markets for trading electricity. NTT Anode Energy will work to solve the issues it is currently facing through this demonstration project toward the opening of this market.

3.2 Verification of measures to reduce rate of electricity by using NTT buildings

NTT Anode Energy is implementing initiatives to control facilities on the demand side remotely to reduce rates of electricity used in NTT buildings. The company is aiming to reduce electricity charges through the following measures: (i) *peak cutting*, i.e., reducing electricity consumption when electricity is used the most (peak time) and (ii) *energy saving*, i.e., suppressing reducible power consumption. As a concrete approach, a gateway (GW) is installed on the demand side to control equipment and monitor electricity-usage status remotely. Then, if the usage exceeds a threshold, the equipment is controlled in a manner that suppresses electricity usage. The challenge is to reduce the installation cost of the GW and increase the amount of controllable equipment. A limited amount of equipment that can be controlled means that the cost effectiveness of these measures is also limited. Therefore, *peak-shifting* measures, i.e., storing electricity with storage batteries (expected to become more popular) during off-peak demand time and using the stored electricity during peak demand time to increase cost effectiveness will be undertaken. NTT Anode Energy also aims to use energy resources that it can control in the market.

3.3 Efforts to provide *power source I'* reserve capability for severe weather

NTT Anode Energy is making efforts to provide *power source I'*[*4] severe-weather-response reserve capability to general electricity transmission and distribution companies[*5]. These companies need to secure additional adjustable power sources (reserve capability) to balance electricity supply and demand in the rare cases of tight supply and demand (such as during extremely hot or cold weather). From the perspectives of offering fair participation opportunities for providers of many power sources, etc. and ensuring transparency and appropriateness of procurement costs, general electricity transmission and distribution companies procure reserve capability through public bidding. NTT Anode Energy is working on providing power source I' by suppressing demand by using permanent generator facilities owned by the NTT Group when a general electricity transmission and distribution company issues an order. Power source I' is a mechanism that is beneficial for both the electricity transmission and distribution company and the demand side: it is rarely issued and is issued for activation three hours in advance, so the demand side can generate profit by suppressing demand (providing negative power) through adjustment of the operational plan of its facilities.

*1 Demand response: A mechanism of balancing electricity supply and demand as a whole by controlling electricity consumption at the demand side.

*2 Aggregation coordinator: A company that aggregates electricity that is controlled by a resource aggregator and trades that electricity with general electricity transmission and distribution companies and electricity retailers.

*3 Resource aggregator: A company that enters into a VPP service contract with electricity customers and controls the electricity consumption of the customer.

*4 Power source I': Electricity procured by a general electricity transmission and distribution company to adjust the electricity demand and supply during extreme hot and cold weather by complementing *power source I*, i.e., a dedicated power source that is constantly secured.

*5 General electricity transmission and distribution company: A company that provides a wheeling service or electricity quantity adjustment service in its service area by using facilities for the transmission and distribution of electricity that it independently maintains and operates.

In addition to making the above-mentioned efforts to control the facilities on the demand side, NTT Anode Energy also plans to target renewable energy to be used for adjusting energy supply and demand in the future. As well as possessing many central offices and storage batteries throughout Japan, the NTT Group owns the information and communication technology required for supply-and-demand adjustment. NTT Anode Energy intends to build the platform required for VPPs by leveraging the resources and strengths of the NTT Group.

4. Future developments

With the demand for improved regional power-supply resilience, a new energy system is needed to supplement the vulnerabilities of existing energy systems, and a distributed energy system is one of the solutions to meet this need. The backup-power-supply service being developed by NTT Anode Energy adopts a distributed energy system; accordingly, NTT Anode Energy believes that it can contribute to improving regional power-supply resilience through its introduction nationwide. To expand the use of renewable energy, a mechanism for stable renewable-energy supply is necessary and constructing VPPs is one solution to meet that need. Accordingly, NTT Anode Energy will contribute to the expansion of renewable energy by building a VPP platform.

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Future Energy Technologies

Jun Kato and Hidetoshi Takada

Abstract

The NTT Group is promoting measures to address the rapidly changing situation surrounding energy. To contribute to this effort, NTT Network Technology Laboratories (NTT Space Environment and Energy Laboratories at present) has begun research in the area of energy distribution and is moving forward on research and development related to providing electric power services that use renewable energy while maintaining the same quality as commercial power supply. This article provides an overview of this research and development, and describes the NTT Group's efforts to promote future energy business.

Keywords: DC transmission/distribution, virtual energy-distribution platform, IOWN

1. Energy issues of Japan

How best to use limited energy resources in the years to come has become a worldwide issue, and the last few years have seen dramatic changes in the energy situation. Japan is faced with the following three main energy issues:

(1) Response to the international environmental framework (The Paris Agreement, etc.)
(2) Energy security (reduce energy dependency on overseas sources)
(3) National resilience in energy (construct an infrastructure robust against disasters)

A breakdown of Japan's primary energy supply is shown in **Fig. 1** [1]. Among the various forms of energy used, *primary energy* refers to energy that is directly obtained from nature, such as coal, oil, liquefied natural gas (LNG), hydroelectric power, nuclear power, wind power, geothermal power, and solar energy. In Japan, dependency on fossil fuels has been increasing due to a reduction in nuclear power generation since the Great East Japan Earthquake of 2011, and today, approximately 90% of Japan's primary energy supply is made up of coal, oil, and LNG. The use of fossil fuels increases carbon dioxide (CO_2) emissions, which makes it difficult to work within the international environmental framework in issue (1) above.

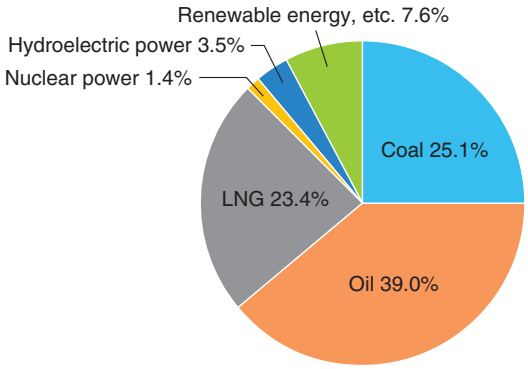
The primary energy self-sufficiency ratios for major nations are shown in **Fig. 2**. The energy self-sufficiency ratio of resource-poor Japan is less than 10%, despite using a large amount of energy. It can therefore be inferred that securing primary energy sources in the event of an international emergency or future depletion of natural resources would be difficult, resulting in insufficient motive and electric power. There is also a need to prevent power losses, e.g., a blackout[*1], during a disaster and long-term power outage such as those that occurred in Hokkaido and Chiba prefectures in 2019.

To address these issues, it will be necessary to increase the ratio of renewable energy to the total amount of power used in Japan and to both reduce CO_2 emissions and increase the country's energy self-sufficiency ratio.

2. Energy business in the NTT Group and related research and development

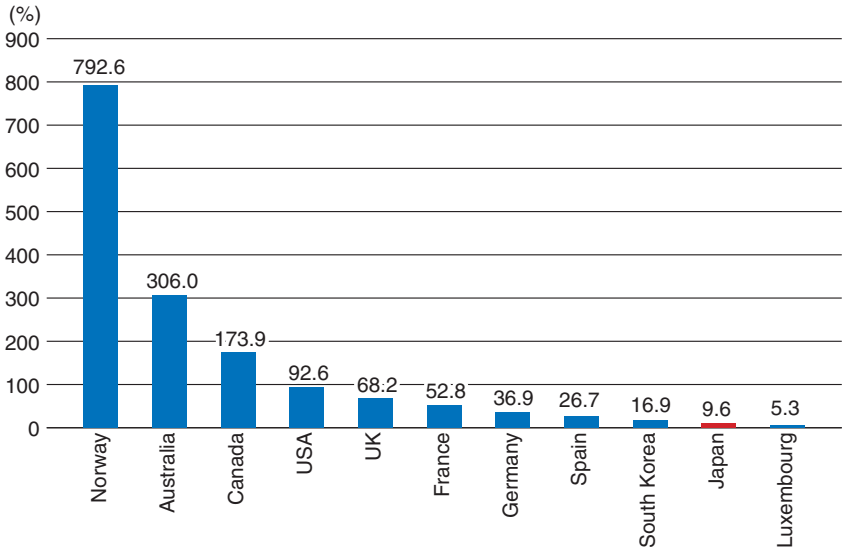
Consuming approximately 1% of Japan's power, the NTT Group bears much responsibility in the use of energy. To help address social issues related to the environment and energy, NTT established NTT Anode Energy in June 2019 as a company overseeing energy-related business in the NTT Group. This company aims to develop *smart energy* businesses [2] that will

*1 Blackout: A state in which power plants or power lines are heavily damaged during a disaster, such as an earthquake or tsunami, resulting in a sudden loss in power.



Source: "Japan's Energy 2018," Agency for Natural Resources and Energy

Fig. 1. Breakdown of Japan's primary energy supply (FY2017).



Source: "Japan's Energy 2018," Agency for Natural Resources and Energy

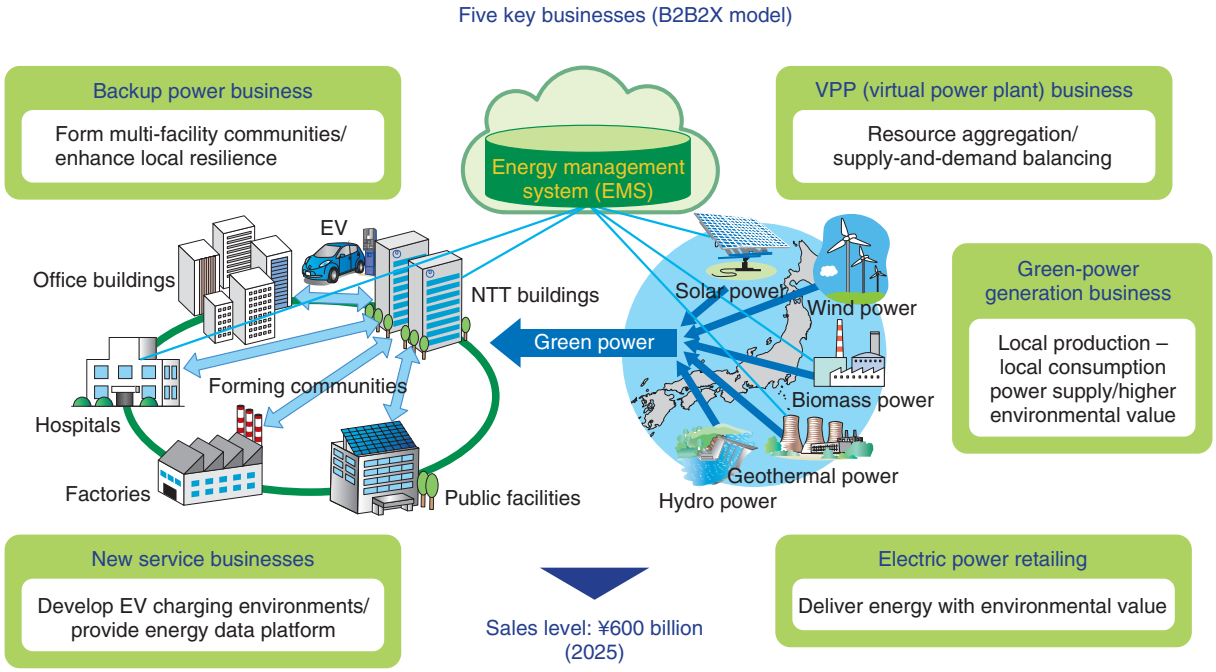
Fig. 2. Primary energy self-sufficiency ratios for major nations (FY2017).

combine expertise in existing NTT Group telephone exchanges, infrastructure facilities, direct-current (DC) transmission/distribution, storage batteries, etc. with an information and communication technology (ICT) platform. The business lineup of NTT Anode Energy is shown in **Fig. 3**. The NTT Group plans to enter the energy business on a broad scale including green-power generation, backup-power supply, and electricity retailing to sell energy and provide energy services to other companies in addition to promoting energy measures within the Group. It also plans to actively invest in distributed energy platforms related to renewable energy (such as solar power and wind power), storage batteries, and electric vehicles (EVs).

We next introduce research and development (R&D) in the energy field at NTT Network Technology Laboratories (NTT Space Environment and Energy Laboratories at present).

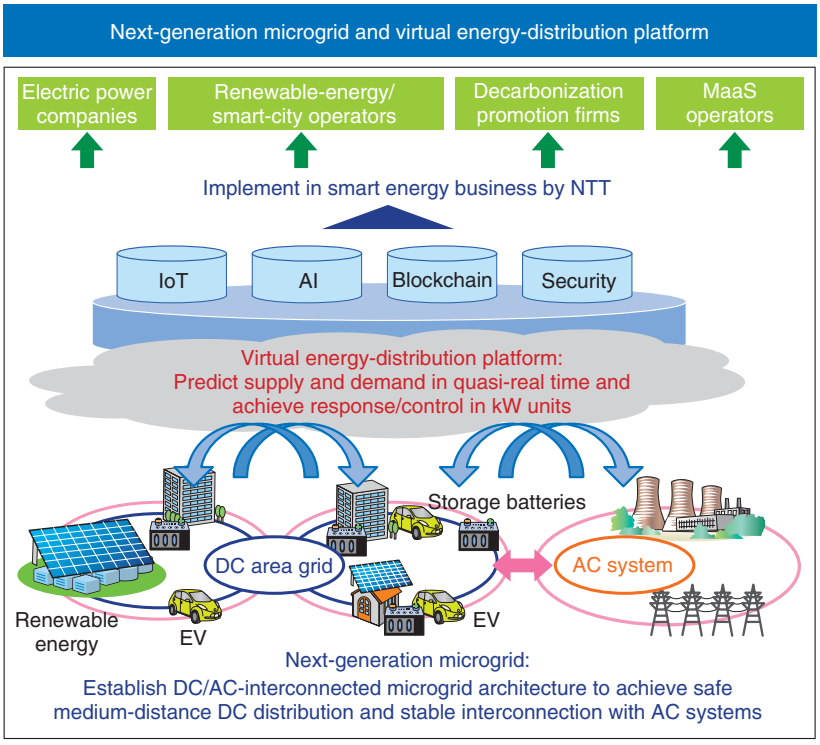
3. NTT energy research

An overview of NTT's research in the energy field is shown in **Fig. 4**. Our research policy is to contribute to addressing Japan's energy issues and expanding



B2B2X: business to business to X

Fig. 3. Business lineup of NTT Anode Energy.



AC: alternating current
AI: artificial intelligence
IoT: Internet of Things
MaaS: mobility as a service

Fig. 4. Overview of NTT's energy research.

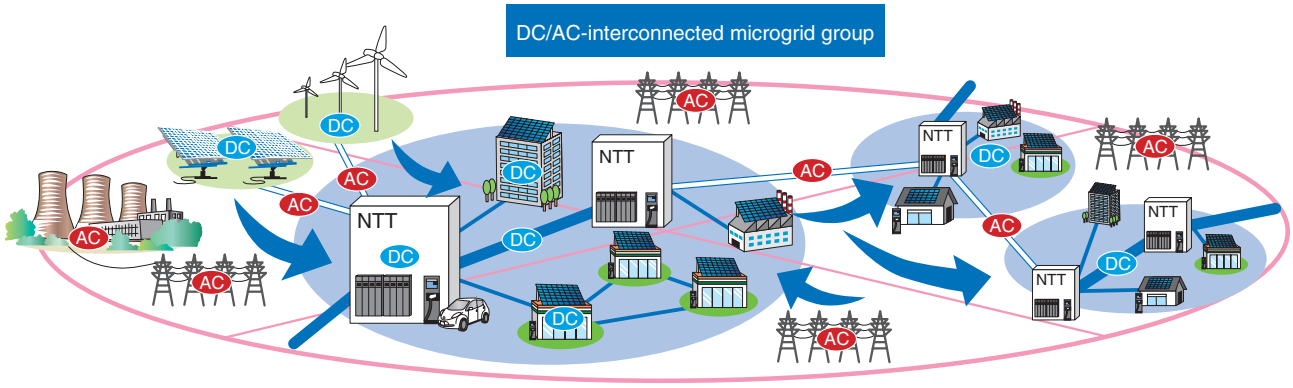


Fig. 5. Next-generation microgrid.

NTT Group's energy business. Therefore, we aim to make maximum use of DC technologies and micro energy to construct sustainable communication networks and lifelines robust against long-term power outages caused by natural disasters and other factors.

Specifically, we are researching and developing *next-generation microgrid technology* to make the best use of renewable energy without waste and achieve regional energy interchange and resilience, *virtual energy-distribution platform technology*, which features a virtual power generation function of several hundred megawatts that can monitor, measure, and control several hundreds of thousands of power resources scattered throughout Japan and respond within several seconds (a feature that other operators have been unable to achieve), and *micro energy utilization technology*, which enables communications unrestricted by place, condition, etc.

3.1 Next-generation microgrid technology

A next-generation microgrid[*2] refers to a low-cost and simple regional microgrid that introduces DC technology in a stepwise and safe manner to promote energy self-sufficiency in the region and support municipal and corporate business continuity planning. The concept of the next-generation microgrid is shown in **Fig. 5**. This grid uses assets such as storage batteries in NTT's telecom buildings, and the power is interchanged among consumers within the grid. The objective is to construct a DC/alternating current (AC)-interconnected microgrid that has the advantages of both commercial power and DC power output from renewable energy sources and storage batteries within the grid and that can interchange both types of power. To this end, we will first need to research and develop a DC transmission/distribution system architecture and means of ensuring the electrical safety of this system, both of which are important elements of a DC/AC-interconnected microgrid.

(1) DC/AC-interconnected microgrid architecture

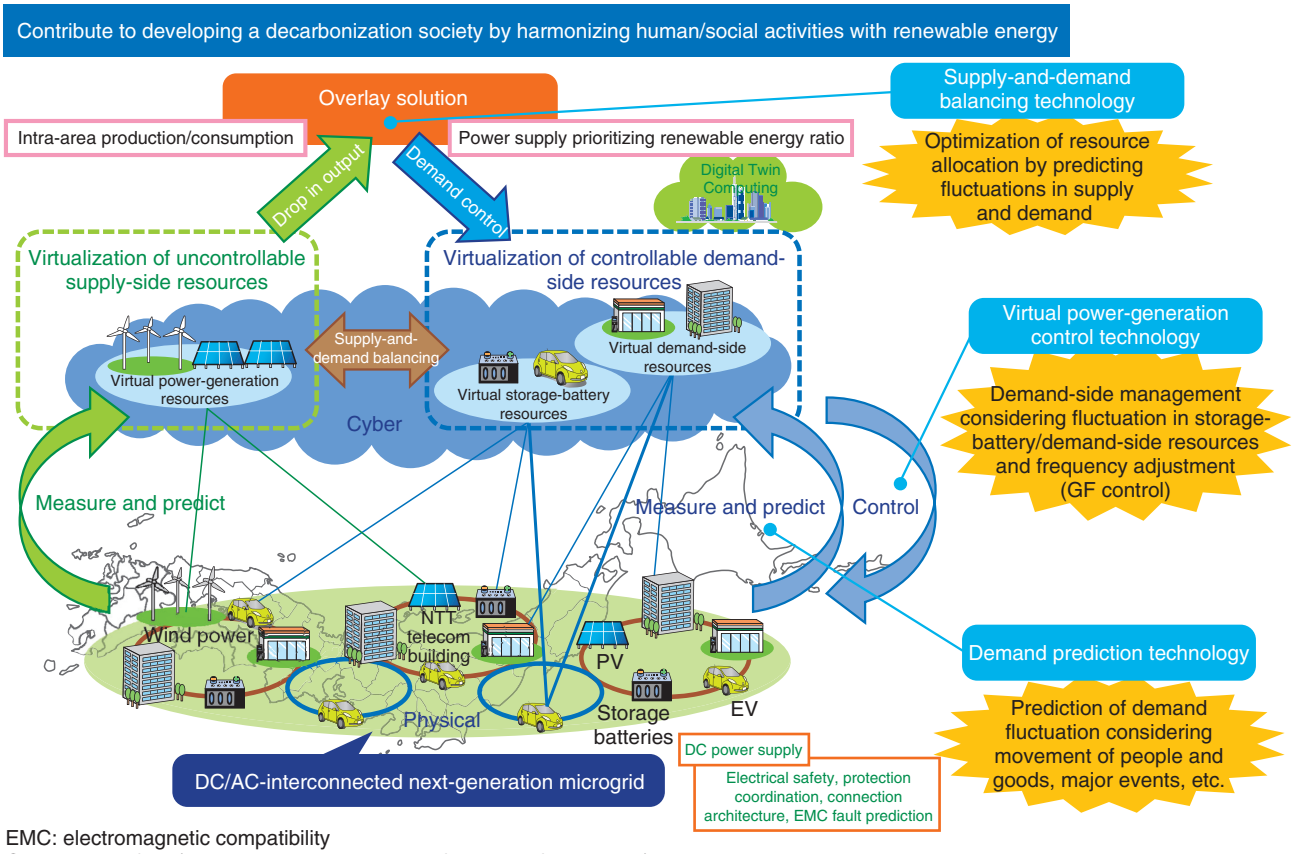
To investigate a DC/AC-interconnected microgrid architecture, we are researching technologies for interchanging power between suppliers and consumers in an area. These include load-sharing and power-interchanging control technologies that take into account the characteristics of DC distribution cables, storage batteries, power conditioners, power-conversion equipment, etc., as well as the response speed and demand-fluctuation characteristics of such constituent elements. Furthermore, to establish a microgrid architecture that can provide necessary and sufficient stability while taking into account innovative information-communication network architecture of the future and changing reliability in commercial power supplies due to recent climate change, we will study methods of optimizing the balance between reliability and total cost of ownership (TCO)[*3].

(2) Electrical safety technologies for DC transmission/distribution

A DC transmission/distribution system for outdoor delivery of power is highly susceptible to surge current/voltage caused by lightning and must therefore

*2 Microgrid: A small-scale energy network having energy-supply sources and consumption facilities with practically no dependence on transmitted power from existing large-scale power plants.

*3 TCO: Total expenditure from acquiring equipment, software, and systems to their end of use and disposal.



EMC: electromagnetic compatibility
GF: governor-free (operations that responds to frequency fluctuations)
PV: Photovoltaic (solar power generation)

Fig. 6. Virtual energy-distribution platform.

incorporate appropriate countermeasures. The occurrence of electrical leakage due to aging of the DC transmission/distribution system or unforeseen faults must also be considered. We will therefore construct test systems in actual buildings to collect data with the aim of establishing technologies for countering direct lightning strikes and lightning-induced surges and for detecting faults for the target network topology as electrical safety technologies for DC-transmission/distribution.

3.2 Virtual energy-distribution platform technology

A virtual energy-distribution platform is an energy platform for linking and controlling physical energy resources across Japan and virtual-power-generation and demand-side resources to contribute to the creation of a decarbonized society by harmonizing human/social activities with renewable energy. It is a platform for accepting supplies of renewable energy while maintaining the quality of electricity supply equivalent to that via the transmission and distribution networks of major electric power companies. The concept of a virtual energy-distribution platform is shown in **Fig. 6**. Since the amount of power generated by renewable energy changes rapidly according to weather conditions and other factors, the aim is to maintain the quality of electricity supply through large-scale, fast-responding virtual power plant (VPP)[*4] control technology that performs optimal control of storage-battery and demand-side resources within the platform. We are also working on high-accuracy demand-prediction technology for predicting demand volume by taking into account the movement of people and goods, major events, etc.

*4 VPP: A means of providing functions equivalent to those of a power generation plant by having the owners of demand-side energy resources, power-generating facilities, and storage-battery facilities directly connected to the power system, or a third party control those energy resources.

(1) Large-scale, fast-responding VPP control technology

We aim to establish technology for carrying out optimal and immediate allotment and control of power resources by modeling the input/output characteristics of the energy creation/storage equipment group such as instantaneously changing renewable energy, storage batteries, etc. and by modeling the input/output characteristics of the power-demand group such as network equipment. We will also investigate technology for configuring a VPP on a scale of several hundred megawatts with a fast response performance and electricity quality control by integrating power resources via a nationwide ultra-high-speed network.

(2) Integrated energy supply-and-demand balancing technology

We aim to establish large-scale peer-to-peer energy trading technology supporting several hundreds of thousands of supply-and-demand devices. This technology will enable request-level optimization and supply-and-demand matching based on power supplies with diverse characteristics and multiple customer policies while comparing diverse types of request timing and composite request values with procurable electricity.

(3) Quasi-real-time supply-and-demand prediction technology

In addition to enhancing the accuracy of existing solar/wind power-generation prediction based on weather information and that of demand prediction for each service area, we aim to establish technology for making quasi-real-time predictions of local supply-and-demand fluctuations affected by the flow of people and goods (data possessed by the NTT Group), community events, and EV usage.

3.3 Micro-energy utilization technology

We are investigating systems for extracting and storing micro amounts of energy in the peripheral environment (light, pressure, etc.) and using that energy after a certain amount accumulates (analogous to a Japanese *shishi-odoshi* water fountain in which a hallow bamboo branch on a pivot slowly fills with water until the amount of water is enough to tip the branch and dump out the water). As a means of addressing environment and energy issues, we are working on artificial photosynthesis technology for generating useful substances from sunlight by mimicking photosynthesis in plants. To establish such technologies, we are looking to use semiconductor growth technologies and catalyst technologies that have supported the information-communications field.

(1) Optical-energy high-efficiency utilization technology

To improve the resilience of the All-Photonics Network, we are investigating technology for using micro optical energy as efficiently as possible in a safe manner. Specifically, we are researching basic technology for separating the optical energy transmitted along with communications data, converting it to other forms of energy, and using it efficiently by taking into account usage conditions during a power outage.

(2) Micro-energy creation and storage technology

We will conduct basic research on micro-energy creation that extracts the micro energy all around us in the form of vibrations, heat, static electricity, etc. and increases its density. We will also research micro-energy storage for using such micro-energy-creation technology and wearable technology. We will research and develop energy-storage/discharge technologies that use accessories such as clothes, belts, eyeglasses, and terminals.

3.4 IOWN

In the R&D projects described above, a high-speed, low-latency, and high-functional network is essential to controlling and operating energy resources. NTT has proposed the Innovative Optical and Wireless Network (IOWN) [3] and is currently working toward its implementation. IOWN consists of three main components: the All-Photonics Network that introduces optical processing not only for the network but also terminals; Digital Twin Computing that enables sophisticated and real-time interaction between things and people in cyberspace; and Cognitive Foundation® that efficiently deploys a variety of ICT resources.

To maintain quality of electricity under large-scale, fast-responding VPP control, high-speed and low-latency communications is necessary to determine and control the state of energy resources in real time. There is also a need for an operation system with dramatically higher functionality than current systems to control from several million to several tens of millions of energy resources. In our energy research, we plan to study energy-system requirements and implement them in a new network as an important use case of IOWN.

4. Future developments

Going forward, we will promote R&D that can contribute to the growth of NTT's energy business in collaboration with NTT Group companies.

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International Standards on Communication Technology for Immersive Live Experience Adopted by ITU-T

Jiro Nagao

Abstract

International standards on immersive live experience (ILE) have been adopted by the International Telecommunication Union - Telecommunication Standardization Sector in November 2019. ILE captures an event and transports it to remote viewing sites in real time and reproduces it with high realism. It is expected that the series of standards on ILE will facilitate the creation of a world where people can enjoy highly realistic reproduction of events in real time wherever they are. This article is an introduction to such ILE standards.

Keywords: immersive live experience, live public screening, highly realistic real-time reproduction

1. Immersive live experience

Public live screening, where popular events such as music concerts and sports games are relayed to movie theaters and large screens outside the actual event sites and people at remote locations can enjoy the events at the same time as the actual events, has become increasingly popular. The advantage of public live screening is that those who cannot go to the actual events for various reasons, such as they live far from the actual event sites, can enjoy the event at more convenient places and share their emotions and experiences with each other.

Public live screening, however, has the drawback of being less realistic than the actual event. Therefore, technologies to enable more realistic public live screening is needed. Such technologies may enable images of artists in an actual event site to be shown at viewing sites with high realism, as if they were performing in front of the remote audience, sounds to come from the actual objects on the screen, or the atmosphere, i.e., the vibration or heat from the actual event site, to be reproduced. If such technologies are feasible, public live screening with much higher realism can be achieved. The feeling as if one is at the actual event site from images (videos) and sounds is called *immersive experience*, and there have been studies on achieving such an experience. When immersive experience is achieved in real time, it is called *immersive live experience (ILE)*. ILE enables real-time experience of remote events with highly realistic sensations anywhere in the world. It is especially advantageous in cases such as sports matches in which simultaneity is an important factor of entertainment.

ILE requires technologies to capture various conditions (environment information) of the event in detail, transport them along with video and audio to viewing sites at remote locations, and reproduce them in real time. The information to be captured includes three-dimensional (3D) positions of persons and objects, positions of sound sources, and lighting-control signals. Reduction in the conversion time of formats between different systems and interconnectivity of content transport to remote locations are necessary for real-time reproduction. Therefore, international

Table 1. ITU-T standards on ILE.

Number	Title	Adopted
H.430.1	Requirements for immersive live experience (ILE) services	Aug. 2018
H.430.2	Architectural framework for immersive live experience (ILE) services	Aug. 2018
H.430.3	Service scenario of immersive live experience (ILE)	Aug. 2018
H.430.4	Service configuration, media transport protocols, signalling information of MPEG media transport for immersive live experience (ILE) systems	Nov. 2019

Table 2. Requirements of ILE.

No.	Requirements	Required/Recommended/ Optional
1	Life-size display	Recommended
2	Direction of sound	Required
3	Atmosphere reconstruction	Recommended
4	Spatial reconstruction	Required
5	Synchronous representation	Required
6	Augmented information	Optional
7	Real-time object extraction	Required
8	Spatial object information	Recommended
9	Synchronous transmission	Required
10	Data storage	Optional
11	Reconstruction processing	Required
12	Auditory lateralization	Recommended
13	Video stitching	Optional

standards to ensure global interconnectivity are needed. However, there have not been standards specialized in transporting environment information in real time along with video and audio and reproducing an event at viewing sites with high realism.

2. International standards on ILE

The International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) Study Group (SG) 16[*1] launched Question 8 "Immersive live experience systems and services" in 2016 to address the issues regarding the implementation of ILE that provides highly realistic sensations to many audiences anywhere in the world in real time by internationally connecting the systems at actual event sites (source sites) and remote viewing sites. The ITU-T Recommendation H.430 series has been adopted as the result of the activities of this Question [1–4]. **Table 1** shows the ITU-T standards on ILE.

2.1 H.430.1

Standard H.430.1 defines ILE and identifies its requirements. **Table 2** shows these requirements, which include life-size display of images and auditory lateralization[*2] for highly realistic reproduction of events, real-time extraction to reproduce images of people at the viewing sites, and real-time synchronized transport of environment information along with video and audio.

2.2 H.430.2

Standard H.430.2 identifies the high-level functional architecture and the general model of ILE. It also introduces candidate technologies for ILE functions. **Figure 1** shows the high-level functional

*1 ITU-T SG16: The ITU is the United Nations specialized agency in the field of telecommunications, information and communication technologies. The ITU-T is responsible for issuing Recommendations on this field. SG16 leads ITU's standardization work on multimedia coding, systems, and applications.

*2 Auditory lateralization: To reproduce or the methods of reproducing direction of sound using multiple loud speakers.

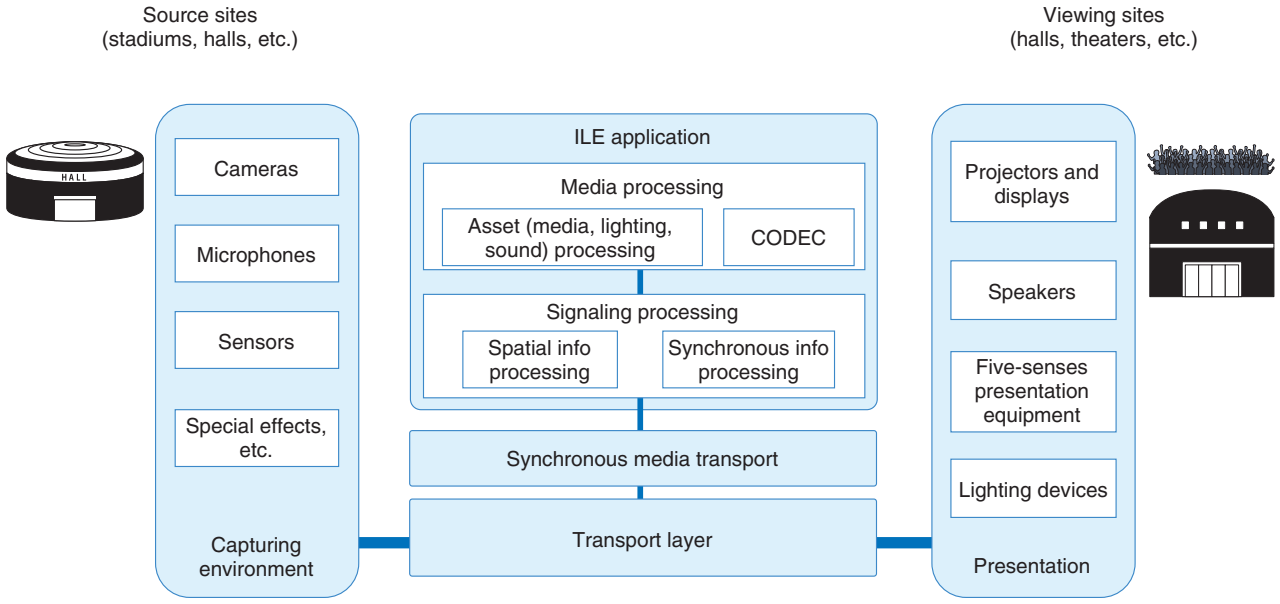

Fig. 1. High-level architecture of ILE system.

architecture of ILE. The architecture consists of the following functionalities.

(1) Capturing environment

Environment information, such as the video, audio, positions of people, and lighting-control signals at the source site, is captured with cameras, microphones, sensors, etc.

(2) Synchronous media transport

Synchronous media transport is a function that transports multiple media synchronously.

(3) Transport layer

Media data at the source site are transported to the remote sites with considerations on content protection and network delay.

(4) ILE application

Asset processing performs, for example, extraction of images of people from video and integration of videos to achieve a higher sense of realism. CODEC encodes and decodes media content. Spatial information processing integrates, for example, the 3D position information obtained from camera images and positional sensors. Synchronous information processing synchronizes content, such as video, audio, lighting control, and sensor information, for reproduction with the presentation functionality.

(5) Presentation

The presentation functionality displays video, lateralizes audio, reproduces lighting, etc. at the viewing sites. Synchronized presentation of such media provides highly realistic sensations to the audience.

2.3 H.430.3

Standard H.430.3 categorizes ILE service scenarios with use case examples, providing clear ideas of novel experiences enabled by ILE services. Some of the examples are as follows:

(1) Live broadcast service of first-person synchronous view

The first-person view of an athlete in a fast-moving vehicle such as a racing car or bobsled is transported and reproduced at viewing sites in real time. Additional information, such as speed, acceleration, current ranking, and remaining distance, can be presented to enhance the excitement of the competition.

(2) On-stage holographic performance service

A live concert performance is captured with ultra-high definition cameras and high-quality microphones. The captured data are processed and transported to the viewing sites then used to reproduce the event in 3D or pseudo-3D images with high-quality audio and special effects, providing the audience with highly realistic sensations.

(3) Multi-angle viewing service

The images of artists or athletes are captured with cameras from multiple directions and transported to remote viewing sites in real time along with high-quality audio and environment information such as the 3D positions of the artists or players. The data are

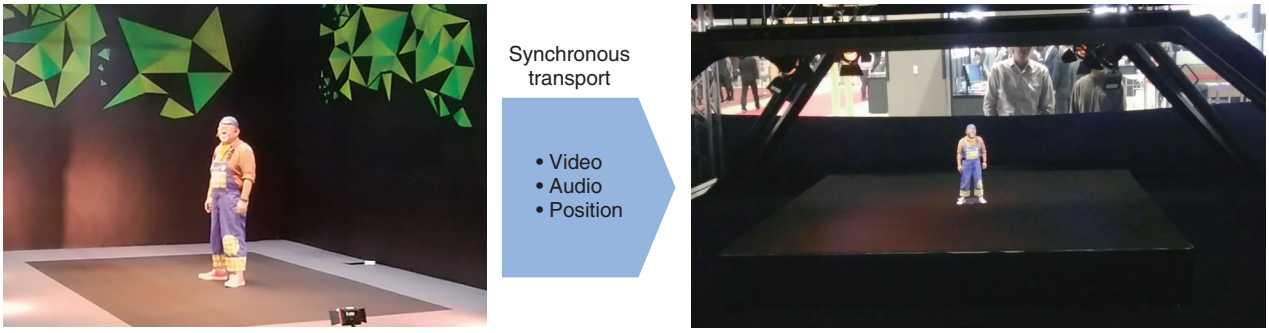

Fig. 2. A prototype system for the multi-angle viewing service.

reproduced at the viewing sites on special display devices with multiple displays to show views from all directions. The 3D position information is used to add a stronger sense of depth to the displayed images. Auditory lateralization can be provided with multiple loud speakers. A prototype system built for this purpose is shown in **Fig. 2**. The display device can show not only the view from front but also views from sides and behind, providing the impression as if moving around the actual event site.

2.4 H.430.4

Standard H.430.4 identifies the MPEG Media Transport (MMT[*3]) profile for ILE to provide synchronous transport of spatial information, such as the 3D position of objects, along with video and audio for reproduction of events with high realism.

The spatial information includes the following:

- Size (width, height, depth) of the source site
- Equipment information (equipment type, model, location, direction, size) of the source site
- 3D positions, positions in video, and bounding rectangles of the performers on stage

Spatial information enables the reconstruction of 3D positions of the performers at the viewing sites while adapting to the difference between the size and location of equipment at the source and viewing sites.

3. Future prospect

Further development of Recommendations, including reference models and implementation guidelines of the presentation environment, and incorporating related technologies such as virtual reality are planned by ITU-T in collaboration with other standards developing organizations.

References

[1] H.430.1: Requirements for immersive live experience (ILE) services, https://www.itu.int/rec/T-REC-H.430.1/en
[2] H.430.2: Architectural framework for immersive live experience (ILE) services, https://www.itu.int/rec/T-REC-H.430.2/en
[3] H.430.3: Service scenario of immersive live experience (ILE), https://www.itu.int/rec/T-REC-H.430.3/en
[4] H.430.4: Service configuration, media transport protocols, signalling information of MPEG media transport for immersive live experience (ILE) systems, https://www.itu.int/rec/T-REC-H.430.4/en

*3 MMT: A standard for media transport developed by the international standards developing organization ISO/IEC JTC 1/SC 29/WG 11 (International Organization for Standardization/International Electrotechnical Commission Joint Technical Committee 1/Subcommittee 29/Working Group 11), also known as MPEG (Moving Picture Experts Group).

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External Awards

2019 IEEE MTT-S Japan Young Engineer Award

Winner: Teruo Jyo, NTT Device Technology Laboratories
Date: November 28, 2019
Organization: IEEE Microwave Theory and Techniques Society (MTT-S) Japan Chapter

For "Fast and Accurate THz Permittivity Measurement Using a Self-heterodyne Technique and Multitone Signal with Nonuniform Intervals" and "An Accurate Permittivity Measurement Using Interferometric Phase Noise Averaging for Terahertz Imaging."

Published as: T. Jyo, H. Hamada, D. Kitayama, M. Yaita, A. E. Moutaouakil, H. Matsuzaki, and H. Nosaka, "Fast and Accurate THz Permittivity Measurement Using a Self-heterodyne Technique and Multitone Signal with Nonuniform Intervals," IEEE Trans. Microw. Theory Tech., Vol. 66, No. 10, pp. 4649–4657, 2018.
T. Jyo, H. Hamada, D. Kitayama, M. Yaita, and H. Nosaka, "An Accurate Permittivity Measurement Using Interferometric Phase Noise Averaging for Terahertz Imaging," IEEE Trans. Terahertz Sci. Technol., Vol. 8, No. 3, pp. 278–286, 2018.

Papers Published in Technical Journals and Conference Proceedings

The Dominant Limb Preferentially Stabilizes Posture in a Bimanual Task with Physical Coupling

A. Takagi, S. Maxwell, A. Melendez-Calderon, and E. Burdet
Journal of Neurophysiology, Vol. 123, No. 6, pp. 2154–2160, June 2020.

Humans are endowed with the ability to skillfully handle objects, like when holding a jar with the nondominant hand while opening the lid with the dominant hand. Dynamic dominance, a prevailing theory in handedness research, proposes that the nondominant hand is specialized for postural stability, which would explain why right-handed people hold the jar steady using the left hand. However, the underlying specialization of the nondominant hand has only been tested unimanually or in a bimanual task where the two hands had different functions. Using a dedicated dual-wrist robotic interface, we tested the dynamic dominance hypothesis in a bimanual task where both hands carry out the same function. We examined how left- and right-handed subjects held onto a vibrating virtual object using their wrists, which were physically coupled by the object. Muscular activity of the wrist flexors and extensors revealed a preference for cocontracting the dominant hand during both holding and transporting the object, which suggests proficiency in the dominant hand for stabilization, contradicting the dynamic dominance hypothesis. While the reliance on the dominant hand was partially explained by its greater strength, the Edinburgh inventory was a better predictor of the difference in the cocontraction between the dominant and nondominant hands. When provided with redundancy to stabilize the task, the dominant hand preferentially cocontracts to absorb perturbing forces.