NTT DOCOMO

Technical Journal

Vol.21 No.4 | Apr. 2020

NTT docomo

Device Development for the 5G Era and Beyond

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The excitement generated by the rugby international tournament held throughout Japan in the fall of 2019 no doubt created a lasting impression in many people. It was exactly on the opening day of this international tournament that NTT DOCOMO launched its 5G pre-commercial service.

While it can be said that the 5G era has already begun, I would like to introduce two key points of device development at NTT DOCOMO with a view that extends even beyond 5G. These are "edge AI" and "xR*1 devices."

Let's begin with edge AI. Here, the word "edge" refers to devices rather than the "edge" of a network as in Multi-access Edge Computing (MEC)*2. Why then is edge AI becoming so important? I would like to touch upon this here. A major social issue enveloping Japan at this time is the declining birthrate and aging population. It is said that Japan's working population will fall by about 6.44 million workers by 2030. This shrinking of the working population is making it all the more important to automate various types of manual work through a process called Digital transformation (DX)*3. Here, an indispensable technology for promoting DX will be AI. This is because work performed by human hands can be reduced by accumulating various types of on-site information on the cloud, analyzing that information and predicting optimal behavior by AI, and feeding back the results of that analysis to the work site. However, problems remain with collecting data on the cloud. In addition to privacy issues, these include latency and unstable communications. In the face of these problems, edge AI has been attracting much attention. One example of a field in which edge AI could be applied is video analysis by surveillance cameras. Video captured by a surveillance camera includes various type of personal information that should be kept private. However, if AI could analyze this personal information on a surveillance-camera device (edge) without sending that information to the cloud, such privacy issues could be resolved. In this way, there are cases applicable to processing on the edge side and cases applicable to processing on the cloud side. Looking forward, I would like NTT DOCOMO to develop technical expertise in finding optimal allocations of AI processing on the cloud side and edge side in accordance with on-site needs with the ultimate aim of solving problems.

Turning now to xR devices, we can look back at the evolution of devices up to now and see that progress has been made not only in increasing transmission speeds as communication methods evolved but also in increasing the size and resolution of display screens. A device screen can be thought of as a window that allows people in the real world to take a peek inside all sorts of cyber worlds. It stands to reason as a basic human desire that people would like to have a broader view of these cyber worlds and take a peak into cyber worlds of higher quality, so I think this is why screens have become progressively larger with higher resolution. However, regardless of basic human desire, there are limitations as to how large a device that people always carry around with them can be. It can probably be said that current smartphones are already bumping up against this portability wall. On thoroughly examining how to go about overcoming this portability wall, we might come to the conclusion that a better idea than one of peeking into a cyber world from a device screen would be to leap over the screen and immerse oneself in that cyber world. How could this be done? Well, focusing on the five senses through which humans obtain various types of information, it is said that approximately 95% of that information is obtained through the sense of sight and the sense of hearing. In other words, if we can control these two key senses, we should be able to greatly enhance this sense of immersion in a cyber world. With this in mind, it would seem that glass-type devices would be the inevitable form of post smartphones. For this reason, I would like to aggressively ramp up our efforts in the development of technologies related to xR devices.

Going forward, NTT DOCOMO will continue to focus its efforts on providing real-world devices that inspire and move its customers.

*1 xR: A generic term for VR, AR, MR, etc.

*2 MEC: A system that installs servers at locations near users. Standard servers are typically placed on the Internet, but MEC servers are installed within the carrier network to reduce latency. This scheme greatly improves response speeds.

*3 DX: The changes that the digital technology causes or influences in all aspects of human life.

NTT DOCOMO
Technical Journal
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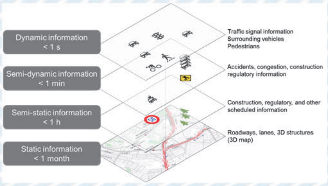

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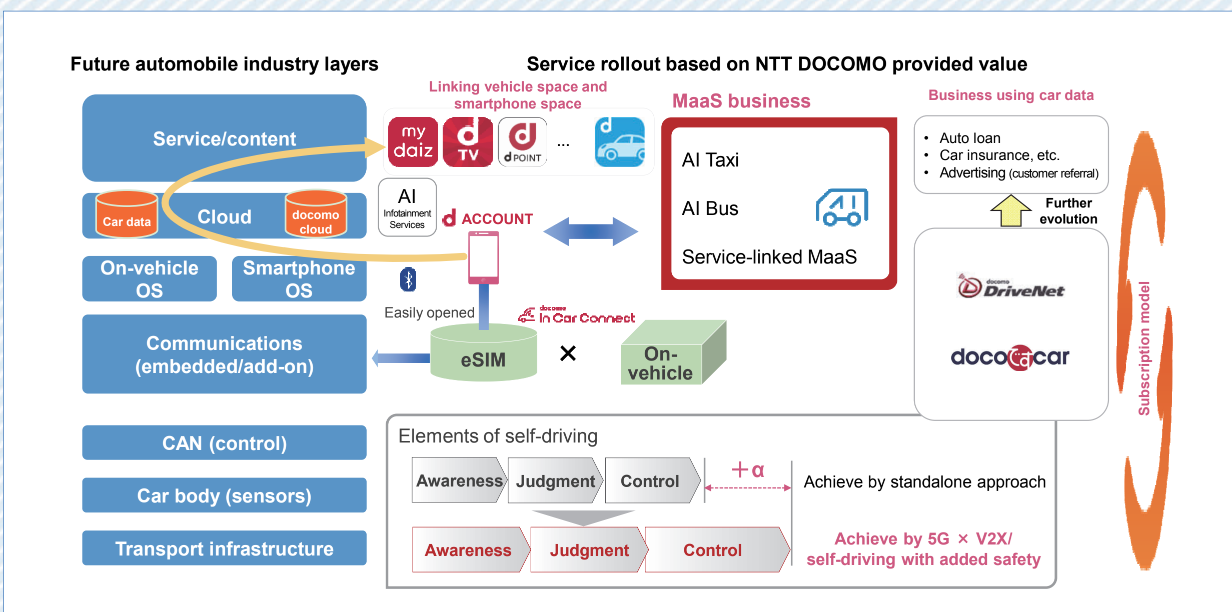

NTT DOCOMO initiatives toward early deployment of 5G services

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Special Articles on Next-generation Mobility Services

Toward Safer and More Comfortable Mobility Services for Anyone, at Anytime and Anyplace —Next-generation Mobility Services at NTT DOCOMO—

Connected Car Business Office Hidekazu Fukai

The automobile industry is undergoing a once-in-a-hundred-years transformation owing to new areas of development known as CASE (connected, autonomous, shared, electric). These areas are driving efforts toward the creation of new businesses by a wide variety of players. Against this background, NTT DOCOMO is committed to "continuous provision of safer and more comfortable mobility services for anyone, at anytime and anyplace" as a vision for the future and to enhancing added value in user mobility.

1. Introduction

The automobile industry is undergoing a once-in-a-hundred-years transformation commonly referred to as "connected, autonomous, shared, and electric" (CASE*1). Here, "autonomous" and "electric cars" can help solve social problems such as the shrinking of the working population and environmental damage, and in the area of "shared" cars, Mobility as a Service (MaaS)*2 that defines the concept of next-generation mobility can help solve mobility problems such as traffic congestion and CO_2 emissions. Interest is also growing in creating new means of mobility such as AI Bus*3 and developing completely new business areas.

In addition, CASE assumes that cars will be "connected." In other words, all cars will be equipped with a communications function with the aim of exchanging various types of data and making movement more efficient while maintaining a continuous connection with the Internet.

In this regard, 5G is a technology that can be

*1 CASE: An acronym coined from the words "connected, autonomous, shared, and electric" corresponding to major trends in the automobile industry.

*2 MaaS: A new concept of "mobility" in which all means of transport are seamlessly connected and treated as a single service.

used in wide range of self-driving use cases thanks to features such as high-speed and large-capacity communications, low latency, and massive device connectivity. There is consequently growing interest in 5G not only from the automobile industry but also from a variety of players that wish to enter the connected car area.

In this article, amidst a greatly changing concept of mobility, we describe NTT DOCOMO's efforts in rolling out next-generation mobility services.

2. Connected Car Services

Beginning with a car phone service in 1979, NTT DOCOMO has grown together with the automobile industry through its development of a telematics*4 module, creation of a global connectivity management platform, and provision of a variety of services including a vehicle movement management system and car navigation application. Now, with the coming of the CASE era, it intends to provide connectivity solutions to support the foundation of the mobility revolution and to bring the worldview of the smartphone—one of its major fields—to the automobile as only NTT DOCOMO can do.

For example, NTT DOCOMO is studying an "on-vehicle embedded Subscriber Identity Module (eSIM)*5 for consumer devices" as one means of achieving a new mobility experience that seamlessly connects smartphone and car. This on-vehicle eSIM for consumer devices will make it possible to remotely write a profile (subscriber information) to on-vehicle devices supporting an eSIM for consumer devices from the user's own smartphone. Additionally, by linking the smartphone's contract and profile, it can bring the worldview of the smartphone that user's are already familiar with to the automobile as in in-vehicle voice communications, mobile data communications, and content services.

3. MaaS at NTT DOCOMO for Optimal Transportation

Countries around the world are actively promoting MaaS initiatives that propose optimal movement tailored to regional characteristics. At NTT DOCOMO, we are focusing our efforts on making user movement more convenient and solving social problems and on achieving an on-demand system based on the use of Artificial Intelligence (AI) in taxi and bus services.

"AI Taxi" uses past ridership data and statistical location data of people to predict taxi demand up to 30 minutes ahead and provide that information to taxi drivers. In this way, taxi drivers can get a feel for ride demand that changes in real time and thereby improve productivity through efficient operation. AI Taxi is also expected to shorten wait times for riders.

NTT DOCOMO has also developed "AI Bus" on-demand transportation targeting areas lacking a built-up public transport network. The idea here is to achieve a new means of transportation that can make the operation of transport companies more efficient while also making transportation more convenient for users. AI Bus will make it possible to provide high-quality movement tailored to the needs of users.

In the above, we have described two transport

*3 AI Bus: AI Bus and its logo are trademarks or registered trademarks of NTT DOCOMO, INC.

*4 Telematics: Refers to "information provision services for automobiles" consisting of the transmission of various types of information from an information provider to the driver and the transmission of operation and driving information from the car. "Telematics" is a coined word combining "telecommunications" and "informatics."

*5 eSIM: An embedded SIM that enables the remote writing of telecom carrier information.

systems as MaaS initiatives that have already been put into use. Looking forward, we aim to create new "movement × services" businesses that link peripheral services such as retail shopping and medical care with transportation. Here, instead of the conventional approach of simply collecting the price of movement as fare, a new model might be to pay transport companies a fee for referring customers to such commercial establishments as revenue sharing*6.

4. docomo Smart Parking System

Recent years have seen initiatives in a variety of industries on using ICT to optimize existing social systems. As part of this trend, NTT DOCOMO has taken up the challenge of open innovation with the pay parking industry in the form of a "docomo Smart Parking system™*7" project.

With this system, a driver in need of a place to park can use a dedicated smartphone app to reserve and use an empty parking space in a parking lot. In this way, the inconvenience of having to look around for a parking lot displaying "space available" while driving near one's destination can be avoided and the risk of an accident decreased. In addition, payment after use can be automatically performed through a means of settlement tied into a previously registered driver's account so that the driver can leave the parking lot immediately without having to wait for settlement processing.

This system is also equipped with a management system for parking-lot operators that enables online, real-time settings such as changes in parking rates, temporary suspension of parking lot use on specific days or time slots, etc. In this way, the system reduces the burden of parking-lot management tasks even for parking-lot operators using scattered idle land and expanding in a decentralized manner.

5. Toward a Safe Self-driving Society

With a view to the self-driving era of the future, NTT DOCOMO has undertaken a "cellular Vehicle-to-Everything (V2X)*8" initiative as technology for contributing to an even higher level of safety. "High-reliability, low-latency direct communications technology connecting vehicles to everything" as prescribed by 3GPP is expected to improve vehicle communication ability as a complement to vehicle sensor technology so that an even broader range of information can be detected and peripheral conditions recognized even in non-line-of-sight environments.

In addition, we can expect 5G to be an elemental technology that will not only enable the use of large-capacity data such as real-time traffic information and digital maps but also provide significant driving support as in remote operation of self-driving cars. NTT DOCOMO intends to make the most of 5G to bolster its efforts in creating a smooth and secure self-driving society.

6. Conclusion

In this article, we described an overview of connected car services, MaaS, docomo Smart Parking system, and V2X as NTT DOCOMO initiatives in next-generation mobility services. We ask the reader to refer to other special articles in this issue for detailed explanations of the services and technologies introduced in sections 3 – 5 above [1] – [3].

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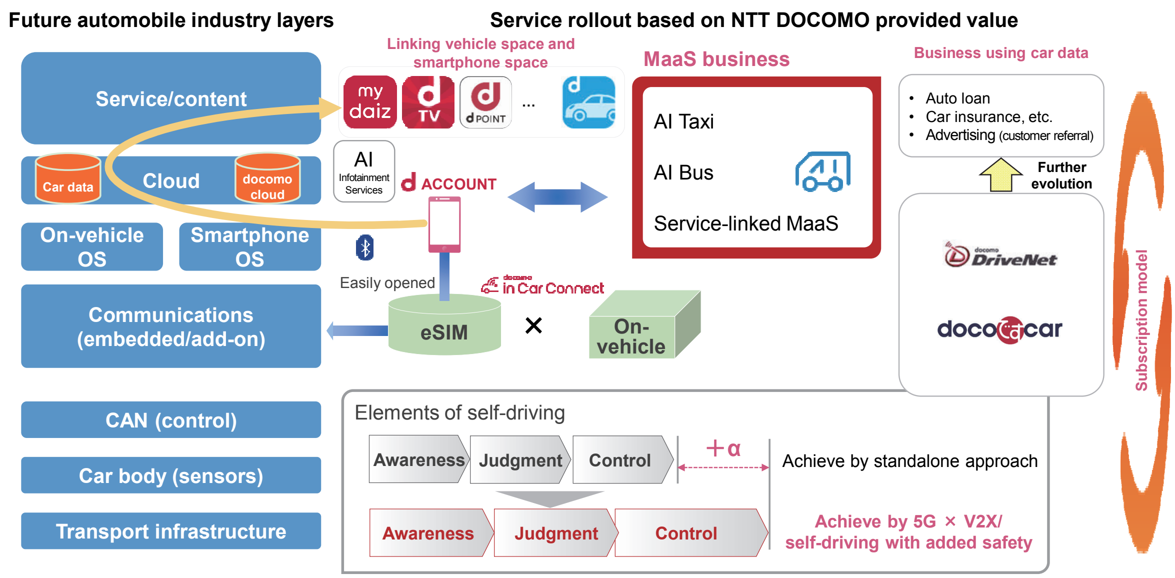
*6 Revenue sharing: The sharing of obtained profit at an allocation rate determined beforehand between the business enterprises of concern.

*7 docomo Smart Parking system™: A trademark of NTT DOCOMO, INC.



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"doco desu car" and its logo are trademarks or registered trademarks of DOCOMO Systems, Inc.
Bluetooth and its logo are registered trademarks of Bluetooth SIG, Inc.

CAN: Controller Area Network

Figure 1 NTT DOCOMO initiatives in next-generation mobility

Today, as reforms proceed toward next-generation transportation as reflected by CASE and MaaS, NTT DOCOMO is committed to providing safe and smooth mobility services and to finding solutions to social problems in the area of transportation. Furthermore, in addition to providing communication environments, NTT DOCOMO aims to create new business fields and provide new value together with co-creation partners on diverse layers of the automobile industry from transport infrastructure to automobile-related services (**Figure 1**).

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*8 V2X: A generic name for Vehicle-to-Vehicle (V2V) direct communications between cars, Vehicle-to-Infrastructure (V2I) direct communications between a car and roadside devices (radio communications equipment installed along a road), Vehicle-to-Pedestrian (V2P) direct communications between vehicles and pedestrians, and Vehicle-to-Network (V2N) wide-area communications via base stations in a cellular network such as LTE and 5G.

Technology Reports | MaaS | Passenger Demand Prediction | Population Statistical Data

Special Articles on Next-generation Mobility Services

MaaS at NTT DOCOMO —Finding Solutions to Social Problems in Mobility—

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The new concept of MaaS targeting the movement of people will provide a seamless service that uses ICT to coordinate various means of mobility such as trains, buses, taxis, and rental bikes and integrate all steps from making a reservation to paying the fare. Amid this trend toward next-generation mobility, NTT DOCOMO is promoting MaaS initiatives in the three areas of advanced mobility, integrated mobility, and service linking (mobility × services). In this article, we describe an overview of the key technologies in each of these categories and NTT DOCOMO's approach to MaaS business development.

1. Introduction

Problems related to mobility are not limited to eliminating traffic jams or congestion at major transport terminals. They extend to maintaining routes in public transportation and providing mobility for people in areas with a small residential population where establishing new routes is difficult and for elderly residents who cannot easily use a private car. In addition, the increase in tourists visiting Japan is already generating new problems such as severe traffic jams in areas where tourists tend to congregate (**Figure 1**). A solution to these problems that is now attracting attention is Mobility as a Service (MaaS), which is a new concept in mobility that aims to integrate different means of mobility such as trains, buses, taxis, and rental bikes. NTT DOCOMO is promoting initiatives in

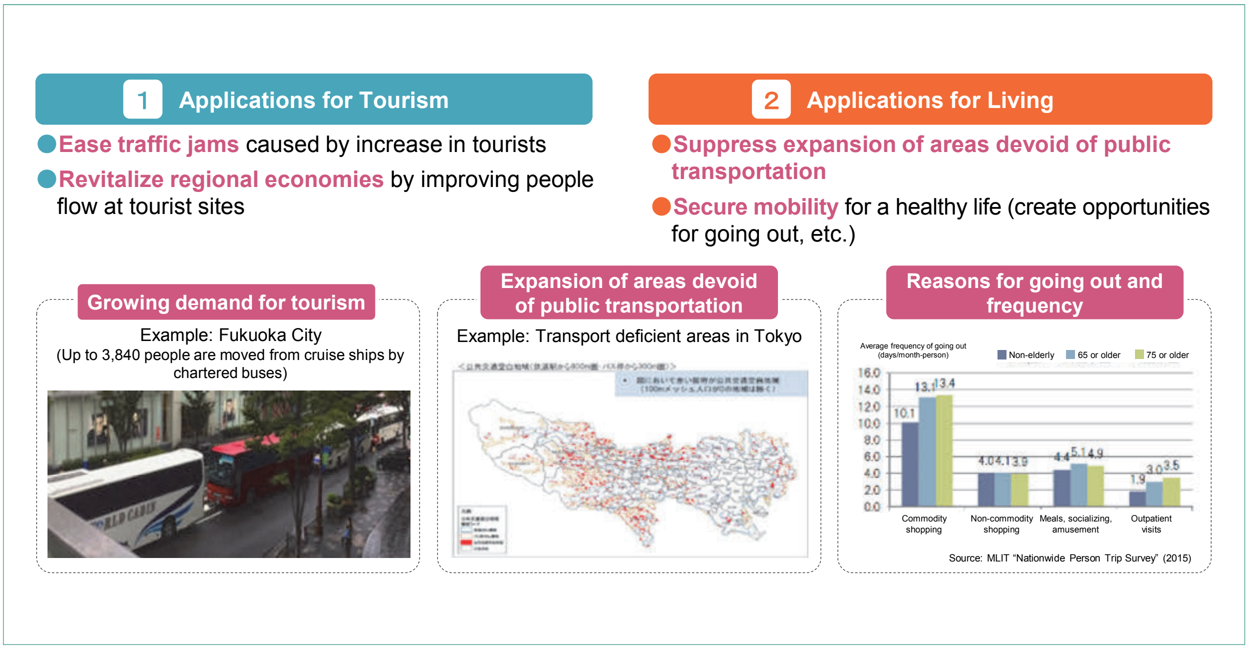


Figure 1 Background to MaaS initiatives at NTT DOCOMO—severe mobility problems—

the three categories of mobility enhancement, mobility integration, and service linking (mobility × services). In this article, we provide an overview of a real-time version of Mobile Spatial Statistics*1 [1] (population statistical data) using the mechanism of NTT DOCOMO's mobile phone network and describe technology that can improve mobility efficiency in combination with AI technology. We also describe NTT DOCOMO's approach to MaaS business development.

2. MaaS Initiatives at NTT DOCOMO

In simple terms, NTT DOCOMO thinks of MaaS as a means of "solving diverse social problems related to mobility in Japan." With this in mind, it classifies MaaS into the following three types as targets of development:

- Advanced MaaS

  Enhancing individual modes of transportation for personal movement such as walking, bicycling, riding a bus, and riding a taxi
- Integrated MaaS

  Integrating multiple modes of transportation typified by Finland's Whim*2 platform
- Service-linking MaaS

  Linking transportation with peripheral services such as retail sales, lodging, amusement, medical care and welfare, and finance and insurance

Among the above, the most urgent problem that NTT DOCOMO needs to address lies in the first-mile and last-mile of transportation (secondary transportation). For this reason, NTT DOCOMO is first studying advanced means of dispatching in on-demand transportation using AI technology in

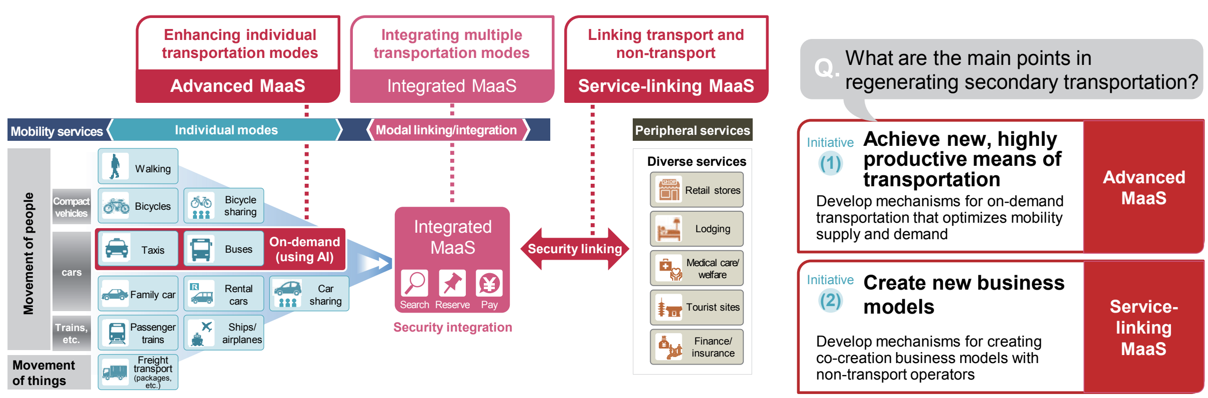
*1 Mobile Spatial Statistics: Population statistical data generated according to the "Mobile Spatial Statistics Guidelines," from NTT DOCOMO mobile network operations data. Population distributions on a grid and by municipal boundaries are estimated such that individual users cannot be identified, using an estimation of the number of mobile phones currently in each base-station area and adjusting based on base-station area data, NTT DOCOMO phone usage rates and other information.

*2 Whim: A MaaS solution developed by the Finnish startup MaaS Global. The Whim platform provides the world's first service to seamlessly connect different modes of transportation via a single application.

the area of "advanced MaaS."

Furthermore, to achieve sustainable means of secondary transportation, NTT DOCOMO is conducting parallel studies on the creation of new business models in the area of "service-linking MaaS" that combines mobility services with services in other industries (**Figure 2**).

To give two examples, NTT DOCOMO has already implemented AI Taxi [2] that optimizes mobility supply through demand prediction and AI Bus*3 [3] that optimizes mobility supply and creates business in the form of "mobility × services (referrals)" (**Figure 3**).



*NTT DOCOMO revisions to materials from MLIT "Working Group for New Mobility Services in Cities and Regional Areas"

Figure 2 NTT DOCOMO's approach to MaaS—initiatives toward solving mobility problems—

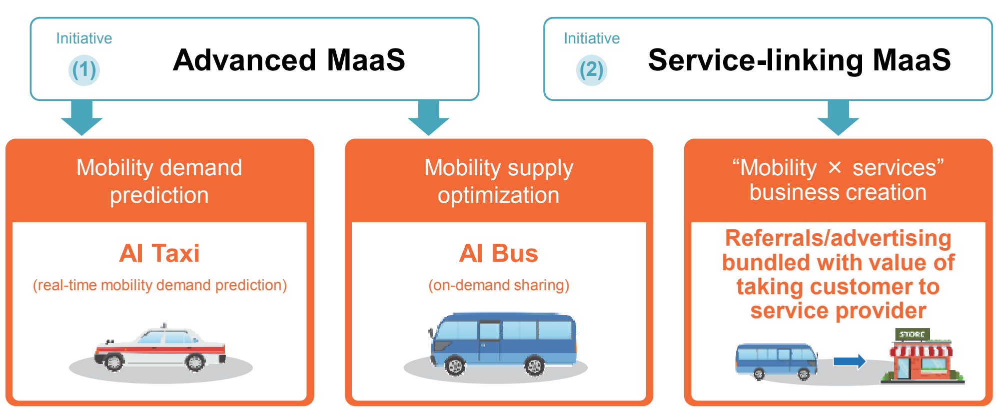


Figure 3 NTT DOCOMO MaaS initiatives

*3 AI Bus: A trademark or registered trademark of NTT DOCOMO, Inc.

3. Advanced MaaS: AI Taxi —Mobility Demand Prediction—

NTT DOCOMO is rolling out a service called AI Taxi with the aim of optimizing the dispatching of taxis. It has been providing the service commercially since February 2018 after developing technology for predicting mobility demand for taxi services and conducting business trials. AI Taxi predicts taxi passenger demand up to 30 minutes into the future in units of 500 m squared cells. This prediction data is provided to taxi operators every ten minutes so that taxis can be dispatched to areas of high demand based on prediction results (**Figure 4**). In addition to shortening the time for customers to find an empty taxi, this service is expected to benefit taxi operators too by reducing the time that their taxis are empty and maximizing the time that they are occupied (the state in which they are carrying passengers) thereby increasing revenue.

3.1 Improving Accuracy of Demand Prediction Using Population Statistical Data

The prediction of taxi passenger demand makes use of population statistical data in addition to actual passenger data from the past, weather forecasts, etc. This makes for more accurate prediction even under unexpected conditions such as train delays or one-time events that are difficult to predict solely on the basis of past results (**Figure 5**). Furthermore, since it is known that correlations can be observed between changes in population and changes in taxi passenger demand even in normal periods, using change in population as input data makes it possible to predict change in passenger demand.

3.2 Hybrid Prediction Technique

The prediction technique in AI Taxi uses a prediction model that combines a multivariate auto-regressive model*4, a type of time-series prediction

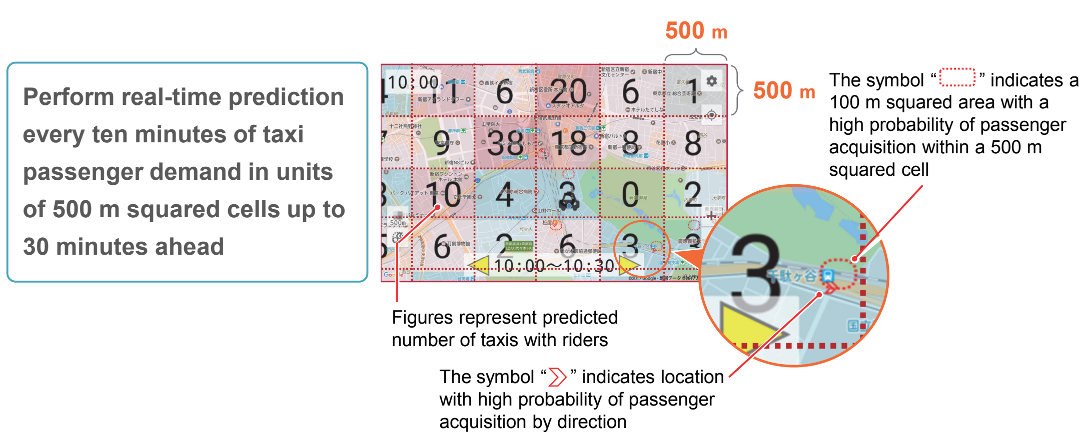


Figure 4 AI Taxi service scheme

*4 **Multivariate auto-regressive model**: An auto-regressive model extended for multiple variables. Also called a vector auto-regressive model.

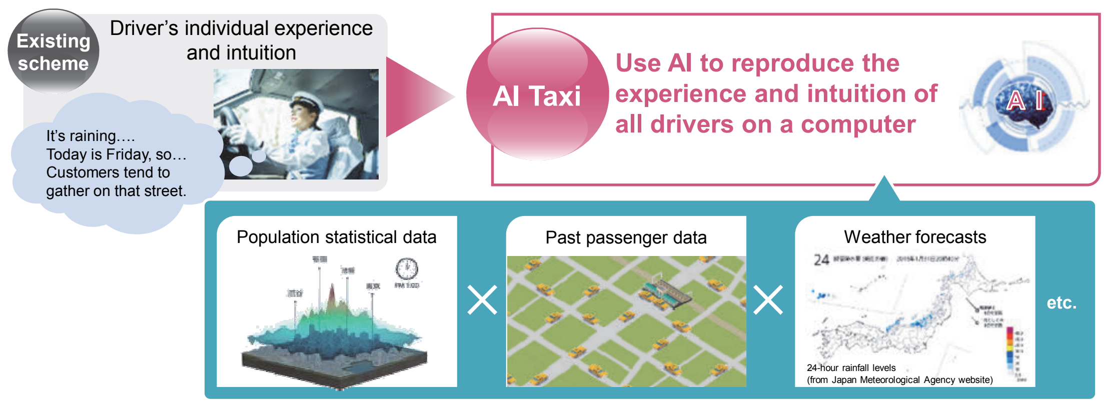


Figure 5 AI Taxi initiative

model, and a deep learning*5 model [4]. Although correlations can be observed between changes in population and changes in passenger demand, there are some cases in which passenger demand increases with increase in population and others in which passenger demand increases with decrease in population depending on the area. In addition, the time delay in passenger demand following a fluctuation in population depends on the area. For example, given an area in which other transportation facilities exist such as a train station, taxi passenger demand will soon increase along with an increase in population. However, given an area in which commercial facilities or event venues exist, it may take several hours for passenger demand to increase since potential passengers will stay in those facilities for a certain amount of time. In this way, our technique is combined with deep learning that can mechanically extract features so that data having area-specific correlations can be handled correctly.

4. Advanced MaaS: AI Bus —Mobility Supply Optimization—

AI Bus is an on-demand transportation system that can take you where you want to go when you want to go (**Figure 6**). It enables a user to reserve a ride through a dedicated smartphone app by simply specifying ride time and pickup and drop-off points without having to worry about bus routes or schedules.

4.1 Efficient On-demand Dispatching Using AI

Achieving efficient on-demand dispatching in response to real-time ride requests requires that optimal vehicle allocation and operating routes be computed using AI. Having each driver operate the bus according to an operating plan calculated and presented by AI at any time makes for pickup and drop-off that can meet user mobility demand in the most efficient manner. This operating plan

*5 **Deep learning**: A method of machine learning using a multi-layered neural network.

takes the shortest route between the pickup and drop-off points and makes it unnecessary to drive in intervals having no users, which shortens travel time compared with conventional fixed-schedule/fixed-route buses. Furthermore, as a shared type of transportation service that assumes simultaneous use by multiple riders, AI Bus can lower the cost per trip and provide a relatively inexpensive service compared with individual means of conveyance such as taxis.

4.2 Operating Area Recommendation Function Based on Demand Prediction

To further improve operating efficiency, NTT DOCOMO has achieved an "operating area recommendation function based on demand prediction" (**Figure 7**). In

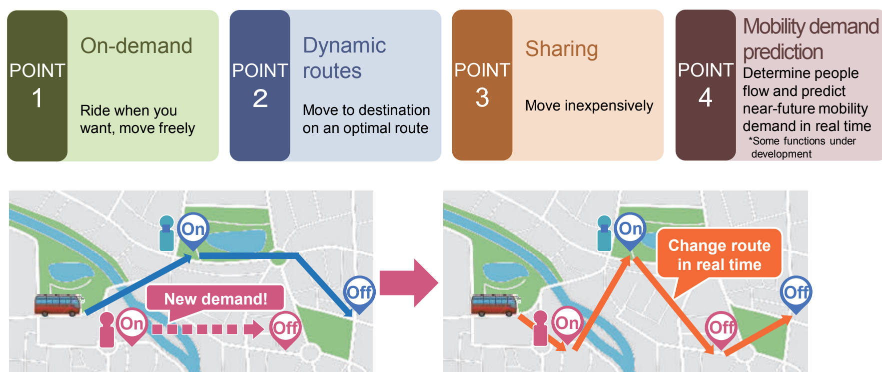


Figure 6 AI Bus initiative

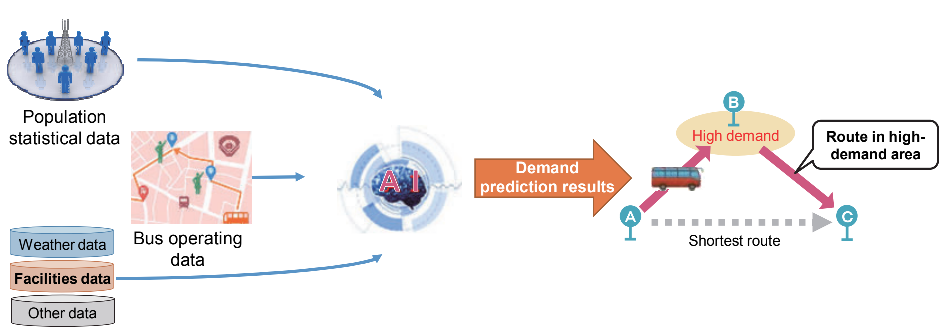


Figure 7 Recommendation of routes or waiting points by passenger demand prediction

on-demand dispatching described above, the operating plan of each vehicle is recomputed whenever a new ride reservation comes in from a user. At this time, however, the plan must be updated without causing a major delay in the picking up and dropping off of confirmed users such as those already on the bus in transit. There is consequently concern as a result of this constraint that pickup for new users will be put off even if seats are available especially when many ride reservations are coming in all at once. To solve this problem, the proposed function predicts the number of reservations in each area and presents drivers with recommended routes or waiting points in high-demand areas. As a result, drivers take routes that make the rounds of high-demand areas while satisfying the above constraint instead of only running between pickup and drop-off points by the shortest route based on existing predictions. Additionally, having empty vehicles wait in standby mode in high-demand areas should make it possible to shorten user wait time and accommodate more users.

As in the case of AI Taxi, AI Bus uses past passenger data, population statistical data, etc. to construct a demand prediction model, but as a learning algorithm, it adopts eXtreme Gradient Boosting (XGBoost)*6 [5], which is a type of ensemble learning*7 especially effective for fast learning. The reason for using this requirement is as follows.

To make this recommendation function effective, a period is needed for collecting model-training data after commencing actual use of the service in the target region. From a business perspective, however, it is desirable to construct a model as early as possible to make this function effective. With this in mind, and considering that the amount of data obtained in a one- or two-month period is small, we adopted this technique to achieve predictions having fluctuations in results as small as possible.

5. Service-linking MaaS: "Mobility × Services" Business Creation via AI Bus

In this section, we first present an example of using MaaS for creating a convenient and low-priced tourism mobility experience (**Figure 8**) and then describe a mechanism for new business creation through "service-linking MaaS" that links mobility with services in other industries.

5.1 Tourism Mobility Experience by MaaS

When wanting to visit a tourist site for the first time, it's difficult for a tourist to select an optimal travel route to that destination without being familiar with that area. Furthermore, considering that the trip may require connections over multiple routes, the complexity involved may prompt the tourist to simply give up on the trip. With this in mind, we considered a method that would provide the tourist with another means of mobility. This method would uncover latent mobility needs that existing means of transportation cannot easily satisfy and make it easier for a tourist to move about.

In this method, the tourist uses a rider application to get information on the desired destination such as a tourist site or commercial facility and calls an AI Bus (secondary transportation) that can take the tourist from a nearby pickup point to the destination in an on-demand manner. In this way,

*6 XGBoost: A type of ensemble learning that has been attracting attention in recent years.

*7 Ensemble learning: A technique that constructs a number of different models and integrates the prediction results of those models at prediction time. This approach is expected to enhance prediction performance with respect to unknown data.

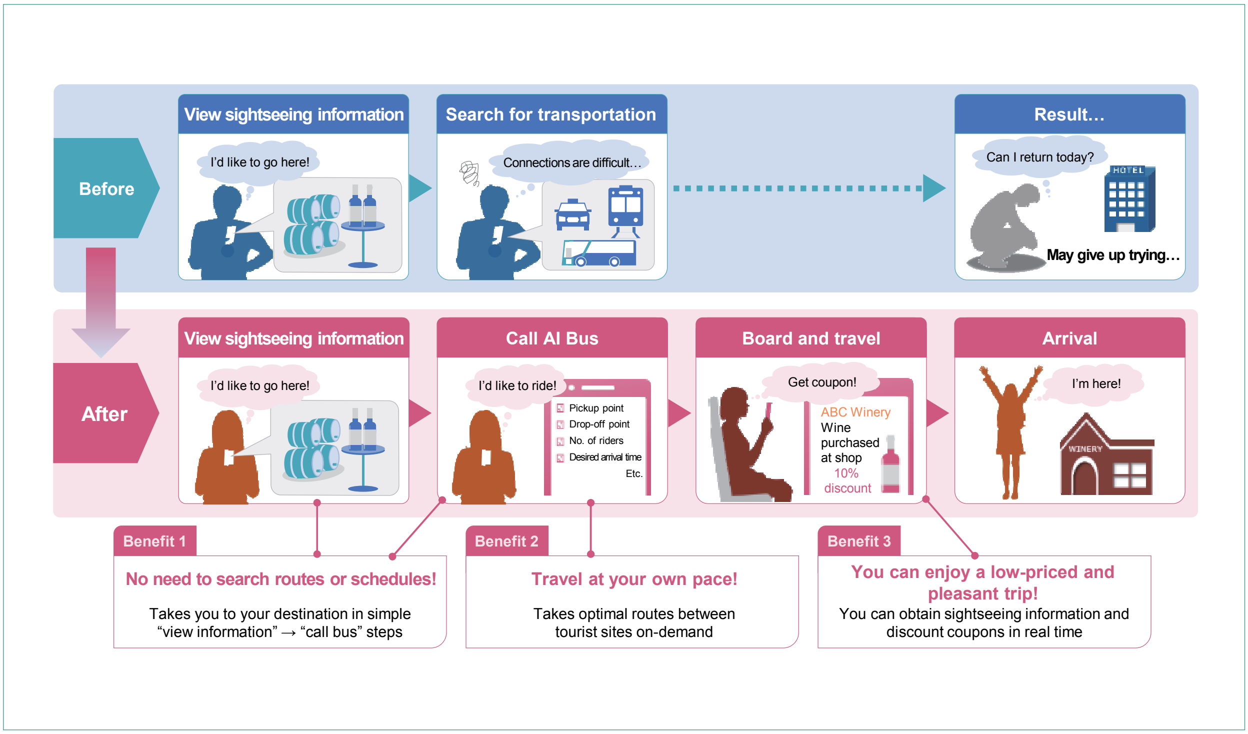


Figure 8 Convenient and low-priced tourism mobility experience by service-linking MaaS

the tourist has no need to check routes or schedules and can easily get to the desired destination at one's own pace. Additionally, the user can obtain sightseeing information on the destination and surrounding area and discount coupons as well while waiting to be picked up by the AI Bus or while riding. This makes for a leisurely tour while enabling the user to receive discount services in meals, shopping, etc.

At the same time, NTT DOCOMO is providing a store management portal for stores as a support tool for attracting customers. This portal applies near-future people flow prediction*8 [6] using corevo®*9 AI technology from the NTT Group to enable stores to reference the number and attributes of visitors as a visual representation of future mobility demand and to understand how people are checking and browsing through information on one's own store on the Web. A retail store or commercial establishment can use this portal to deliver coupon information in real time along with announcements and a description of its business with the feeling of a blog via the rider application used by tourists (Figure 9).

5.2 Expanded Linking of Mobility and Other Services through API Development

In addition to the above, we aim to promote business creation in the form of "mobility × services," and to this end, we have converted the function dealing with AI Bus reservations to an application programming interface (API)*10 to enable linking with peripheral services in other industries such as retail sales, lodging, medical care and welfare,

*8 Near-future people flow prediction: A trademark or registered trademark of NTT DOCOMO, Inc.

*9 corevo®: A registered trademark of Nippon Telegraph and Telephone Corporation.

*10 API: A general-purpose interface for using functions and data.

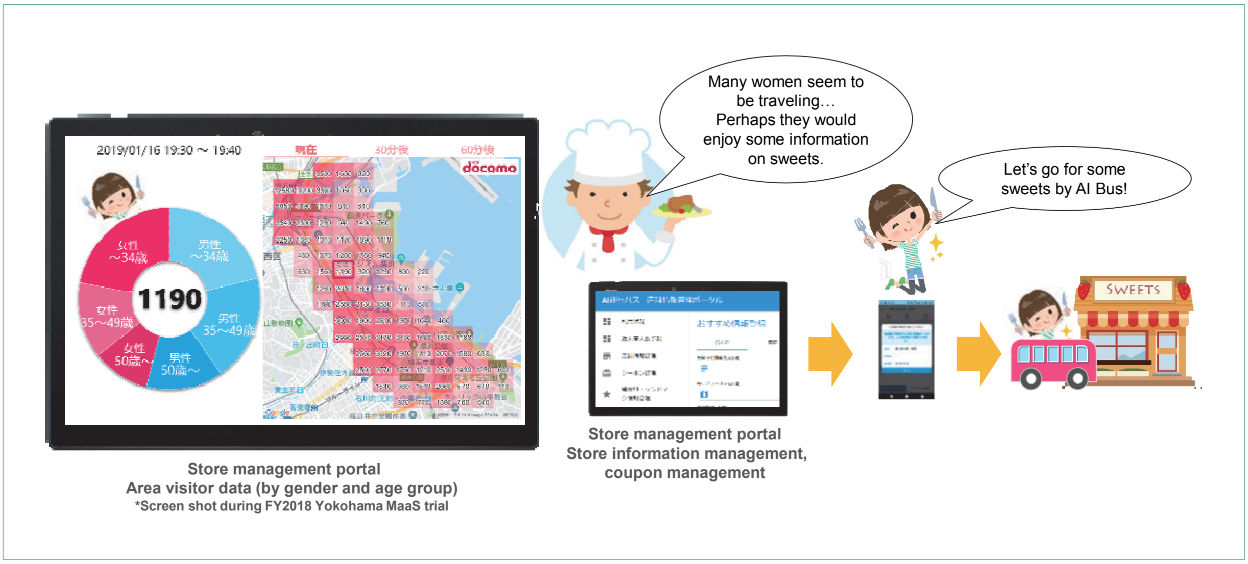


Figure 9 Yokohama MaaS trial: Screen shots of store management portal

sightseeing, finance, and insurance. In this way, we have created a mechanism that enables a peripheral service to specify pickup and drop-off points, number of riders, desired time of pickup, etc. and to reserve a vehicle thereby making it easy to dispatch an available AI Bus.

For example, this mechanism could be linked to a hospital system so that an AI Bus could be arranged as a means of taking a patient home in conjunction with payment procedures after an examination. The mechanism could also be linked with the hospital's reservation system to send the patient a reminder on the day before the patient's next examination and to reserve an AI Bus for the day of the examination if needed.

Our plan is to promote business creation in the form of "mobility × services" by expanding the linking of mobility with services in other industries as demonstrated by this example of linking with hospital services.

6. Conclusion

In this article, we described MaaS initiatives at NTT DOCOMO while providing overviews of relevant technologies. With an eye toward future technology development, we plan to study ways of improving accuracy and providing new added value through advanced AI technologies based on real-world data from the field and population statistical data.

Furthermore, in parallel with such technical enhancements, we will strive to build relationships between local governments and transport operators and expand the MaaS coverage area. We also aim to develop diverse methods for providing MaaS systems and to support the creation of new business such as by expanding business partnerships with peripheral services.

From here on, as self-driving reaches the practical level, the concept of mobility and its business structure will surely undergo major changes. At that time, we feel that the technologies and service scenarios introduced here will become indispensable to modern mobility. At NTT DOCOMO, we plan to boost our efforts in MaaS development to contribute to the solving of social problems such as by making mobility even more convenient for all and revitalizing regional economies.

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Technology Reports

IoT | Lean Style | Parking Lots

Special Articles on Next-generation Mobility Services

The "docomo Smart Parking System" —IoT based Pay Parking Solution—

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Recent years have seen initiatives in a variety of industries on using ICT to optimize existing social systems. As part of this trend, NTT DOCOMO has taken up the challenge of open innovation with the pay parking industry, which continues to increase in importance as infrastructure in our automobile-supported society. This article gives an overview of the "docomo Smart Parking System™*1" project being commercialized as a concrete outcome of this challenge, and describes technological features of this solution.

1. Introduction

Pay parking, which supports our everyday, automobile-based transportation environment, appeared in the 1990s in Japan, and reached its current form through successive improvements and advancements.

From the perspective of drivers, pay parking is a sharing economy*2 service that enables them to temporarily rent parking space near their destination. From the perspective of land owners, it provides a business model for generating return from land assets. These effects have multiplied, leading to establishment of more pay parking, so that as of 2018, there were approximately 85,000 parking lots [1] operating throughout Japan.

However, the following issues have recently appeared in the pay parking market.

- Required to support Web-based business models such as Mobility as a Service (MaaS)*3 and cashless transactions

*1 docomo Smart Parking System™: A trademark of NTT DOCOMO, INC.

*2 Sharing economy: An economy created by lending, sharing or exchanging goods and services. In a narrow sense, the sharing economy usually entails individuals offering their unused products or assets, or their services to others.

- Drivers are unable to find places to park easily
- A shortage of land suitable for pay parking in urban centers

Considering such conditions, NTT DOCOMO initiated its “docomo Smart Parking System” project in June 2016, with the goal of using its ICT know-how to enable both of the following.

- A system that can utilize small land areas, where it has been difficult for parking lot operators to use existing pay parking systems
- Pay parking services that provide additional convenience for drivers

NTT DOCOMO began offering a commercial service in October 2017 (**Figure 1**). This article gives an overview of the project and describes technical features of the solution.

2. System Overview

2.1 System Architecture

The docomo Smart Parking System project is developing a solution based on the concepts of:

- Reducing construction and operating costs
- Adapting to changes in the market environment
- Providing a User eXperience (UX)*4 that gives broad support for actions before and after using a parking space

The system architecture is shown in **Figure 2**. The system consists of four components: “Smart Parking Sensors,” which are IoT devices that detect when a vehicle enters or leaves a parking space; a gateway*5, which connects these sensors to a server; a parking lot management server in the cloud; and the “Smart Parking Peasy®*6” (hereinafter “Peasy”) application, used by drivers when

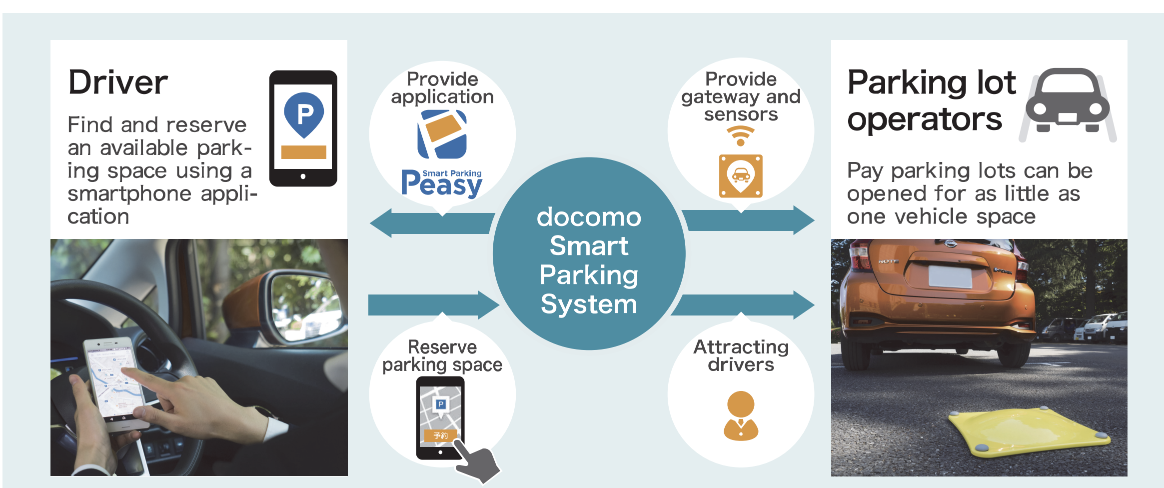


Figure 1 Scheme

*3 MaaS: A new mobility concept, in which all means of transport are handled seamlessly in a single service.

*4 UX: A general term for the experiences gained through the use or consumption of certain products or services.

*5 Gateway: An intermediate device that has functions such as protocol conversion and data transfer, to allow communication between devices. In this article, it refers to a specific device developed to collect and relay data to be sent from sensors to the server.

*6 Smart Parking Peasy®: A trademark or registered trademark of NTT DOCOMO, INC.

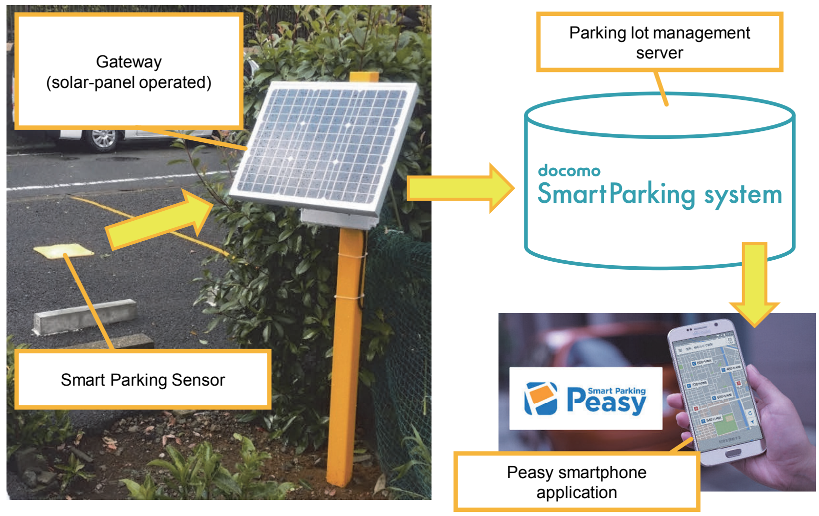


Figure 2 System architecture

using a parking lot.

2.2 System Functionality

The functionality and process of each of the elements that comprise the system are described in detail below.

1) Smart Parking Sensors

A Smart Parking Sensor (hereinafter “the sensor” or “the sensors”) is installed in each parking space in the parking area. The sensors constantly monitor whether a vehicle is parked in the space where they are installed, and periodically send the data to a gateway using 920 MHz band short-range radio communication.

These sensors are smaller and lighter than existing devices used to detect vehicles in pay parking lots and are designed to be fixed to the surface of the ground using anchor bolts. This allows them to be installed easily, without using heavy construction equipment or special tools, and only minor excavation is needed so the site can be restored easily when they are removed. The sensors have built-in batteries, so no electrical work is needed. Since neither electrical nor wired communication work is required, the sensors can be installed inexpensively and with less work than when using other existing devices.

The sensors are made using polycarbonate resin material. Based on the assumption that only one of the four wheels of an average-weight vehicle could rest on the sensor, they are guaranteed to be able to withstand loads of over 2,500 N. They are also water and dust resistant equivalent to class IP67*7, and can operate for approximately two years without changing the internal batteries. Thus, they can operate continuously for long periods in a natural, outdoor environment.

*7 IP67: IP67 and IP65 are IP codes specifying protection classes used in Japan Industrial Standards (JIS). The first digit indicates dust resistance and the second digit indicates water resistance.

2) Gateway

Generally, a single gateway is installed in each parking lot. The gateway receives sensor data from the sensors installed in each parking space and periodically sends it to the parking lot management server in the cloud. Data transmission between the gateway and the parking lot management server is done using LTE wireless communication, so no construction effort is needed for communication between devices for this system. Sensors can be up to approximately 30 m from the gateway, so there is some flexibility in selecting the location of the gateway according to the layout of the parking lot. One gateway is able to connect with up to ten sensors simultaneously.

Gateways also can work with solar panels and internal batteries, which provide power to enable gateways to operate continuously. Thus, gateways can operate in spaces where environmental factors make it difficult to provide a power source, such as vacant land. For indoor parking lots and other areas where light is insufficient for solar panels, gateways can also be installed using an ordinary household power outlet.

As with the sensors, gateways can also be installed without requiring any special tools, and the devices have IP65-level water and dust resistance. Gateways are also equipped with failsafe functionality. If communication from the gateway is temporarily interrupted, data will be stored within the gateway and will be retransmitted when communication resumes. Thus, they can handle situations where communication could become unstable due to radio interference or other environmental factors.

These features realize highly available system operation and very flexible system installation.

Photographs of the sensor and gateway are shown in **Figure 3**, and specifications are shown in **Table 1**.

Smart Parking Sensor

Gateway
(AC power operated)

Figure 3 Sensor and gateway photographs

Table 1 Basic specifications for a sensor and gateway

	Smart Parking Sensor	Gateway
Dimensions	388 mm (*D*) × 388 mm (*W*) × 46 mm (*H*)	105 mm(*D*) × 290 mm (*W*) × 208 mm (*H*) (Solar panel: 445 mm (*D*) × 510 mm (*W*) × 40mm (*H*))
Waterproof/ Dustproof	IP67	IP65 (Solar panel: IP67)
Weight	3.05 kg	1.55 kg (Solar panel: 3.5 kg)
Communication	920 MHz band communication	920 MHz band communication (between sensors and gateway) LTE (between gateway and server)
Operating voltage	DC3.3 V	DC3.8 V
Operating environment	Temperature: −20°C to 70°C*	Temperature: −20°C to 60°C
	Humidity: 0 to 100%	Humidity: 0 to 100%

* For outdoor installations on asphalt, external temperature approx. 45°C

3) Parking Lot Management Server

The parking lot management server (hereinafter "server") centrally manages the state (occupied or not, rate settings, settings for when the parking lot is open or closed, etc.) of all parking spaces with sensors installed, throughout Japan in real time.

The server has the following functionality.

(a) Parking lot availability management

The availability state of each individual parking space is managed by the server, based on the sensing data sent by the gateways. Parking space availability is also displayed in real time, based on parking lot information on the server, in an application called Peasy, which will be described below. The application is able to compute the remaining available parking spaces in a parking lot from the total number of parking spaces, the number reserved, and the number that are occupied, and to update the display of parking space availability.

(b) Parking fee settlement

The server computes the driver's parking fees based on fee settings in the server and the times of entering and leaving the parking space. The system completes payment processing on-line, so equipment to accept cash payments does not need to be installed at the parking lot. Fees can be configured in units of as little as one yen, and one minute, and detailed settings can be set for days of the week or hours of the day can be made, to balance supply and demand.

(c) Monitoring sensor and gateway faults

The server continuously monitors data sent from sensors and gateways, so it is able to detect unauthorized parking and any problems, such as low battery levels or other device faults, in real time, 24 hours-a-day, and 365 days-a-year. If a problem is detected, the server automatically sends an alert classified by type of problems to the maintenance department. The maintenance department can then arrange operations on-line, such as restarting the sensor or gateway, telephoning or emailing the user, or arranging to send personnel to handle it on-site, depending on the type of alert received. If on-site maintenance is needed, the maintenance person can check the type of alert and the location of the parking lot and parking space where the trouble is occurring beforehand, and prepare the necessary equipment and materials efficiently, before departing for the site.

(d) Management functionality for parking lot operators

A management system for parking lot operators is also provided, allowing dynamic settings such as changes to parking rates, or temporary closures for parking lots by day of the week and time of day. In most conventional parking lot systems, these management functions required going to the site and changing settings on the devices, but with this system, changes to settings can be made on-line in real time. This helps reduce the workload for managing parking lots, even when parking lot operators manage parking lots that are spread widely across a region by utilizing idle land in scattered locations.

2.3 Parking Lot Service Functionality

Peasy is a smartphone application that enables drivers to use parking lots where the system has been installed. By registering their account after installing the application, drivers are able to use parking lot services provided by the system. Screen images of the sequence of operations when using a parking lot with Peasy are shown in **Figure 4**. The main services provided by Peasy are described below.

(a) Account registration

Users can register and log in to Peasy using a LINE™*8 account, a Facebook®*9 account, or a Google™*10 account. The system has been designed to be easy to use, even for the first time when the parking lot at a driver's destination is using the system. This reduces the effort required before using the system for the first time, by having the driver select and register with an account they already have, and not requiring them to create a new ID and password for Peasy.

(b) Reserving and using a parking space

Peasy provides a service that enables drivers to reserve an available parking space 30 minutes before they arrive, free of charge. This enables drivers to decide where they will park while they are traveling to their destination, reducing the inconvenience of looking at signs to find available parking near the destination after arriving, and the accompanying risk of accident. While a parking space is reserved for a driver, the system displays the space as occupied to other drivers and does not accept multiple reservations for the space.

When a driver enters a space that they

*8 LINE™: LINE is a trademark or registered trademark of LINE Corporation.

*9 Facebook®: A registered trademark of Facebook, Inc.

*10 Google™: A trademark or registered trademark of Google LLC.

(1) Find, select and reserve a parking space　(2) Park and begin using the space　(3) While using the space　(4) Leaving and payment

Figure 4　Using a parking lot with Peasy

have reserved, a push notification is sent to the driver’s Peasy application to confirm their intention to start using it. Instructions to start parking are displayed on the application. When the driver follows these instructions, the system relates the driver, the vehicle parked in the space, the driver’s account, and the payment method, so the driver can finish preparation for payment before leaving the parking space.

(c) Automatic cashless settlement

Through the steps in (a) and (b), the driver can have payment of parking fees completed automatically when they leave the parking space. Existing pay parking systems require paying cash to a machine in the parking lot to settle payment before leaving the parking lot, but this inconvenience is not necessary with Peasy.

When the vehicle leaves the parking space, the sensor detects that it has left and automatically records the time. Based on this departure time, and the similarly detected entry time for that parking space, the server automatically computes the parking fee. This fee is settled automatically using a credit card that the driver has preregistered in Peasy. Thus, drivers need not wait for payment to complete, and can proceed to their next destination.

(d) Electronic receipts, aggregated payment for corporations

Peasy is able to issue digital receipts for settlement of expenses. Compared with paper receipts, this reduces the risk that the driver could lose them, and for the parking lot operator, it avoids difficulties with paper jams and maintenance costs such as replenishing paper, printer ink and other consumables.

For corporate drivers, there is also a service for aggregate payments by corporate account, which issues a single invoice to the account after aggregation. For corporations using this service, a single receipt is issued monthly, aggregating the parking fees for each corporate account. This receipt can be processed directly by the company’s accounting department, simplifying the settlement of expenses.

2.4 Response from Users

After drivers used Peasy at a parking lot for the first time, NTT DOCOMO asked them to respond to an optional survey through the application. The survey responses are shown in **Figure 5**:

- 89% of users responded 4 (“Satisfied”) or greater on a 5-step scale.
- 92% of users responded 4 (“I would like to use the service again”) or greater on a 5-step scale.

3. Lean-style Solution Development

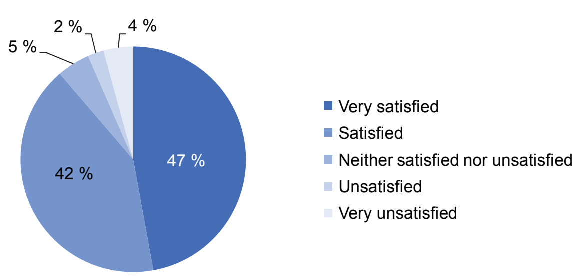
To develop a high-quality service within constraints, such as project organization with a small staff, market environment with high uncertainty, and equipment operating conditions in a largely-unknown outdoor parking-lot environment, the docomo Smart Parking System project was managed using a “Lean style[*11].” NTT DOCOMO applied this style for development the entire solution, including servers, applications, and also sensors and other specialized devices.

Below, we give an overview of the development process for a representative element of the project, the sensors.

The main requirements for the sensors were

Q1: Please give your impressions of using this service.

Very satisfied	Satisfied	Neither satisfied nor unsatisfied	Unsatisfied	Very unsatisfied
288	254	29	14	26
47 %	42 %	5 %	2 %	4 %



Q2: Do you think you would you use this service again?

Yes, definitely.	I think so	No opinion	I don’t think so	Definitely not.
331	231	31	5	13
54 %	38 %	5 %	1 %	2 %

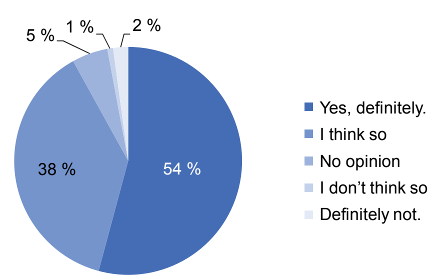


Figure 5 Survey of users after using Peasy (N = 611)

*11 Lean style: A method of implementing projects with uncertain goals, starting small and using feedback from customers and the market for guidance.

as follows:

- Operational accuracy: Vehicle detection accuracy, wireless communication accuracy
- Construction simplicity: Can be installed without roadway or electrical construction
- Durability: Withstands the weight of a vehicle, low power consumption, continuous operation in a natural, outdoor environment

NTT DOCOMO developed and implemented a dedicated sensor satisfying all of these requirements.

While building the first theoretical prototypes, we repeated a trial and error process, building knowledge within the project team and gradually increasing development efficiency, following the steps below.

(1) Repeated laboratory vehicle-detection tests and selection of the detection method and basic device structure.

(2) Install the prototype in an operating real, outdoor pay parking lot, measure noise due to changes in weather and the location of the vehicle, and analyze and estimate noise factors using multiple sets of test data.

(3) Based on the data obtained in (2), determine a model to improve noise resistance and to achieve accuracy similar to or better than vehicle detection devices currently used for pay parking.

In this process, we prioritized shortening the feedback cycle by performing development in-house, and at our busiest times, we were able to achieve multiple prototype improvements in a single week, steadily increasing accuracy.

Later, when moving into mass production, we made additional improvements to water and dust resistance, weight tolerance, communication power, and low power consumption. Regarding quality, during that time, we also installed the equipment in multiple parking lots to increase the number of trials, and as a result, we successfully reached mass production in approximately 1.5 years from the theoretical prototype.

4. Conclusion

This article has given an overview of the docomo Smart Parking System project and described some technical features of it.

NTT DOCOMO began commercially offering this system in October 2017. In addition to the technical aspects discussed in this article, we also adopted Lean style in development of sales channels. We continue to learn about the pay parking market, and are reflecting knowledge gained for further penetration of the market. In particular, we are developing the market focusing on metropolitan areas like Tokyo, Osaka, and the Kansai area, where there tends to be an excess of demand for pay parking.

This solution has received awards including the 2017 Good Design Awards, “Good Design Best 100,” and “Good Design Special Award [Design for the Future]” [2], and the “Best Selection” award from the 2017 JPB Awards, sponsored by the Japan Parking Business Association [3]. Our concept also has been very highly evaluated within and outside the pay parking industry.

In the future, we will continue to search for more advanced solutions for the opposing requirements of low power consumption and high detection accuracy, strengthening our contribution in support of further advancements in the pay parking industry.

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Technology Reports | Connected Car | Cellular V2X | Safe Driving Support

Special Articles on Next-generation Mobility Services

NTT DOCOMO Initiatives for the Connected Car Era

5G Laboratories Junichi Abe Shohei Yoshioka
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The automotive industry is entering an era of innovation that is being expressed with the word “CASE,” referring to four elements: Connected, Autonomous, Shared & Services, and Electric. Technologies related to these elements are currently being studied actively. Of the four, the “Connected” technologies contribute to advancing the other three, and there is considerable anticipation for use of 5G and LTE in this area. This article focuses on the “Connected” aspect of CASE, giving an overview of safe-driving assistance, for which cellular communication is expected to be effective, and describing initiatives at NTT DOCOMO in this area.

1. Introduction

Recently, there are increasing expectations that the automotive ecosystem will be enhanced to provide smart mobility. In 2016, Daimler proposed that the automobile industry would be revolutionized by four elements: Connected, Autonomous, Shared & Services, and Electric; represented by the word “CASE.”

Of these, the “Connected” element contributes to advancing the other three. For example, sensor information obtained using radar or cameras installed in vehicles or over roadways could be shared using wireless communication, for mutual benefit or to analyze traffic conditions. Results of such analysis could be used to notify of hazards that could cause accidents, or to distribute information that could help traffic flow through intersections, helping to realize safe and efficient autonomous driving.

"Public-Private ITS Initiative/Roadmaps 2019" [1] has outlined a vision of building a society with "safest, smoothly-operating roadway and traffic systems in the world." To contribute to this vision as a telecommunication operator, NTT DOCOMO is focusing on the "connected" aspect of CASE, and is promoting initiatives utilizing cellular communication.

This article gives an overview of safe driving assistance utilizing cellular communication and describes various initiatives by NTT DOCOMO in this area.

2. Overview of Safe Driving Assistance Using Cellular Communication

2.1 Role of Communication in Safe Driving Assistance

Advanced Driver Assistance Systems (ADAS)*1 are becoming more common. They use cameras and other sensors mounted in vehicles to recognize people and other objects near the vehicle, to detect potential accidents, and perform actions such as applying emergency braking, contributing to safer driving. On the other hand, technologies are also being studied that use radio communication to gather and distribute information that is difficult to detect with the vehicle's sensors, such as hazards that are hidden or out of visual range, or that covers a wider area, such as traffic or congestion information. These are being implemented as Intelligent Transportation Systems (ITS)*2 such as Vehicle Information and Communication System (VICS)®*3 and ITS Connect®*4 [2] [3].

As an example of detection using sensors and collection and distribution of data, an overview of dynamic maps is shown in **Figure 1**. Dynamic maps are expected to be used for autonomous driving, and use 3D maps and results from onboard sensors to accurately comprehend the position of the autonomously driving vehicle and to map information detected using sensors and distributed through wireless communication in real time, to understand the traffic conditions along the driving route.

Dynamic maps define four layers of information according the frequency of updates. They are: static information, semi-static information, semi-dynamic information, and dynamic information.

The static through semi-dynamic information layers provide information regarding the traffic environment that changes over time. It is being considered for use with wireless communication, for autonomous driving systems, and also for safe driving assistance while driving manually.

Dynamic information includes information regarding traffic signals and surrounding vehicles and pedestrians. This information is expected to be updated every second or less, and neglecting to do so could result directly in an accident. Information from the onboard sensors fits this category, but wireless communication is also being considered for information that cannot be detected with sensors or is outside of visual range.

2.2 Overview of Cellular V2X

Vehicle to Everything (V2X) technology is being

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*1 ADAS: Systems that use cameras and other sensors in a vehicle to improve safety in operating the vehicle. Operation of a vehicle involves three elements, "Perception," "Decision," and "Operation," and a mistake in any of these can result in accident or dangerous operation. ADAS can provide assistance to any of these three elements by using sensors and other means to detect surrounding conditions.

*2 ITS: An overall term for transportation systems using communication technology to improve vehicle management, traffic flow and other issues.

*3 VICS®: A trademark or registered trademark of the Vehicle Information and Communication System (VICS) Center.

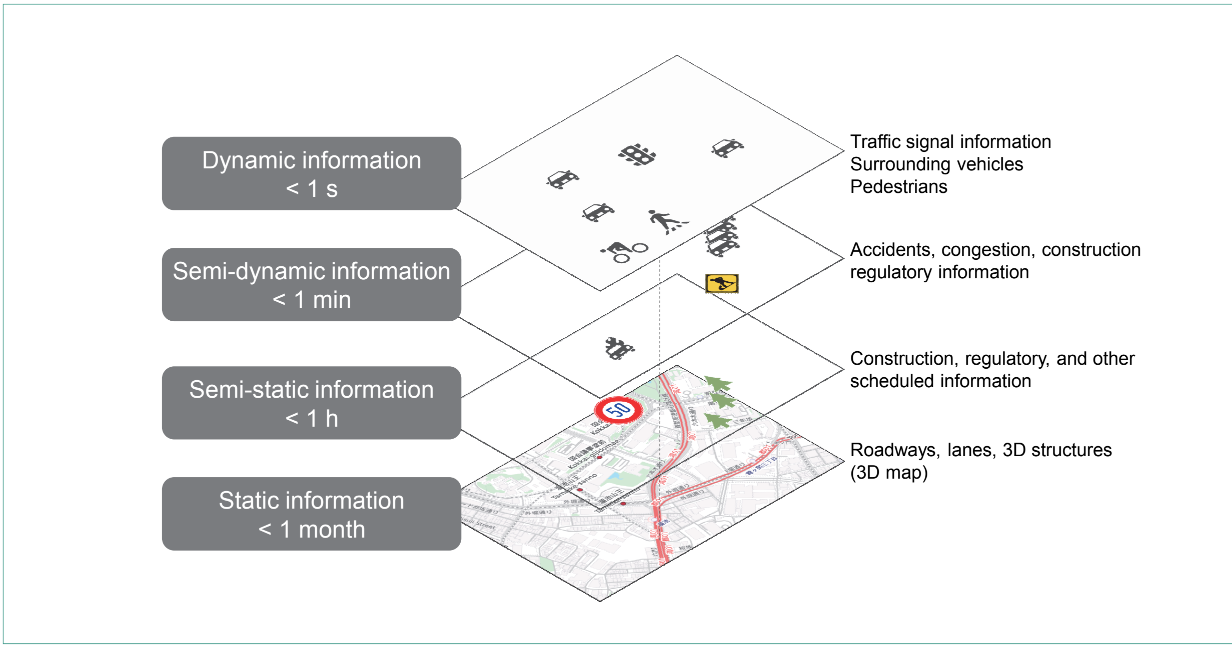

Figure 1 Dynamic map overview

studied as a means of connecting vehicles to all kinds of objects using wireless communication and sharing information. It includes direct communication Vehicle-to-Vehicle (V2V), direct communication Vehicle-to-Infrastructure (V2I: wireless communication between vehicles and equipment installed along roadways), direct communication Vehicle-to-Pedestrian (V2P), and wide-area communication via LTE and 5G cellular network base stations, called Vehicle-to-Network (V2N) communication.

The 3rd Generation Partnership Project (3GPP), which creates standards for mobile communication systems, is standardizing a V2X technology called cellular V2X, based on cellular communication technology. Technical study and testing for cellular V2X is in progress. The scope of application for cellular V2X is shown in **Figure 2**.

V2V, V2I and V2P (hereinafter "direct-communication V2X") use direct communication to gather information in the area near the vehicle but beyond the range of the onboard sensors. This area is called the "direct-communication assistance area" Direct-communication V2X use a radio interface called PC5, which is capable of low-latency communication. As an example, a use-case for this technology is to broadcast notification of sudden breaking to surrounding vehicles, to help following vehicles navigate intersections safely. Most information in this direct-communication assistance area corresponds to "dynamic information" within the dynamic maps described earlier.

V2N uses the wide-area aspect of cellular networks, mainly to cover the range beyond the direct-communication assistance area. A use case example anticipated for this technology is congestion information, which is not directly related to detecting emergency conditions, but contributes to smooth operation. Note that V2N can provide

*4 ITS Connect®: A driving assistance system with vehicle to roadside and vehicle to vehicle communication using dedicated frequencies in the 760 MHz band. A trademark or registered trademark of Kazuya Enya.

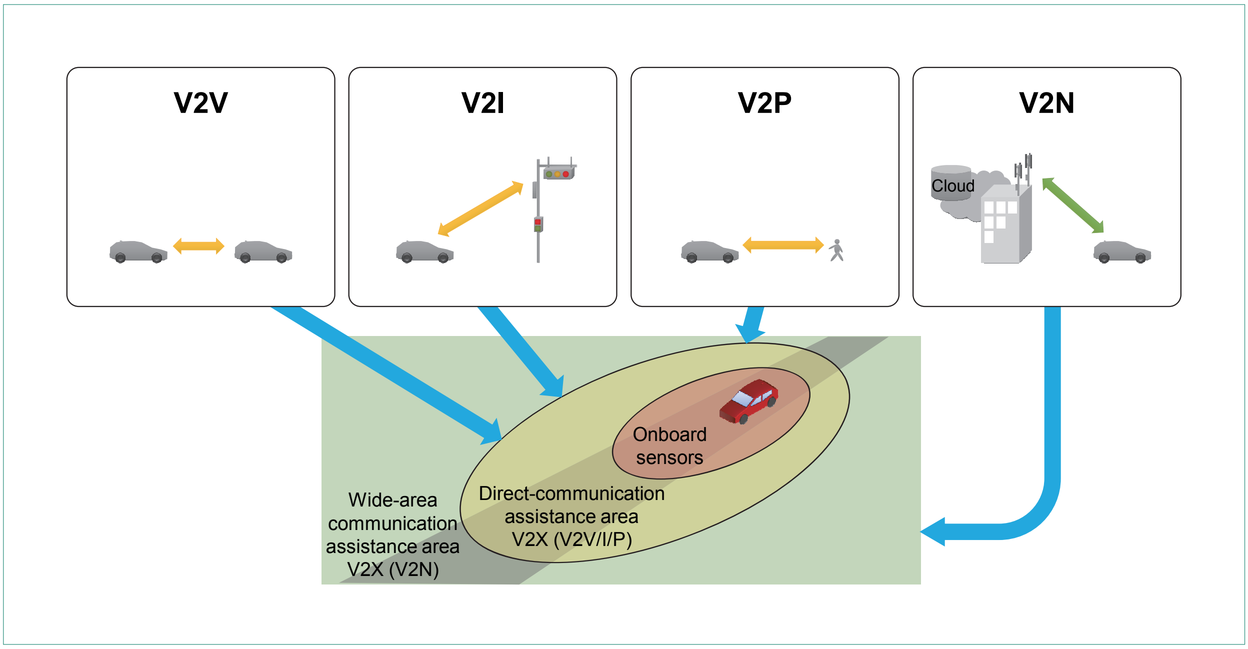

Figure 2　Range of application for cellular V2X

communication with other vehicles, roadside equipment and pedestrians through network base stations. This is called Vehicle to Network to Everything (V2N2X) communication. The wide-area communication assistance area corresponds mainly with "static" to "semi-dynamic" information within the dynamic maps described earlier.

2.3 Trends in Cellular V2X standardization

In standardization of cellular V2X, 3GPP Service and System Aspects (3GPP SA)*5 has decided use cases, requirements, architectures, security and other aspects. Based on these, wireless interfaces for V2N and direct-communication V2X have been studied in the 3GPP Radio Access Network (RAN)*6. In its deliberation, 3GPP is also exchanging information with the 5G Automotive Association (5GAA), an association in the automotive industry that discusses connected car services using cellular V2X.

1) Direct-Communication V2X

For direct communication V2X, LTE Release 14, 15 have been specified as updates from 3GPP Rel. 12, 13, for communication between terminals. LTE Rel. 14, 15 provide higher mobility support, communication range expansion, and transmission resource control by base-station or autonomous resource selection based on frequency sensing at terminals. Rel. 14 covers basic applications for safe-driving assistance, where the specification is optimized for periodic broadcast transmission of small packets with several hundred bytes. The frequency band for ITS operation (5,855 to 5,925 MHz) is generally assumed for the specification. Rel. 15 further provides increased data rates through carrier aggregation*7 and higher-order modulation functions.

For the New Radio (NR) Rel. 16 specification,

*5 3GPP SA: The 3GPP group handling standardization of service requirements, architectures, security, codecs, and network administration.

*6 3GPP RAN: The group that handles standardization of the segment between terminal devices and base stations within 3GPP, an organization that standardizes 3G and later mobile communication systems. There are several working groups (WG) within 3GPP RAN such as WG1, which studies Layer 1 radio specifications; WG2, which studies Layer 2/3 radio specifications; and WG4, which studies radio performance. Details of each of these technologies are studied separately in each group.

which is scheduled to be completed in March 2020, aperiodic data communication and unicast/groupcast communication are being studied in addition to periodic broadcast communication. It also provides retransmission control using feedback information, and Quality of Service (QoS)*8 control with higher accuracy and efficiency. Rel. 16 assumes a wide range of frequencies below 6 GHz including ITS frequencies and millimeter-wave*9 frequencies from 24.25 GHz to 52.6 GHz, where it is expected to co-exist with UpLink and DownLink (UL/DL) communication in the same frequency bands.

2) V2N

It is assumed that both unicast communication (between a base station and a specific vehicle) and multicast communication (between a base station and multiple vehicles) will be used for V2N. Existing LTE standards as completed in Rel. 13 can be used for V2N, and the first release of the NR format for 5G (Rel. 15), which was completed in June 2018, can also be used. Work on specifications for Ultra-Reliable and Low Latency Communications (URLLC)*10, with latencies of 0.5 to 1 ms on the radio segment and maximum packet error rates of 10^{-6}, is also in progress for Rel. 16.

3. Initiatives at NTT DOCOMO

3.1 Overview

NTT DOCOMO is collaborating with the Ministry of Internal Affairs and Communications (MIC) and partner enterprises to implement safe driving assistance with connected cars, evaluating performance of direct-communication V2X, studying conditions of interference with existing systems, and performing demonstrations of cellular V2X. We are also mapping information transmitted through V2X and testing distribution of dynamic maps using cellular networks. These will be described below.

3.2 Evaluation of Direct V2X Communication Performance and Investigation of Interference with Existing Systems

In FY2018, NTT DOCOMO was entrusted with technical examination services*11 as part of the MIC process for allocating frequencies [4], as a preliminary study for the introduction of V2X.

These technical examination services included evaluation of basic communication performance with respect to requirements of two use cases for direct communication specified in 3GPP Rel. 14 (**Figure 3** (1)), study of interference conditions with existing systems (Fig. 3 (2)), and study of technologies to prevent interference (Fig. 3 (3)). The direct communication use cases were "Highway merging and lane changing assist" and "Emergency hazard notification" for autonomous driving and safe-driving assistance. The existing system examined for interference was 5.8 GHz Dedicated Short Range Communications (DSRC), specified in Association of Radio Industries and Businesses (ARIB)*12 STD-T75 [5], which is an ITS radio system in operation in Japan as the Electronic Toll Collection System (ETC/ETC2.0).

In evaluation of communication performance, we were able to confirm inter-vehicle communication distances of 830 to 1,000 m and vehicle-roadway distances of 400 to 620 m for conditions with a line-of-sight environment and no screening objects, no interference from within the system or adjacent channels, and packet error rates of 10^{-2} or less.

In the study of interference conditions, we

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*7 Carrier aggregation: A technology for increasing bandwidth and transmission speed, while maintaining backward compatibility, by simultaneously transmitting and receiving multiple carriers.

*8 QoS: Techniques for securing optimal bandwidth according to the purpose of communication and guaranteeing the quality required by that type of communication.

*9 Millimeter wave: Radio signals of frequencies in the range from 30 GHz to 300 GHz.

*10 URLLC: Generic terminology for communication requiring low delay and high reliability.

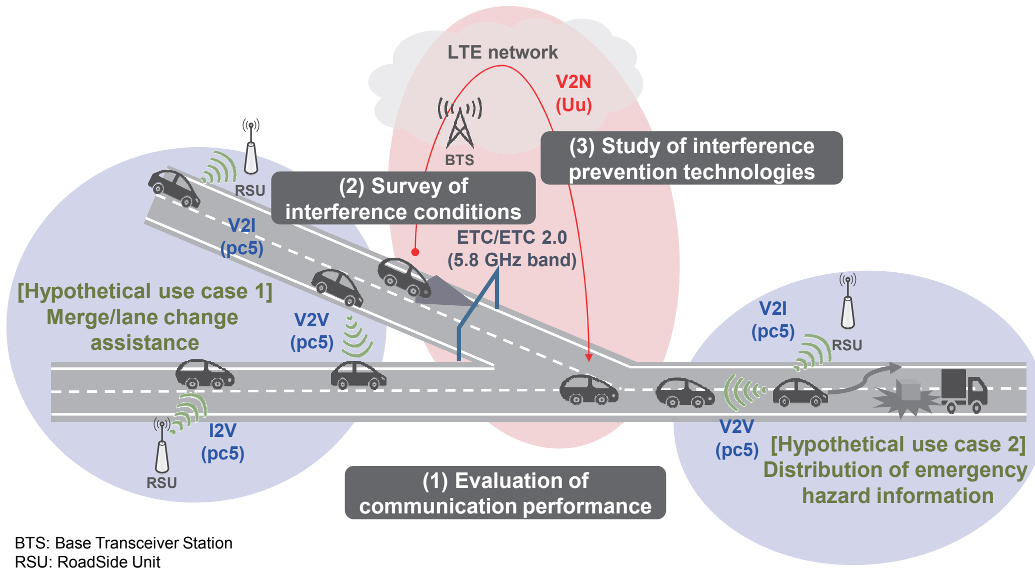

Figure 3　Technology testing for implementing a connected-car society

determined that for ETC, separation distances of 0 to 23.5 m were required for frequency separation of occupied bands for carriers of 20 MHz or greater, and for ETC 2.0, separation distances of 23.5 to 349.5 m were required. We also studied a technology for preventing interference, which builds a geofence*13 using pre-determined locations of ETC/ETC 2.0 base stations and considering separation distances. It then stops direct-communication V2X transmissions in areas of concern, switching to V2N communication.

3.3 Cellular V2X Testing

In cooperation with Continental Automotive Japan Inc, Ericsson Corp., Nissan Automotive, and Oki Electric Industry Co., Ltd., and Qualcomm Technologies, Inc., NTT DOCOMO has successfully conducted the first test of cellular V2X in Japan [6]. NTT DOCOMO developed a system to evaluate V2N (V2N2X) using our commercial LTE network to collect location and other information from each vehicle and distribute safe driving assistance messages, and we conducted driving tests with the system.

The V2N (V2N2X) evaluation system used in the tests periodically collected information from each vehicle on an ITS server using a closed network connection*14 to the commercial LTE network, as shown in **Figure 4**. The ITS server analyzed the information, determined accident risk, and distributed safe driving assistance messages. These included broken-down vehicles or other obstacles in the roadway, risk of collision when passing intersections with poor visibility, and the risk of an approaching vehicle when passing another vehicle (**Figure 5**).

*11　Technical examination service: A project established by the MIC to perform technical studies on highly practical technologies for efficient spectrum use, to promote the early introduction of those technologies.

*12　ARIB: An organization subordinate to the MIC that sets standards for systems that use the radio spectrum in the fields of communication and broadcasting in Japan.

*13　Geofence: A virtual boundary established on the ground. By coordinating with location data, it can be used to regulate terminal behavior or other aspects when the boundary is crossed.

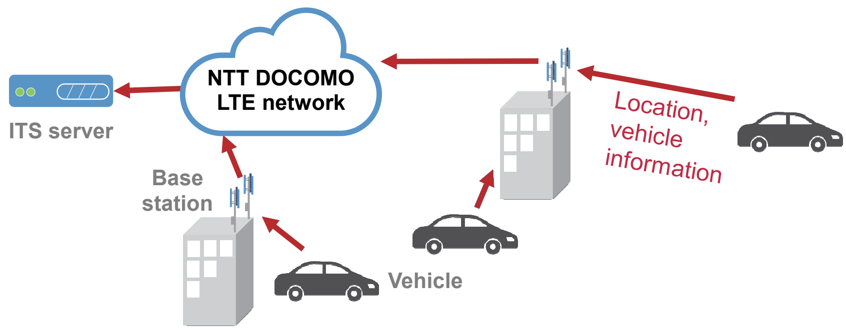

Figure 4　Overview of V2N (V2N2X) evaluation system

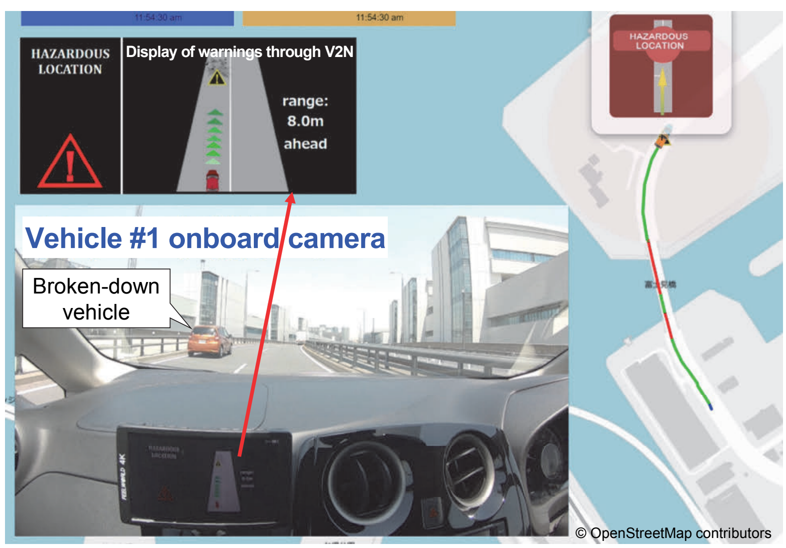

Figure 5　Broken-down vehicle notifications through V2N

In these tests, the median*15 LTE communication delay was less than 50 ms, and at the 95 percentile*16 level, messages were delivered in 60 ms or less. Note that for these results, all vehicles had already established a wireless connection, and results are reference values for the environmental conditions of the experiments.

Tests verified the latency for V2N (V2N2X) communication, but implementing a practical ITS server for collecting information and distributing safe-driving assistance information in real time will require further study of server scalability, overall

*14　Closed network connection: A direct connection to the LTE network that does not go through the Internet, provided by NTT DOCOMO as Access Premium LTE.

*15　Median: The value in the middle when countable data is ordered in increasing (or decreasing) size.

*16　Percentile: For a distribution of measured values, an indication of what proportion (percentage) of values are less than the specified value. For example, for a value at the 65 percentile level, 65% of the samples have a value that is less.

system availability, and how the costs of communication lines, the ITS server and other components should be handled.

3.4 Verification of Technology for Efficient Dynamic Map Distribution

If dynamic map data begins circulating frequently on networks as autonomous driving becomes practical and begins to spread, large increases in communication traffic and increased loads on cellular networks could exceed expectations. With an awareness of this issue, NTT DOCOMO accepted commissions from the MIC from FY2016 to FY2018 to research technologies for efficient distribution of dynamic map information.

It is anticipated that managing map data in a conventional cloud architecture would be too centralized, so this research dealt with technologies to distribute the data over mobile edge servers*17 located in each region within the cellular network; to partition and manage data in units of 125 m or 1 km square, each associated with an update version for partial and differential distribution; and for dynamically switching between cellular and wireless LAN communication, or using both simultaneously, depending on the state of an autonomously driving vehicle, the purpose or amount of the data being distributed and other factors (**Figure 6**).

Testing of these technologies was done by building a test environment that simulates a real environment at the Yokosuka Research Park. This included a communication environment with LTE test base stations, a core network*18 simulator and mobile edge servers; a dynamic map (measurements and mapping done using results from Strategic Innovation promotion Program (SIP)*19 studies); and

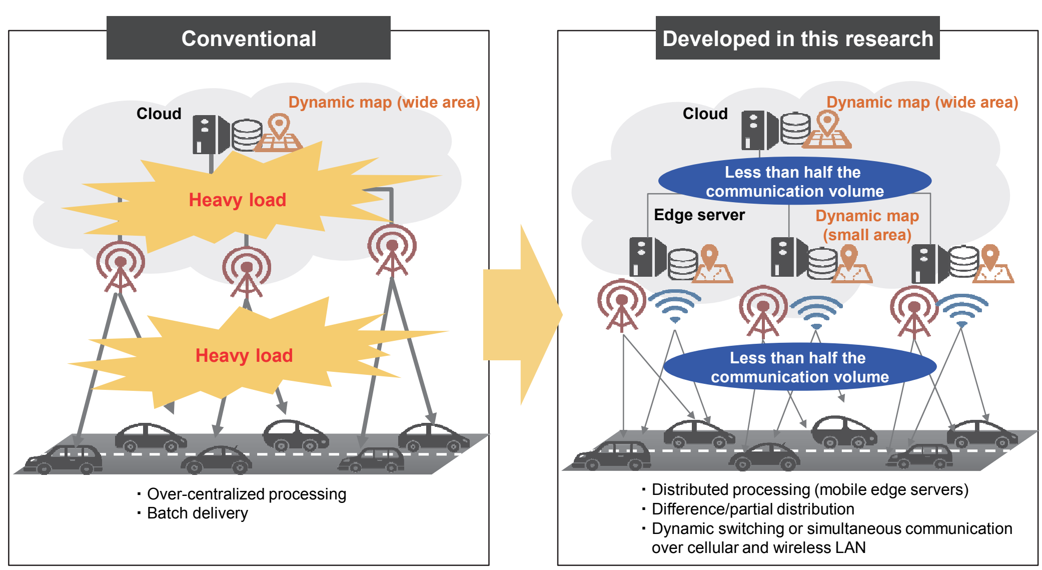

Figure 6　Overview of R&D on technology for efficient distribution of dynamic maps

*17　Mobile edge server: A server that provides service processing within the cellular network, relatively close to terminals and not on the Internet.

*18　Core network: A network consisting of switching entities and subscriber information management equipment, etc. Mobile terminals communicate with the core network via the radio access network.

autonomously driving vehicles (four vehicles prepared in collaboration with Doshisha University, Nagoya University, Kanazawa University, and the University of Tokyo). Testing showed that use of these technologies can reduce traffic on the wired and wireless sections of the cellular network by more than 50%, relative to previously. It also demonstrated that end-to-end service, from distribution of maps to autonomous driving of vehicles, is feasible. In particular, these technologies were used to distribute dynamic maps to four vehicles with different autonomous driving processes, and we showed that the four vehicles were able to receive them and to operate in a similar manner.

4. Conclusion

This article has given an overview of safe driving assistance technologies using cellular communication and introduced various testing efforts being conducted by NTT DOCOMO.

Cellular V2X will connect the many participants in transportation and provide safe driving assistance using cellular communication, but practical implementation will require further testing in various environments, with collaboration among related ministries and the automotive industry, to study its feasibility more deeply. NTT DOCOMO will continue to study sustainable ways to implement safe driving assistance using cellular communication, and contribute to implementing the "safest, smoothly-operating roadway and traffic systems in the world."

Note that this article has used, in part, results from the MIC Technical Examination on Connected Cars, and also MIC contracted research entitled, "Development and Experimental Proof of Autonomous Mobility System (Autonomous Driving Technology, Automatic Control Technology, etc.)," and "R&D of frequency effective utilization technology corresponding to various situations supporting a vast number of autonomous mobility systems."

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*19 SIP: A national project established by the Council for Science, Technology and Innovation within the Cabinet Office, to promote initiatives that span government department frameworks and examine everything from basic research to application and commercialization.

Technology Reports

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Special Articles on Advanced Technologies

Blade-free Drone

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Daizo Ikeda

A "blade-free drone" is a blimp-style drone for safe indoor flying without the use of propellers or flapping wings. It stays afloat through the buoyancy of a balloon filled with helium gas and moves through the air by a propulsive force generated by microblowers that can operate as "air pumps." In this article, we present an overview of this blade-free drone and describe demonstrations in Japan and abroad.

1. Introduction

Unmanned aerial vehicles (hereinafter "drones") that can fly around freely in the air have been attracting attention in recent years and have even been called the "Industrial Revolution in the Air." This can be attributed to the rapid drop in the price of drones and improved performance following the market launch of the AR DRONE®*1 from Parrot in 2010 [1], as well as the ability of drones to fly freely in space, their wide range of application, and the many possibilities they hold. Some examples of drone applications are aerial photography, surveying and inspecting, distribution, agriculture, and rescue services plus various forms of entertainment [2] [3].

However, this expansion of drone use has been accompanied by discussions regarding safety and regulations. For example, a fast-moving propeller or flapping-wing mechanism that collides with a person or thing may not only cause serious injury or harm but also damage the drone itself. The noise generated by drones during flight and short flight times are also issues of concern.

With the above in mind, NTT DOCOMO has proposed a blade-free drone that can fly through

† Worked at Research Laboratories up to March 2019

*1 AR DRONE®: A trademark or registered trademark of Parrot, a French company.

the air using microblowers that eject air through safe and small ultrasonic vibrations as an alternative to a rotating-blade or flapping-wing mechanism [4]. These ultrasonic vibrations are very small in amplitude on the order of micrometers, which makes for safe operation without the risk of injuring a person and very quite operation as well. In addition, the blade-free drone uses these microblowers only when moving through the air in the manner of a blimp, which enables long flight times. For these reasons, we expect this technology to be applicable to people-filled environments in which flight by conventional drones is difficult, such as indoor live events and concerts over the heads of spectators, shopping malls and offices, etc.

In this article, we present an overview of this blade-free drone and describe demonstrations at International Broadcasting Convention 2019 (IBC2019), Europe's largest broadcasting equipment exhibition.

2. Overview of Blade-free Drone

An external view of the blade-free drone is shown in **Photo 1**. The blade-free drone has a maximum diameter of about 90 cm with an airframe weighing about 200 g. However, as explained later, its relative weight when in terrestrial air is 0 g as a result of filling the airframe with helium gas to obtain buoyancy equivalent to the mass of the drone.

The structure of the blade-free drone is shown in **Figure 1**. This drone can be broadly divided into the following three sections:

(1) Balloon to produce an airframe center of buoyancy
(2) Microblowers on the left and right sides of the airframe to produce propulsive force
(3) Other parts in the lower section of the airframe such as battery, control circuit, and plumb for adjusting airframe weight

Each of these sections is described in more detail below.

2.1 Balloon

Having a diameter of approximately 80 cm, the balloon is set at the center of the drone and filled

Photo 1　View of blade-free drone

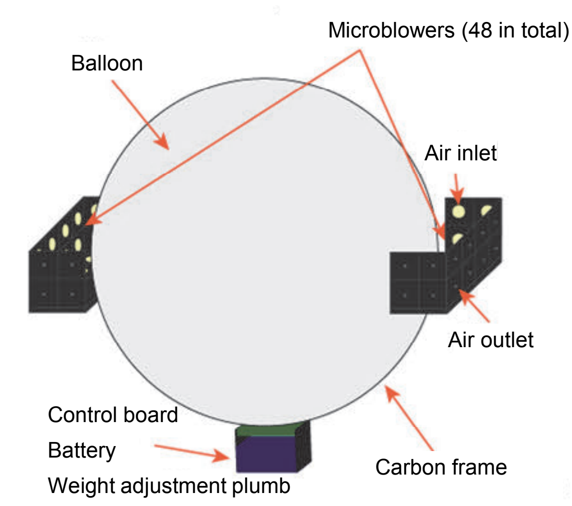


Figure 1　Structure of blade-free drone

with helium gas so as to obtain buoyancy equivalent to the weight of the airframe. It is a commercially available product that is large enough to accommodate the amount of helium gas needed to produce a 200 gworth of airframe buoyancy. The balloon is made of high-strength aluminum metallized film that makes it difficult for helium gas to escape. It is highly crack resistant so that one filling of helium gas obtains enough buoyancy to keep the airframe flying for several weeks. In addition, the balloon can be reused even if the amount of helium gas should decrease with long-term use by simply filling it with more helium, which makes for low-cost operation. The drone is also equipped with a carbon frame surrounding the balloon using tape to attach the former to the latter. Microblowers are installed on the left and right sides of the carbon frame while other parts such as battery, control circuit, and plumb for adjusting airframe weight are installed at the bottom.

2.2 Microblowers

The balloon itself simply floats and requires a separate propulsive force to move about in air on its own. For this reason, our blade-free drone uses microblowers each of which can eject air through ultrasonic vibrations generated by a piezoelectric device as an actuator*2 for obtaining this propulsive force. A piezoelectric device can generate a minute amount of vibration by applying an AC signal, and as such, it has come to be used in a wide range of devices including speakers and ultrasonic motors. The microblower shown in **Figure 2** is an air pump marketed by Murata Manufacturing Co., Ltd. using a piezoelectric device as a drive source.

A conventional air pump takes in and expels gas using a built-in fan and solenoid*3 as a drive

*2 Actuator: A mechanical element which produces a physical force using the energy applied. For example, motors and hydraulic cylinders.

*3 Solenoid: A mechanical element for converting electrical energy to mechanical linear motion using the magnetic effect produced when passing current through a coil of wire.

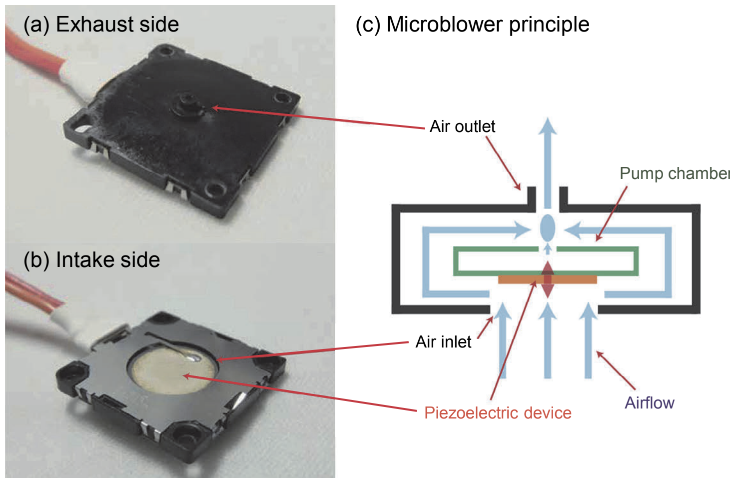


Figure 2 Structure of microblower

source, but with this microblower, the air pump operates by generating ultrasonic vibrations with a piezoelectric device. The microblower is compact and light, and the drive frequency of the piezoelectric device is 26 kHz, which is in the ultrasonic range that can barely be heard by humans resulting in extremely quiet operation. In addition, the amplitude of the built-in piezoelectric device is extremely small on the order of micrometers, which means a highly safe product that eliminates any worries about becoming entangled with fingers or hair. However, in contrast to propeller mechanisms that are frequently used in conventional drones, this microblower produces only a slight amount of airflow. Furthermore, in contrast to rotating blades, it cannot obtain a propulsive force in the opposite direction by reversing operation. To compensate for these shortcomings, we adopted a system that uses a balloon filled with helium gas to generate buoyancy corresponding to the weight of the airframe. This brings the airframe weight to essentially 0 g so that the drone can be moved with only a slight amount of force. As a result, the drone can be steered through the air by simultaneously driving multiple microblowers in the desired direction.

As shown in **Photo 2**, 24 microblowers are installed on either side of the airframe making for a total of 48 microblowers. These 48 microblowers are divided into 6 microblower groups of 8 microblowers each corresponding to the up and down, left and right, and forward and backward directions. The microblowers in each of these directions can be independently controlled, so simultaneously driving the up/down, left/right, and forward/backward microblowers in combination enables movement not only in each of these directions but also in any direction in three-dimensional space. However, pitching*4 and rolling*5 types of rotation cannot be performed since the center of gravity of the drone is located at the bottom of the airframe. On the other

*4 Pitching: Rotation about an axis running from left to right on the airframe.

*5 Rolling: Rotation about an axis running from back to front on the airframe.

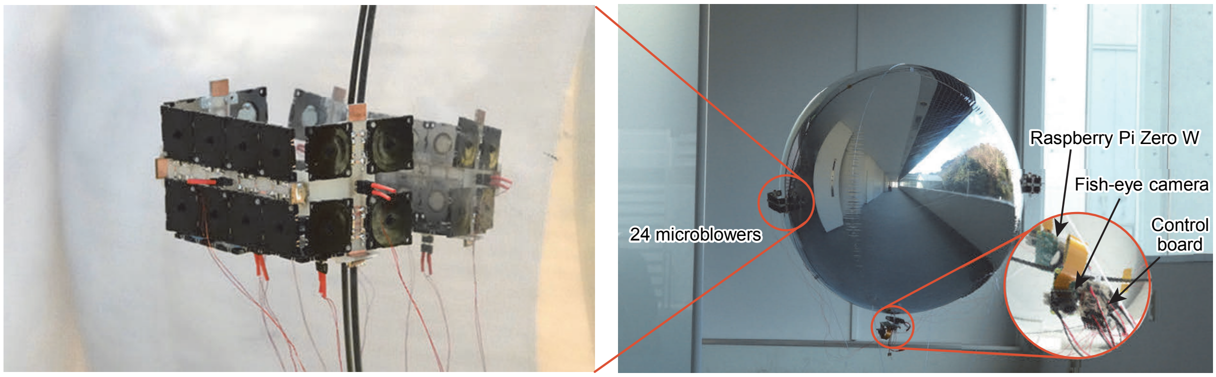


Photo 2 Installation of various parts on airframe

hand, yawing*6, or rotation in the lateral direction, can be achieved by mutually manipulating the microblowers for forward/backward motion attached on the left and right sides of the airframe.

2.3 Lower-section Parts

The lower section of the airframe mounts other parts such as a battery, control circuit, and plumb for adjusting airframe weight. The airframe battery is a 3S 450mAh Li-Po*7 rechargeable battery. Although depending heavily on the type of flight to be performed, a battery of this size can enable flight of about 1 – 2 hours in duration. Drone control is achieved with a Frequency Hopping Spread Spectrum (FHSS)*8 proportional system*9. The control circuit sends a maximum 22.2 V, 26 kHz AC signal to each microblower for control purposes based on signals received from a transmitter. Finally, the plumb for airframe adjustment is a lead ball 1 mm in diameter. The number of plumbs can be adjusted before flight to counterbalance the buoyancy of the airframe. Furthermore, as shown in Photo 2, a wireless camera can be mounted at the bottom of the airframe. Such a camera could be used, for example, to shoot video from above while flying the drone in a people-filled environment such as a shopping mall or office. The video obtained could then be analyzed to provide new security solutions or facilitate marketing by analyzing people flow, etc.

3. Demonstrations

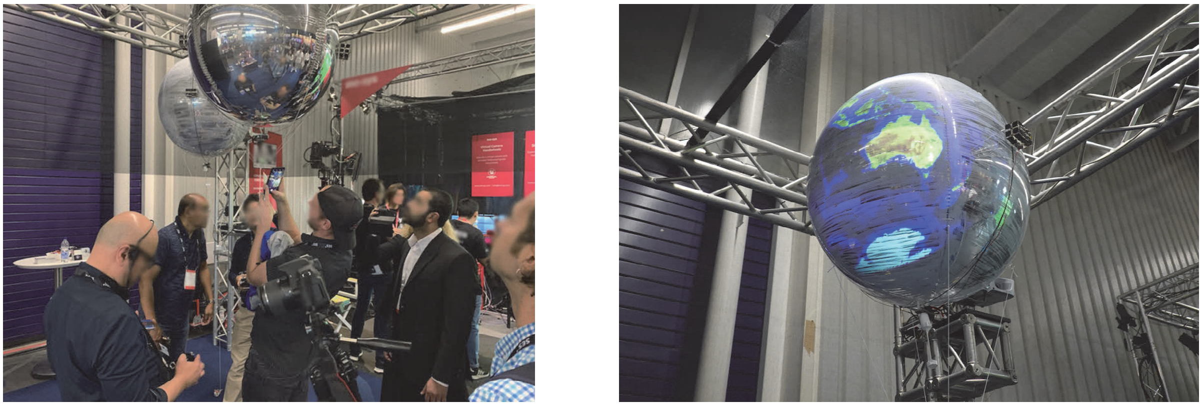
After a press release issued on April 17, 2019, our blade-free drone was exhibited for the first time at "Nippon Telegraph and Telephone Corporation Mikaka Land, NTT Ultra Future Research Institute 6" at "Niconico Chokaigi 2019" held from April 27, 2019. At this exhibit, visitors were asked to pilot the blade-free drone flying within a cage-enclosed booth. The blade-free drone was also presented at International Broadcasting Convention 2019 (IBC2019), Europe's largest broadcasting equipment exhibition, held in Amsterdam from September 2013, 2019. As shown in **Photo 3** (a), this presentation included a demonstration of flying the blade-free drone within the NTT booth with visitors present to showcase its safe and quiet operation. As shown in Photo 3 (b), there was also a demonstration of projecting video onto the

*6 Yawing: Rotation about an axis running up and down on the airframe.

*7 Li-Po: A lithium-ion polymer rechargeable battery.

*8 FHSS: A type of spread-spectrum method used in radio communications that operates by rapidly changing the frequency of signals carrying data.

*9 Proportional system: A system that can steer an airframe in an amount proportional to the pilot's actions.



(a) Flight within booth (b) Video projection

Photo 3 Demonstrations

blade-free drone from an external projector. Combining this drone technology with projection mapping in this way should enable the provision of space design solutions for displaying video in the air.

There is also a floating spherical drone display®*10 as technology for projecting high-resolution video in the air by drone. In contrast to that technology, the technology presented here requires an external projector and suffers from several problems such as low mobility and poor wind resistance. Nevertheless, we expect our blade-free drone to be applicable not only to the space above stages in indoor live performances or concerts but also to the space above spectators as well as to people-filled environments such as shopping malls or offices where the use of drones has traditionally been difficult from a safety perspective.

4. Future Issues

The blade-free drone adopts microblowers instead of propellers or flapping wings used in conventional drones thereby achieving a high degree of safety and quiet operation. Many issues still remain, though, with this technology. For example, the propulsive force of microblowers is very small, and since the drone airframe is large, even a slight breeze from air conditioning equipment can cause the drone to drift. In addition, the drone is slow reaching a maximum flight speed of only 20 cm per second. Moreover, a large balloon filled with helium gas is necessary, so while upsizing is easy, downsizing is difficult. Going forward, we aim to develop an actuator with even greater propulsive force while enhancing wind resistance and mobility so that this blade-free drone can be used to provide practical solutions.

5. Conclusion

In this article, we described a blade-free drone as a new type of drone that can fly without the use of propellers or flapping wings. Following its announcement in a press release, this technology was covered by a variety of television programs, newspapers, and Web news sites in Japan and abroad. The blade-free drone can fly even in environments with people present such as public spaces

*10 Floating spherical drone display®: A trademark or registered trademark of NTT DOCOMO, INC.

and can be used to perform sensing at any location from the air and to output video and audio content. With these capabilities in mind, we consider that the blade-free drone could contribute to the creation of a practical ubiquitous computing environment in the future.

Going forward, we aim to enhance the utility of this technology, develop actuators with even higher output, and develop applications such as projection mapping.

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Pregnancy Mobile Healthcare Personalized Medicine

Collaboration Projects

Joint Research Achievements for Prevention and Early Detection of Disease during Pregnancy —Clarifying Patterns of Change in Lifelogs and Body Substances That Show Signs of Disease—

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Satsuki Kumatani Satoshi Hiyama

Utilizing the NTT DOCOMO Group's mobile healthcare platform to collect and analyze body substances of pregnant women and their daily lifelogs, NTT DOCOMO has clarified patterns of change in lifelogs and specific body substances that indicate signs of pregnancy-related diseases for the first time. This enables the risk of onset of pregnancy-related diseases to be evaluated based on the constitution, physical condition and lifestyle of the pregnant woman. Then, the lifestyle of the pregnant woman can be improved to promote the health of the mother and child. This research was conducted jointly with Tohoku University Tohoku Medical Megabank Organization (Professors Masao Nagasaki, Junichi Sugawara, et al.).

1. Introduction

NTT DOCOMO is working to resolve social issues through its services with the goal of creating value through collaborative creation with various partners. As these social issues are also found in the medical and healthcare fields, NTT DOCOMO is also promoting R&D to solve problems in various stages of life such as lifestyle-related diseases and hence contribute to the realization of healthy and fulfilling longevity, especially through prevention of diseases such as hypertensive disorders and diabetes during pregnancy, a major event for women and their families, and for their children who are starting out in life.

Pregnancy-related diseases (hypertensive disorders of pregnancy, gestational diabetes, preterm birth, fetal growth retardation, etc.) affect the health of mothers and infants throughout pregnancy and postpartum. Approximately 20% of pregnant women are affected with these diseases in Japan. Many of these diseases are caused by complex interactions of genetic and environmental factors. Therefore, comprehensive analysis of genetic factors and keeping track of changes in environmental factors are crucial to understanding the cause of these diseases. Until now, many research institutions and local governments have obtained environmental information using questionnaires, but this has been limited in its frequency of acquisition and accuracy due to self-reported questionnaires only being acquired about once every six months. In addition, research that comprehensively tracks changes in body substances*1 in the blood and urine samples of pregnant women weekly or more frequently and research that comprehensively analyzes differences in the lifelogs*2 and body substances between pregnant women who became ill and those who gave birth without getting ill, have not been performed.

To address these issues, this research aimed to frequently collect the daily lifelogs (blood pressure, heart rate, room temperature, body temperature, body weight, physical activity, physical condition, sleep status, fetal movement, meal content, medication content, etc.) and body substances (DeoxyriboNucleic Acid (DNA)*3, RiboNucleic Acid (RNA)*4, metabolites and bacterial flora*5, etc) of pregnant women as objective numeric values, and analyze this data to understand the changes in lifelogs and physiological conditions to establish personalized prevention and early detection methods of diseases that occur during pregnancy [1] [2]. As a result, we built one of the world's largest research databases on pregnant women, and were able to identify patterns of change in lifelogs and body substances that indicate signs of disease.

This article describes an overview of this research, details of its findings, the expected value of it and the outlook for the future.

This research was conducted jointly with Tohoku University Tohoku Medical Megabank Organization (Professors Masao Nagasaki, Junichi Sugawara, et al., hereinafter referred to as ToMMo).

2. Overview of the Research

2.1 Flow of the Research

NTT DOCOMO and ToMMo began joint research for the prevention and early detection of pregnancy-related diseases on November 19, 2014 [3]. From September 14, 2015 to November 15, 2016, we recruited pregnant women at the Tohoku University Hospital for this research, under the name "maternity log study." 302 pregnant women were recruited and gave their written informed consent [4]. Also, from November 15, 2016, we began integrated analysis of lifelogs and body substances obtained from participants [4]. We concluded the joint research on March 31, 2019 after producing a range of findings which are discussed later.

2.2 The Roles of NTT DOCOMO and ToMMo

The lifelogs of pregnant women were collected daily using the mobile healthcare platform operated by the NTT DOCOMO Group (**Figure 1** (1)). Collection of biological samples such as blood, urine and dental specimens of pregnant women was carried out at Tohoku University Hospital adjacent to ToMMo (Fig. 1 (2)). NTT DOCOMO and ToMMo collaborated to convert information about body substances included in these biological samples into data (Fig. 1 (3)). This enabled us to build a comprehensive database capturing the lifestyles and

*1 **Body substances:** Substances in blood, urine and dental specimens, etc., from which information about DNA, RNA, metabolites and bacterial flora can be obtained.

*2 **Lifelog:** A record reflecting the health status and lifestyle habits of an individual, including blood pressure, heart rate, room temperature, body temperature, body weight, physical activity, physical condition, sleeping conditions, fetal movement, diet and medication details, etc.

*3 **DNA:** A substance carrying genetic information in an organism and consisting of deoxyribose and phosphoric acid, and four types of nucleobases: adenine, guanine, cytosine, and thymine.

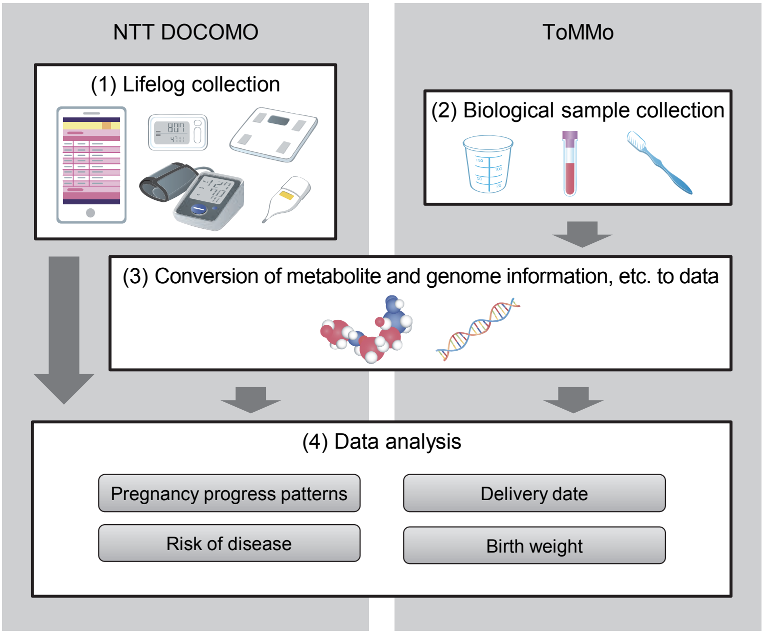

Figure 1 The roles of NTT DOCOMO and ToMMo

physical conditions of the pregnant women during pregnancy. After that, NTT DOCOMO and ToMMo combined DOCOMO's big data analysis technologies it has fostered through analysis of various time series data and AI technologies such as machine learning*6 with ToMMo's information analysis technologies such as genome*7 and life & information science technology to jointly analyze the data (Fig. 1 (4)).

3. The Data Platform

3.1 Lifelogs

As shown in **Table 1**, the daily lifelogs of pregnant women were collected using various devices and applications. The registration rate, which indicates the degree to which lifelogs were measured and input, was approximately 80% or more for most items during pregnancy, which was an amount of data sufficient to comprehensively analyze the daily activities and physical conditions of the pregnant women (**Figure 2**). In the end, the collected lifelogs contained a total of approximately 6 million items of data [4] [5].

3.2 Body Substances

To collect biological samples containing body substances such as blood and urine samples, blood and dental specimens were collected twice during pregnancy and once after birth. In addition, urine samples were collected each routine antenatal visit,

*4 RNA: A substance transcribed using DNA as a template, and composed of ribose and phosphoric acid, and four types of nucleobases: adenine, guanine, cytosine, and uracil. While DNA primarily plays the role of accumulating and preserving information in the nucleus, RNA is responsible for temporary processing of that information.

*5 Bacterial flora: The community of bacteria growing in a certain environment.

*6 Machine learning: A technology that enables a computer to learn useful judgment standards through statistical processing from sample data.

Table 1 List of collected lifelog items

Item	Device or application used		Details of measurement	No. of measurements per day	Measurement, input timing	Time required
Body temperature		Electronic thermometer for women	Basal body temperature	Once	After getting up, lying down	Approximately 10 seconds
Body weight		Weight and body composition meter	Body weight	Once	On principle, within 1 hour of getting up (after using the toilet)	Approximately 4 seconds
Blood pressure		Upper arm blood pressure monitor	Blood pressure, heart rate	Twice	On principle, within 1 hour of getting up (after using the toilet) Before bedtime (after using the toilet)	Approximately 1 minute
Physical activity		Activity monitor	No. of steps, calories consumed	Carried always	–	–
Sleep		Pre-Mama health app (Developed by NTT DOCOMO Research Laboratories)	Bedtime/getup time Quality of sleep No. of wake ups during sleep	Once	Optional	Approximately 10 seconds
Nausea			Time taken feeling nauseous No. of times dry vomiting, vomiting	Once	Optional	Approximately 10 seconds
Uterine contractions, etc.			Uterine contractions, bowel movements Level of pain in each area Palpitations	Once	Optional	Approximately 10 seconds
Fetal movement			Time taken to feel 10 fetal movements	Once	Time slot when fetal movements feel strongest *Measured after the 24th week of pregnancy	Approximately 3 to 10 minutes

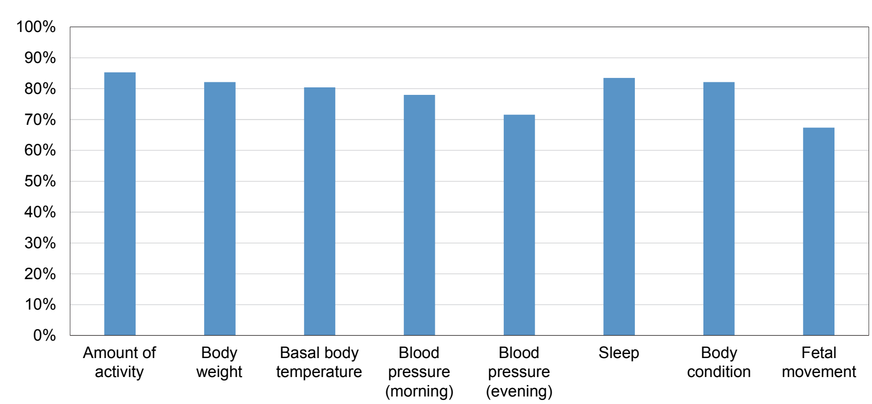

Figure 2 Lifelog registration rates

*7 Genome: All the genetic information in all the base sequences of the DNA constituting an organism's chromosomes.

which finally resulted in approximately 8,000 samples collected [3] [5]. As shown in **Table 2**, analysis of the information on the body substances in these specimens resulted in the accumulation of large amounts of data on multiple layers such as genes and metabolites. This enabled understanding of processes that lead to symptoms of disease and changes in physical condition due to the influences of genetic and environmental factors.

4. Findings of the Research

Integrated and chronological analysis of the above lifelogs and body substances revealed many new findings on pregnancy-related diseases. This chapter describes three of the main research findings.

4.1 Determining Patterns of Change in Lifelogs as Signs of Pregnancy-related Diseases

The database we built enabled a general understanding of the dynamic changes of various lifelog items as pregnancy progresses. For example, as pregnancy progresses, **Figure 3** shows increasing frequency of uterine contractions and increasing weight, while basal body temperature and daily physical activity decrease. Significant differences

Table 2 Body substance information collected from specimens

Biological sample collection	Body substance information
Blood	Millions of genetic mutations
Blood	Tens of thousands of RNA expression levels (multiple time points)
Blood, urine	Hundreds of metabolite levels (multiple time points)
Saliva, plaque	Composition ratio of hundreds of bacterial flora (multiple time points)

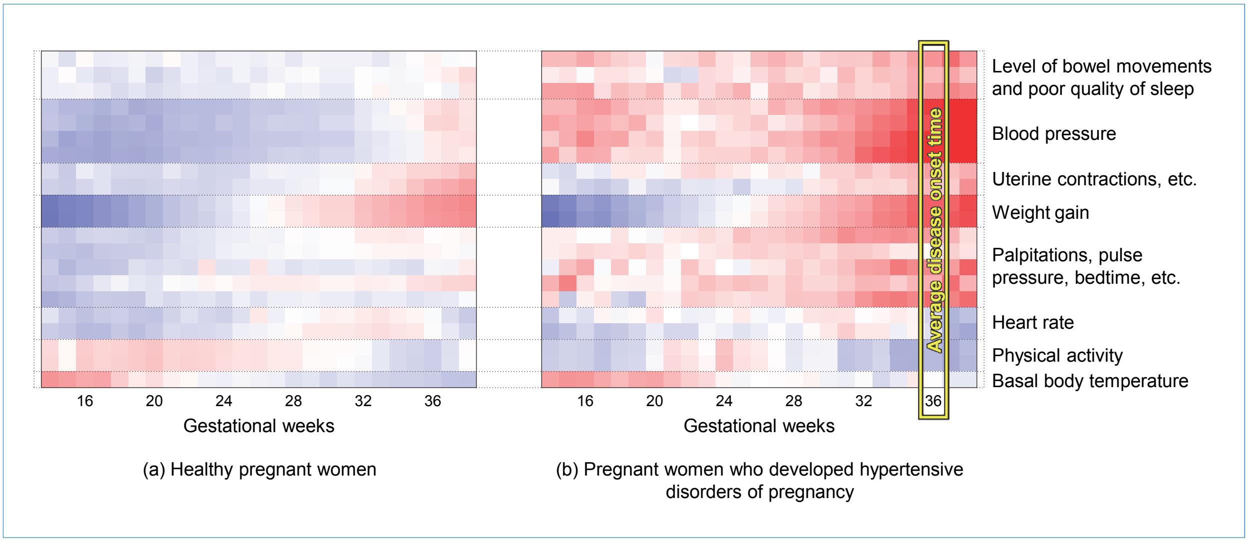

Figure 3 Patterns of lifelog change during pregnancy (red is high, blue is low)

were also found in the fluctuation patterns of various lifelogs between healthy pregnant women and pregnant women who developed pregnancy-related diseases. For example, the results clarified that pregnant women who developed hypertensive disorders of pregnancy tended to have higher home blood pressure from an earlier stage than healthy pregnant women, and that their quality of sleep was poor throughout their pregnancy. Please note that we plan to publish the details in academic journals.

These results enable AI detection of the onset of disease from lifelog fluctuations, suggestions for lifestyle improvements for pregnant women who are likely to develop disease, and enable early examination and treatment by obstetricians or other doctors, and therefore hold promise for personalized prevention and medical treatment to prevent the onset of disease.

4.2 Identification of Metabolites Useful for Predicting Delivery Date

Examination of the relationship between the delivery date in cases in which the child was born at full term and related changes in metabolites in urine and blood samples revealed that there was a characteristic change in specific metabolite concentrations as the delivery date approached. For example, a metabolite was identified in the urine samples that increased in concentration continuously from approximately two weeks prior to delivery until the delivery date **(Figure 4)**. Using several combinations of these metabolite concentration changes makes it possible to predict the delivery date with AI, which will be useful to pregnant women and their families for planning for the date of delivery. This also enables medical institutions to prepare for delivery in advance, which should contribute to safer births. We plan to report the details of delivery date prediction at the Society

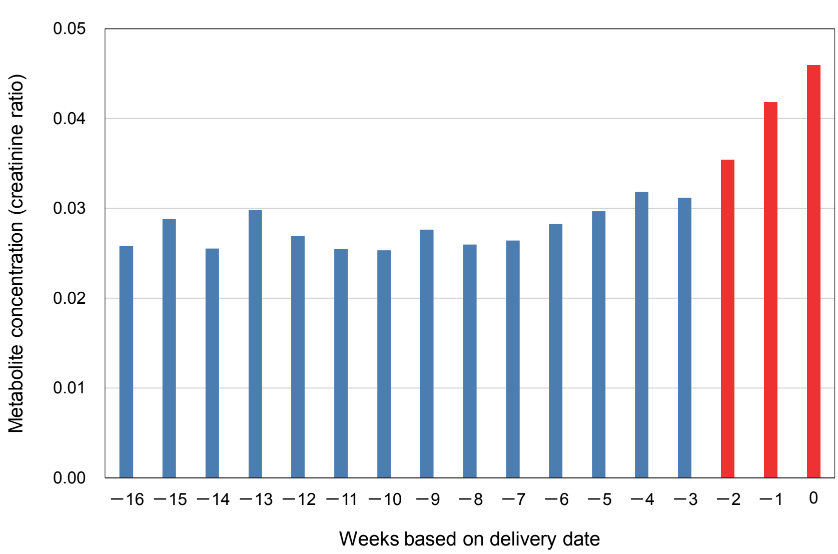

Figure 4 Changes in concentration of metabolite A in urine samples up to delivery date (red: characteristic changes)

for Reproductive Investigation (SRI) 2020 [6], the world's largest international conference on perinatal medicine.

4.3 Identification of Genetic Mutations Useful for Birth Weight Prediction

In recent years, low birth weight infants are increasing in Japan. To investigate the genetic association, we searched for genomic mutations in pregnant women related to birth weight, and identified genetic mutations specifically related to birth weight. Each occurrence of this gene mutation was found to reduce birth weight by an average of approximately 400 to 500 g (**Figure 5**). These results make it possible to know in advance genetically whether there is a risk of an infant being born with low weight, and thus hold the promise of realizing personalized prevention and medical care that enables early diagnosis and treatment by an obstetrician or other physician if there is a high risk of low birth weight.

5. Conclusion

Regarding research conducted by NTT DOCOMO and ToMMo aiming to establish methods of prevention and early detection of illnesses in pregnant women, this article has described an overview of the research we conducted, the big data we accumulated, our research findings, and the outlook for the future. As part of its "+d®*8" initiative to collaborate with partners to create new value, NTT DOCOMO will work to further verify the results of this joint research and put them to practical use to achieve a society in which more pregnant women can give birth safely without being affected by illness (**Figure 6**). We would like to extend the early detection and prevention of illnesses beyond pregnant women and contribute to extending the healthy life expectancy*9 of citizens.

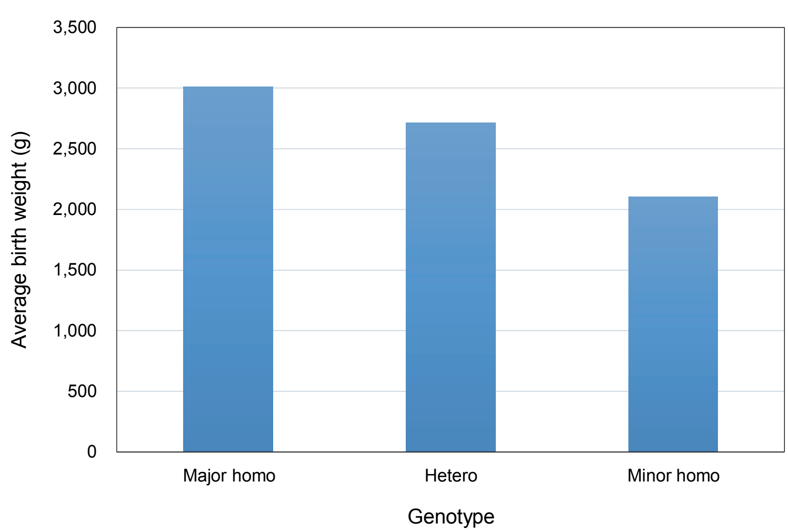

Figure 5 The relationship between genetic mutation B and birth weight

*8 +d®: A NTT DOCOMO medium-term initiative to move forward with its partner companies to create added value in various business areas. A trademark or registered trademark of NTT DOCOMO, INC.

*9 Healthy life expectancy: The expected period of good health in daily life.

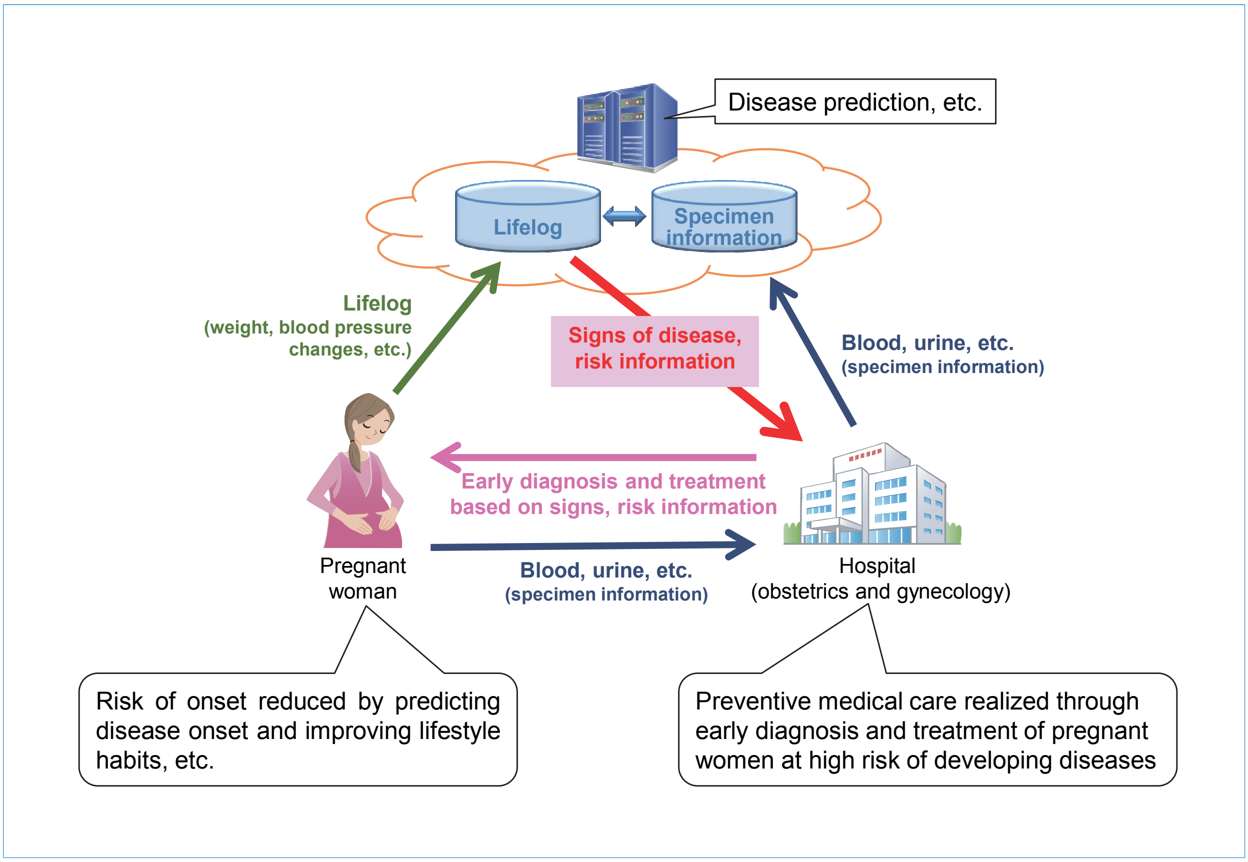

Figure 6 Examples of social implementation of research results

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Technology Reports

CDC-ROADM WSS MCS

Improving the Reliability of Optical Transmission Networks with CDC Technology

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The recent intensification of natural disasters has resulted in disconnected optical transmission lines leading to large-scale communications service failures and problematic recovery times. One possible solution to achieve continuously connected optical transmission networks is the introduction of CDC ROADM for optical transmission lines, which would improve transmission line redundancy and shorten recovery times by switching to detour routes. In this article, we explain an overview of the CDC ROADM and its CDC elemental technology, which NTT DOCOMO began introducing in 2017.

1. Introduction

Conventional optical transport equipment (Reconfigurable Optical Add/Drop Multiplexer (ROADM)*1) secures 1:1 redundancy by using working/detour transmission lines (two directional paths). However, if a transmission line failure occurs on both the working and detour transmission lines due to a large-scale natural disaster, communications services will be interrupted until one of the lines is restored. Also, recovery from a fault may require cable re-laying or splicing work on site, dispatching engineers to the disaster-stricken area could be problematic, and complete service recovery may take a lot of time.

Giving multiple routes to optical transmission lines is a possible solution to this problem. Introduction of optical transport equipment with Colorless, Directionless and Contentionless (CDC) functions, elemental technologies to achieve multiple

*1 ROADM: An optical multiplex system that branches and inserts optical signals.

routing (hereinafter referred to as “CDC ROADMs”), can secure 1: N redundancy with multiple detour transmission lines (N). This also makes it possible to switch to a transmission line that is not damaged by remote switching by the user or autonomous switching of the equipment, which greatly reduces the time required for service recovery.

In this article, we describe an overview of CDC ROADMs and their CDC elemental technology, which NTT DOCOMO began introducing in 2017.

2. Issues with Conventional Networks

Conventional DOCOMO repeated transmission lines entail large-scale optical infrastructure constructed using e-OADM*2 optical transport equipment [1]. The e-OADM optical transport equipment consists of TransPoNDers (TPND)*3, optical wavelength multiplexing/demultiplexing units, and amplifiers (**Figure 1**). The TPND accommodates client equipment such as routers, and has functions for mutual conversion of the transmission/reception signals of client equipment and e-OADM optical transport equipment (electrical signal <--> optical signal, etc.), and connects to an optical wavelength multiplexing/demultiplexing unit for the desired output directional path. The optical wavelength multiplexing/demultiplexing unit has a multiplexing

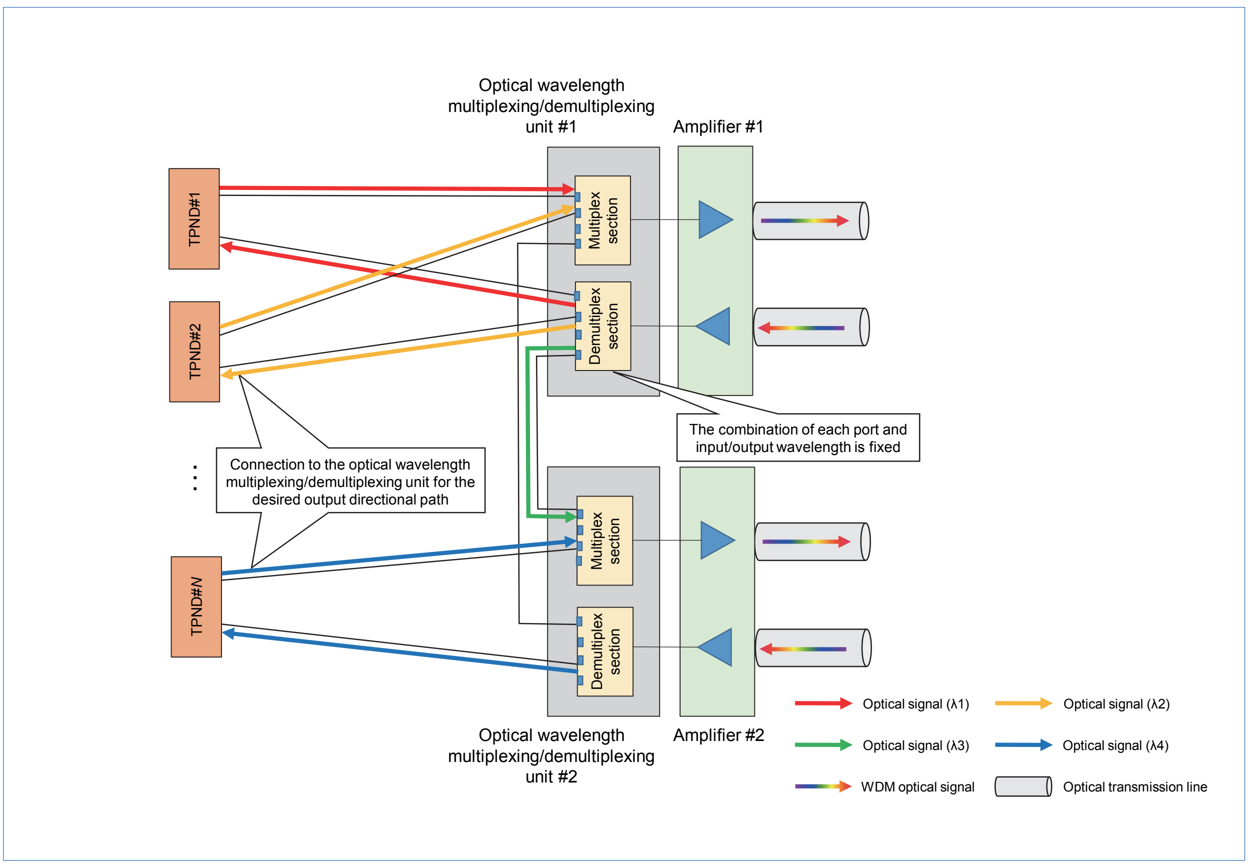

Figure 1　Image of e-OADM optical transport equipment configuration

*2　e-OADM: A compact, low power consumption ROADM.

*3　TPND: A functional section that interconverts signals received and transmitted with client equipment and optical signals transmitted and received with optical transport equipment.

unit for multiplexing multiple optical signals input from the TPND and a demultiplexing unit for demultiplexing Wavelength Division Multiplexing (WDM)*4 signals received from the transmission line. Multiplexing and demultiplexing use Arrayed Waveguide Gratings (AWG)*5. The combination of I/O wavelengths and ports*6 is fixed. Erbium-Doped Fiber Amplifiers (EDFA)*7, etc. are used for the optical amplifiers, which have functions to adjust optical signals to a level that can be received by the TPND or the opposing optical transport equipment.

Since the e-OADM optical transport equipment can output optical signals to a maximum of two directional paths, constructing a ring configuration*8 is an effective way to ensure redundancy of the transmission lines. **Figure 2** (a) shows the signal flow when a ring configuration is constructed using e-OADM optical transport equipment. In this configuration, when a failure occurs on a single directional path, services can be continued by using a transmission line on which no failure has occurred. However, as shown in Fig. 2 (b), if a failure occurs on two directional paths, communication between client equipment becomes impossible and service interruption occurs. On-site work is required to restore the transmission line to eliminate the service interruption. The interruption may be prolonged, depending on the details of the transmission line failure. If transmission line failure recovery is difficult, a new connection to another transmission line that does not pass through the faulty section could be selected, although this could still result in prolonged service interruption because it would require transmission line design or on-site package reseating and wiring.

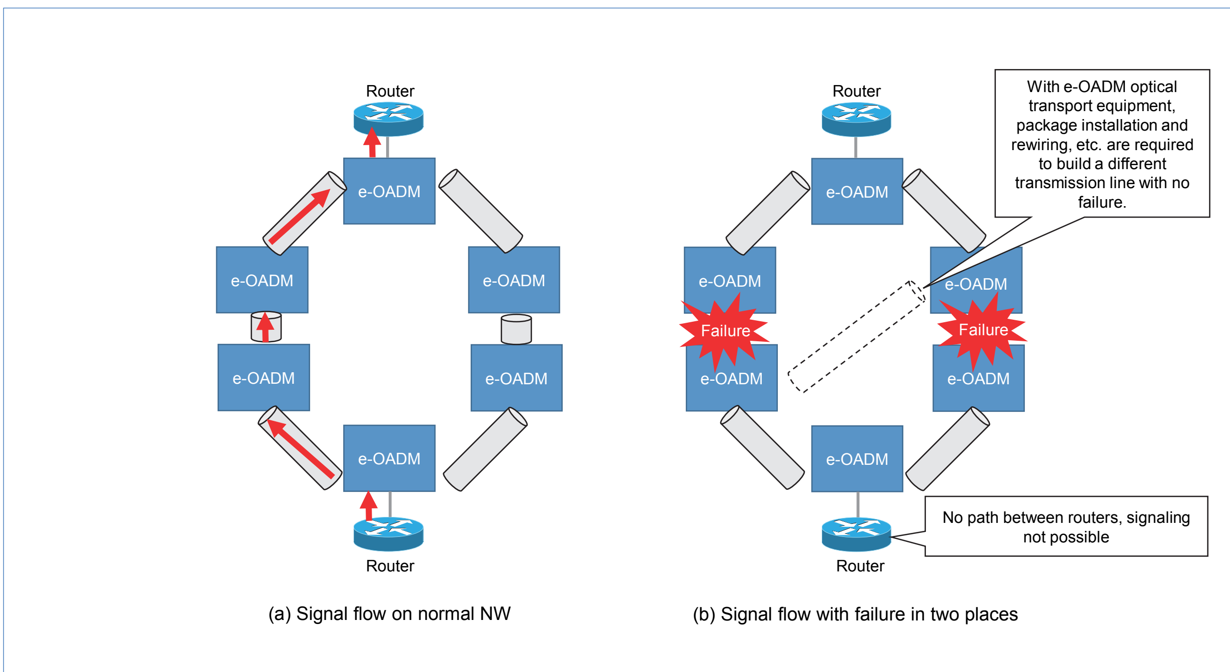

Figure 2 Example signal transport routes in the ring configuration

*4 WDM: Technology to transmit multiple optical signals with different wavelength on one optical fiber.

*5 AWG: An optical component that enables multiplexing and demultiplexing of multiple different wavelengths.

*6 Port: A physical interface for exchanging data with other equipment.

*7 EDFA: A type of optical amplifier for raising the level of optical signals.

*8 Ring configuration: A type of network topology that entails optical transport equipment connected in a ring.

3. Networks Achievable with CDC ROADM

CDC ROADM makes it possible to construct a mesh configuration*9 by connecting to three or more directional paths with the CDC functions and output optical signals on any transmission line without the need to install packages or change wiring. **Figure 3** (a) and (b) show the flow of signals in the mesh configuration. When a failure occurs on multiple transmission lines, services can be continued by using transmission lines on which no failure has occurred.

3.1 CDC ROADM Configuration

Figure 4 shows an image of the functional parts of CDC ROADM and the CDC functions. CDC ROADM is configured by combining TPNDs, a MultiCast Switch (MCS), Wavelength Selective Switches (WSS) [2] and amplifiers. The TPND and the amplifier have the same function as the e-OADM optical transport equipment. The MCS has an $N \times M$ switching function that outputs optical signals input from the TPND side and the WSS side to an arbitrary port. WSS consists of a demultiplexing unit that demultiplexes the WDM signals input from the transmission line side, a switching unit that outputs the demultiplexed optical signals to an arbitrary port, and a multiplexing unit that multiplexes the optical signal input from the TPND side. Combining the elements of MCS and WSS makes it possible to realize the CDC function and establish a maximum of M directional paths to ensure redundancy.

3.2 CDC Function Overview

CDC is an abbreviation that stands for the colorless, directionless and contentionless functions.

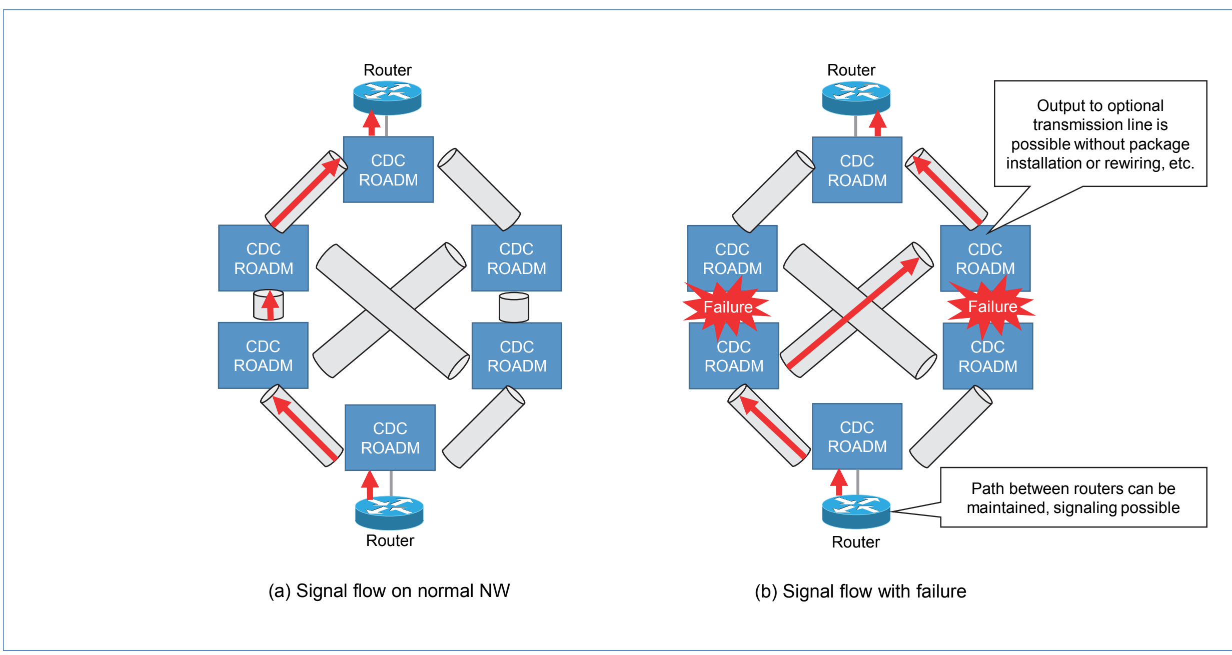

Figure 3 Example signal transport routes in the mesh configuration

*9 Mesh configuration: A type of network topology in which multiple pieces of optical transport equipment are connected to each other in a mesh.

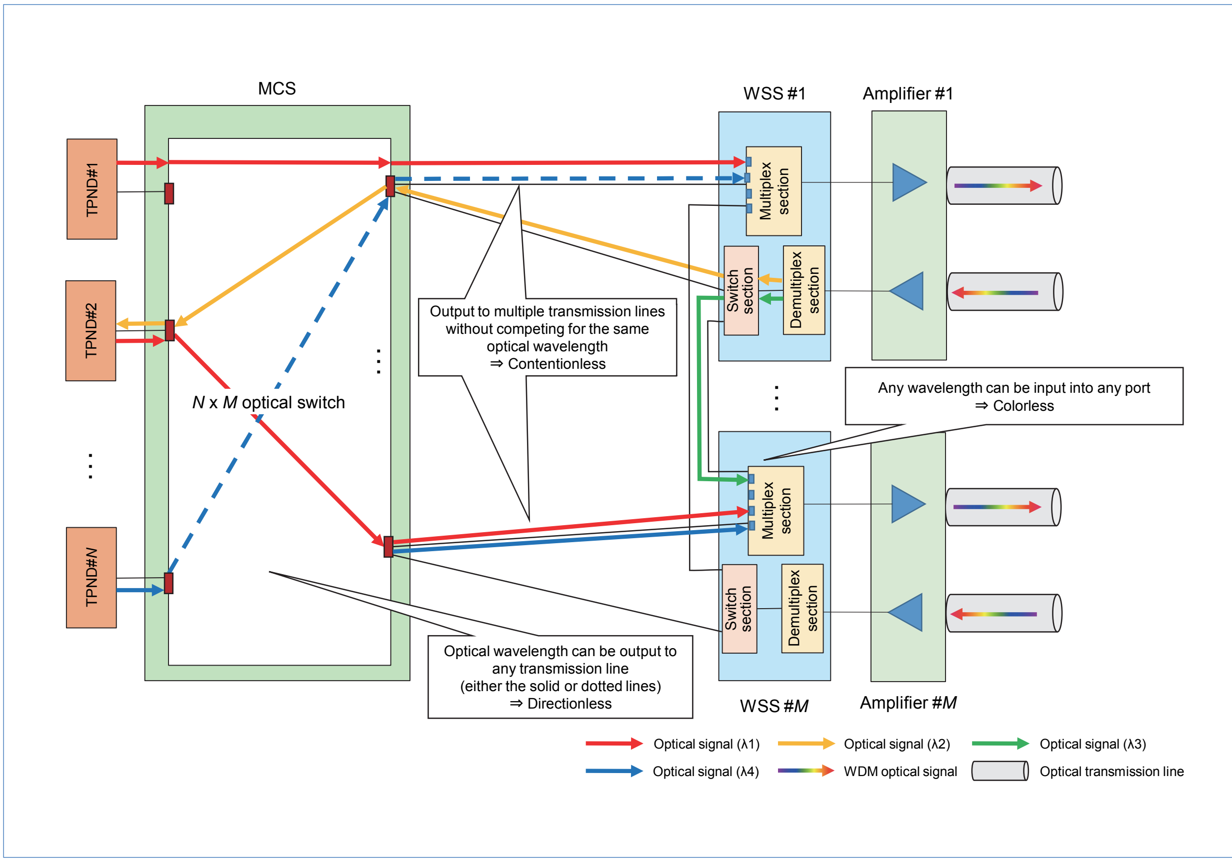

Figure 4　Image of the functional parts of CDC ROADM and the CDC functions

Combining these functions makes it possible to output optical signals with arbitrary wavelengths to arbitrary transmission lines to provide an efficient network operation.

1) Colorless Function

The colorless function assigns an arbitrary wavelength to each port of the multiplexing and demultiplexing units. If equipment does not have a colorless function, the wavelengths that can be input for each port of the multiplexing and demultiplexing functions are fixed. For this reason, if it was necessary to change the wavelength, on-site work to change port connections was required. In contrast, the colorless function enables input with an arbitrary wavelength at each port of the multiplexing and demultiplexing units, which eliminates the need to change port connections on site to change wavelengths, and can be done just by changing equipment settings.

2) Directionless Function

The directionless function enables output of an optical signal with a specific wavelength to an arbitrary transmission line. If equipment does not have the directionless function, the output destination for an optical signal of a specific wavelength is fixed to one transmission line. For this reason, if it is necessary to change the destination transmission line, on-site work to change port connections, etc. will be required. In contrast, equipment with the directionless function enables optical signal output to an arbitrary transmission line by utilizing the MCS or WSS optical switch functions. Therefore, destination transmission lines for output can be switched just by changing equipment settings.

3) Contentionless Function

The contentionless function outputs the same optical wavelength to multiple transmission lines so that there is no conflict in equipment that has the colorless and directionless functions. This enables efficient transmission line switching when failures occur.

3.3 Signal Flow on Normal Transmission Lines

Figure 5 shows the route of the optical signal when a mesh configuration optical transmission network is constructed by combining CDC ROADMs. An optical signal from TPND#A2 of CDC ROADM #A (hereinafter referred to as #A) to TPND#C1 of CDC ROADM #C (hereinafter "#C") is transmitted to WSS#A2 by MCS#A, and output to the optical transmission line to which WSS#A2 is connected. Then, WSS#C2 receives the optical signal and sends it to TPND#C1 via MCS#C.

Similar to the optical signal of TPND#A2, the optical signals transmitted from TPND#A1 and

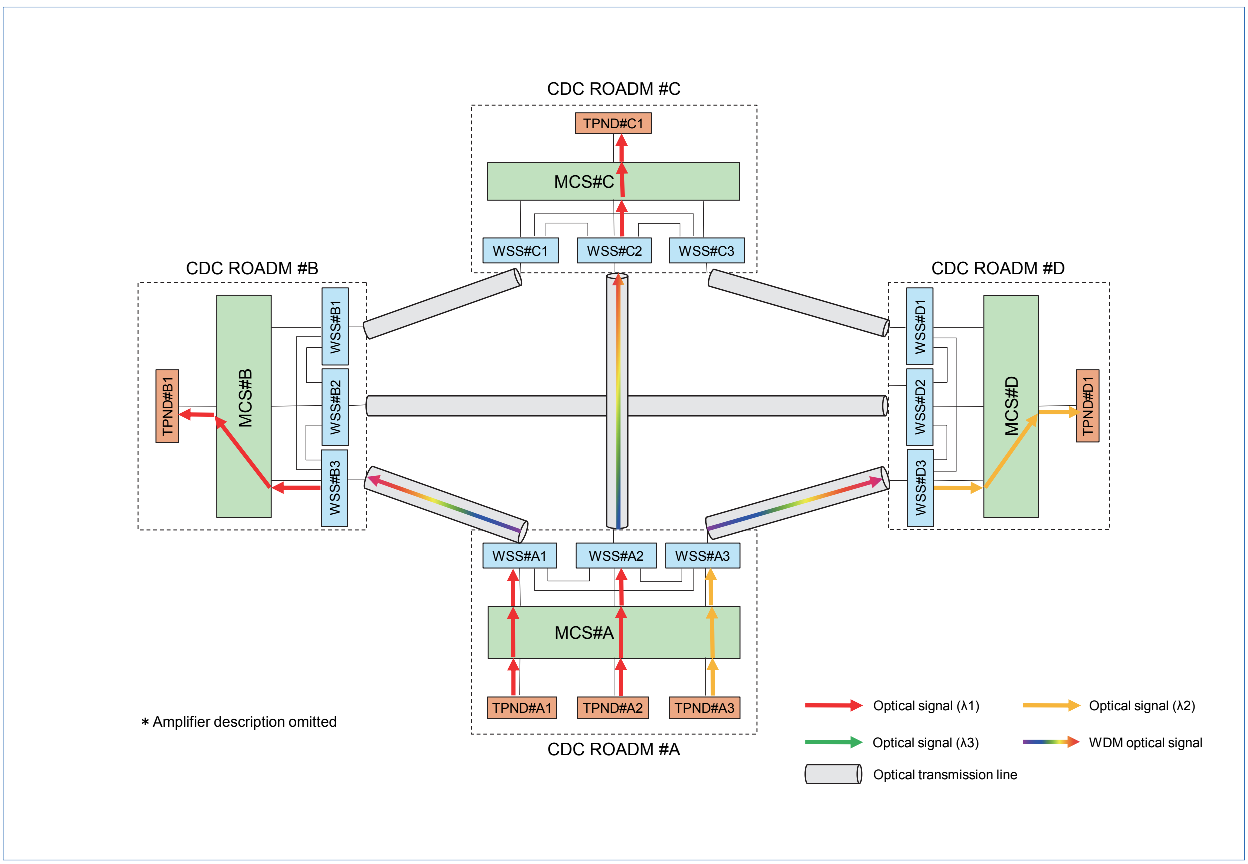

Figure 5 Example of signal routes in a mesh configuration with 4 CDC ROADMs

TPND#A3 are output to arbitrary directional paths by MCS#A. Here, optical λ1 signals are sent to multiple transmission lines without confliction by the contentionless function.

3.4 Signal Flow When Failures Occur on Transmission Lines

1) With an Optical Transmission Line Failure between #A and #C

Figure 6 shows the signal route when an optical transmission line failure occurs between #A and #C in the mesh configuration with four CDC ROADMs shown in Fig. 5.

The optical signal (λ1) of TPND#A2 sent via #A and #C is switched from WSS#A2 to WSS#A3 by MCS#A, and is multiplexed with the optical signal (λ2) of TPND#A3 and output to the transmission line for CDC ROADM #D (hereinafter "#D"). After arriving at #D, the optical signal of TPND#A2 is demultiplexed at WSS#D3, switched to the WSS#D1 direction and output to the transmission line for #C. After arriving at #C, the signal is switched to the direction of MCS#C by WSS#C3 to arrive at TPND#C1. Thus, if an optical transmission line failure occurs between #A and #C, it is possible to bypass the failure and reach the target TPND. Here, the optical signal of TPND#A2 is switched to #C via #D by the directionless

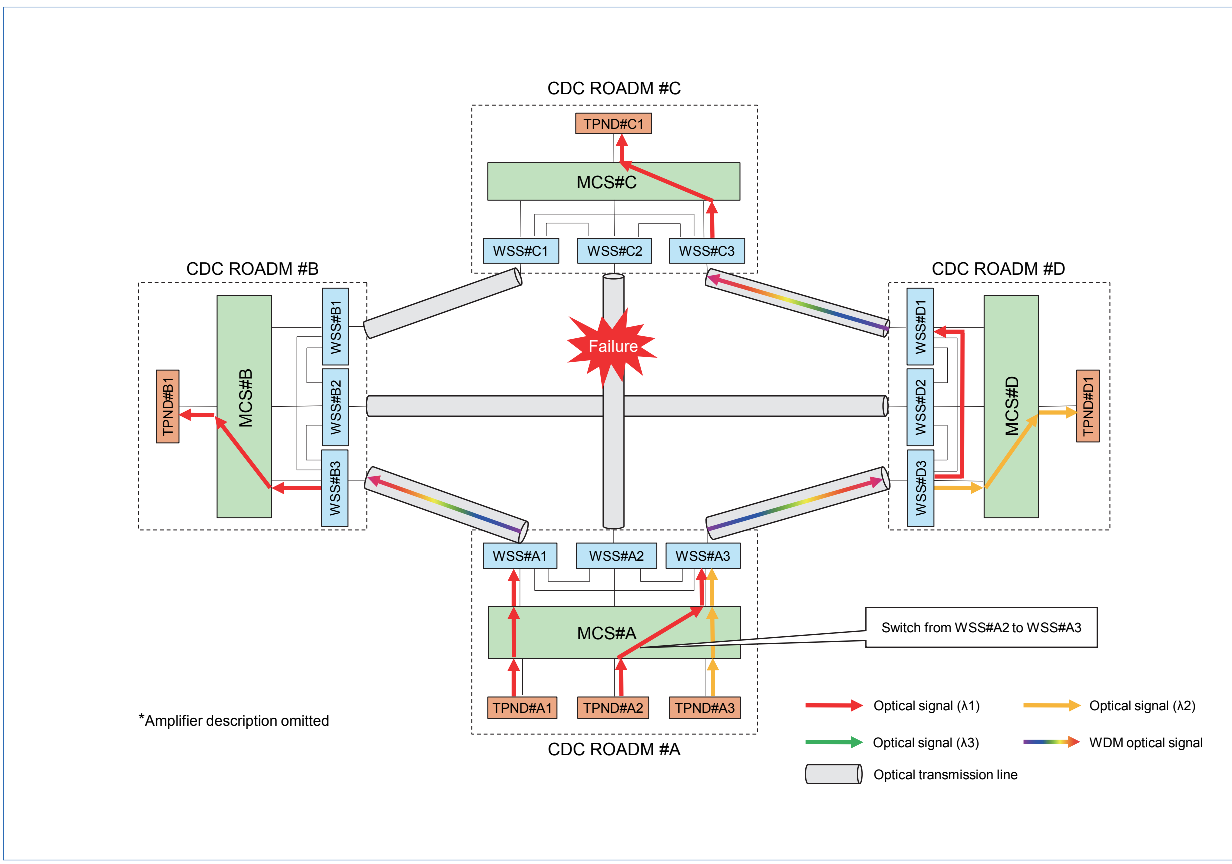

Figure 6 Example of signal route with transmission line failure between #A and #C

function without the need for work such as on-site port connection changes.

2) With Optical Transmission Line Failures between #A and #C, and #A and #D

Figure 7 shows the signal route when an optical transmission line failure also occurs between #A and #D, in addition to the state described in Fig. 6. TPND#A2 changes the wavelength (λ3) that is not overlapping with TPND#A1 to output an optical signal from the transmission line for #B where no failure has occurred, and MCS#A switches the transmission line from WSS#A3 to WSS#A1. Then, the optical signal is multiplexed with another wavelength and output to the transmission line for #B. After arriving at #B, the optical signal of TPND#A2 is demultiplexed at WSS#B3, switched to the WSS#B1 direction and output to the transmission line for #C. After arriving at #C, the signal is switched to the MCS#C direction by WSS#C1 to arrive at TPND#C1. Similarly, the optical signal of TPND#A3 can arrive at #D by MCS#A switching the transmission line through #B. This makes it possible to switch to a normal transmission line even if a failure occurs on two transmission lines. Also, if the same wavelength exists on the switch destination route, the wavelength can be changed to a non-overlapping wavelength by the colorless function of CDC ROADM.

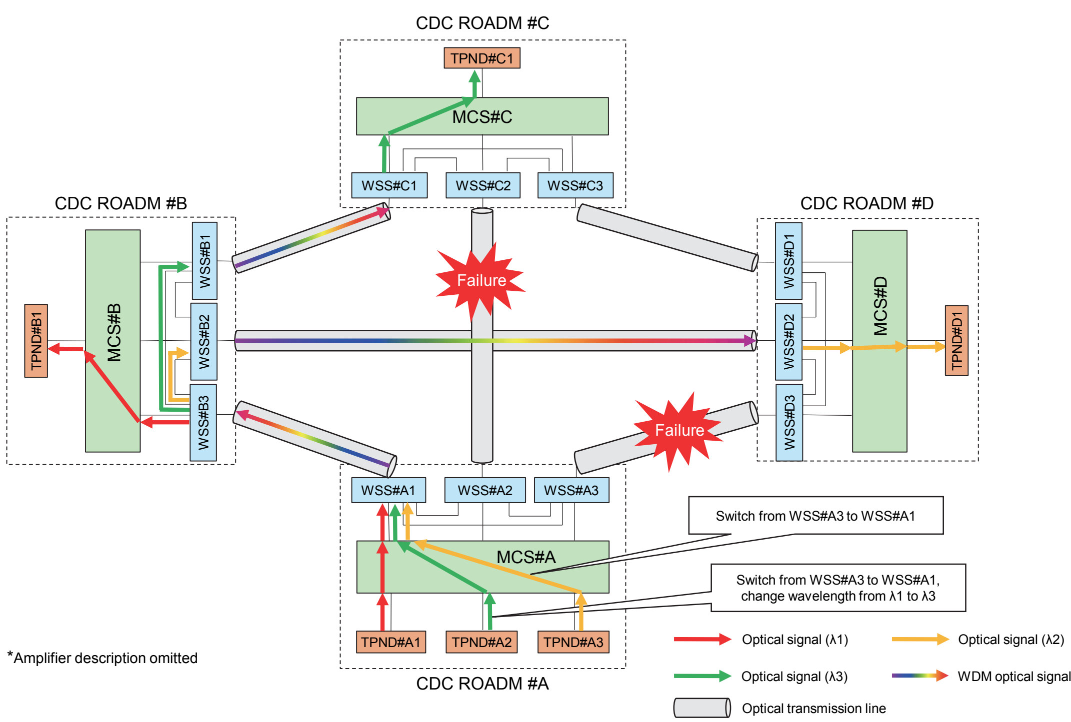

Figure 7 Example of signal route with transmission line failures between #A and #C, and #A and #D

4. Conclusion

This article has described an overview of CDC ROADM and its CDC elemental technology.

As described above, CDC ROADM using CDC technology enables detour by selecting one of multiple routes, which greatly shortens the duration of service interruptions, even in the event of a disaster, and enables construction of optical transmission networks that are continuously connected.

For future support of 5G, realization of more than 100G per wavelength (Beyond100G) will be required to increase the capacity of the inter-branch transmission lines that bundle the traffic of the backbone network. We would also like to study ultra-low power consumption to enable node configuration regardless of the installation location to achieve low latency in consideration of various applications such as eHealth and autonomous driving, and connections to controllers to achieve wavelength visualization in response to the increasing numbers of wavelengths accompanying the larger capacities.

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Technology Reports | Automatic Scoring | Deep Learning | Language Processing

Technology to Grade and Correct Compositions in English

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English education in Japan in recent years emphasizes higher thinking and expression capabilities and requires well-balanced acquisition of the four skills of "listening," "reading," "writing" and "speaking." Among these, NTT DOCOMO has focused on the work of grading English compositions, i.e., "writing," and has developed technology to automatically grade and correct answers with AI. Once used to only evaluate the correctness of vocabulary and grammar, automatic grading can now also capture the meaning of an entire sentence to grade and correct it. This article describes an overview of this technology and its application.

1. Introduction

With globalization, English education in Japan in recent years has come to require well-balanced acquisition of the four skills of "listening," "reading," "writing" and "speaking," with an emphasis on higher thinking and expression capabilities. This has led to attention being focused on automatic grading systems that reduce the burden of grading and correcting as the number of English composition questions inevitably increases in various exams measuring English ability. Against this background, NTT DOCOMO has developed an English composition grading and correction technology that uses deep learning[*1] to grade and correct learners' English compositions. This English composition grading/correction technology can grade English composition for Japanese sentences that don't exist in learning data by making computers learn large amounts of bilingual corpus[*2] of Japanese to English

*1 Deep learning: A type of machine learning method that entails using large amounts of data to teach a computer capabilities that simulate human intelligence.

*2 Corpus: A language resource consisting of a large volume of text and utterances, etc. collected and stored in a database.

translations. The grading process entails expressing the meaning of the Japanese examination sentence as a vector, and generating an answer for it in English from that vector. Depending on the examination sentence, there could be several possible patterns of English that could be answers. The process of generating answers in English from the above Japanese sentence vectors aims to generate and grade English sentences that are closest to the expression of the learner's English composition to grade it. Therefore, if the learner's expression is different from the sample answer but nonetheless conveys the correct meaning, it will be graded highly.

In the past, an English composition was graded based on how close it was to a sample answer, i.e., how many words the answer contained with the same vocabulary and syntax (grammar) as the sample answer. However, with this technology it's also possible to grade for paraphrasing.

This article describes an overview of technology to grade and correct compositions in English.

English compositions can be broadly classified into two types: Japanese to English translation, and free English composition. Japanese to English translation entails replacing Japanese with English, while free English composition entails freely expressing one's ideas about a theme in English. While the above automatic grading technologies can be applied to both Japanese to English translations and free English compositions, what is actually seen as evaluation indicators are mostly such things as differences in grammar or vocabulary and length of sentence, etc. that are used to estimate the evaluation from sentence forms, but which are problematic when judging by correctly understanding the meaning of the overall sentence. English learners in the early stages of learning more often study Japanese to English translations than free English composition. For this reason, the grading and correction technology described in this article focuses on Japanese to English translations and focuses on indicators of whether the meaning of the examination sentence has been expressed.

2. Conventional Automatic Grading Technology

In the past, research on automatic grading of English compositions has generally involved technologies that grade based on how close the composition is to a sample answer at the grammar and vocabulary level. In 1966, Project Essay Grade (PEG®*3) [1], the first automatic grading system, was developed. Currently, various automatic grading systems such as Criterion®*4 [2] developed by Educational Testing Service (ETS) exist. These systems use the aforementioned technology.

3. Proposed Technology to Grade and Correct Compositions in English

As shown in **Figure 1**, this technology firstly entails preparing a large amount of data pairs (a Japanese-English bilingual corpus) consisting of Japanese sentences and sample answers for the Japanese to English translation problems. Then, deep learning is used to understand the meaning of entire sentences and construct a model that can be used for grading English translation answers. The bilingual corpus contains millions of translation pairs including spoken and written words to handle

*3 PEG®: A trademark or registered trademark of Measurement Incorporation.

*4 Criterion®: A trademark or registered trademark of Educational Testing Service.

a variety of sentences. This model is used to understand the meaning of the examination sentence and grade and correct the answer.

For learning, we used a recurrent neural network[*5] encoder/decoder model[*6], and input sequences of words obtained by dividing the words in the Japanese text for examination sentences into the encoder, and input sequences of words obtained by dividing the words in the English text of sample answers into the decoder.

Figure 2 shows the grading method using a model that has done this learning. For example, for the Japanese examination sentence "明日は晴れです," firstly the vocabulary in the sentence is

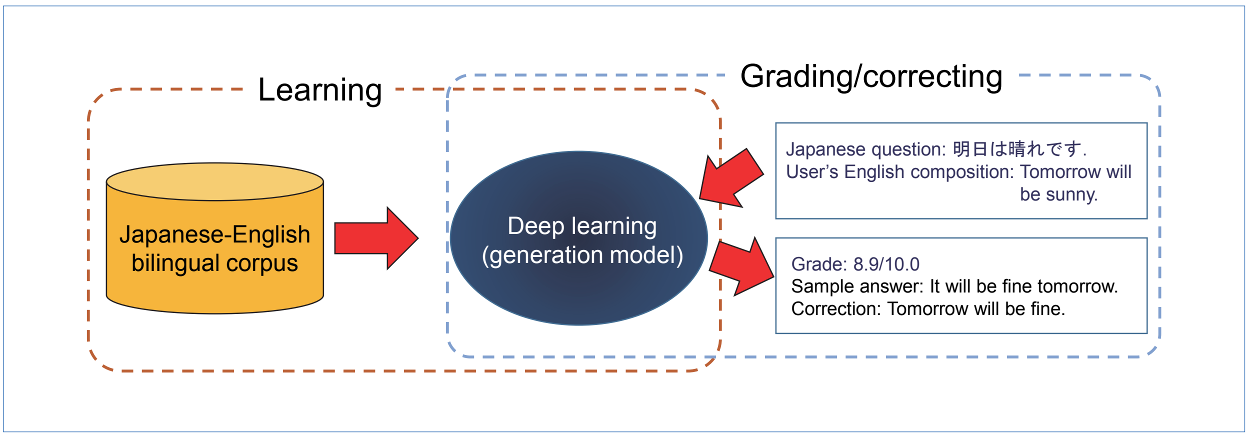

Figure 1　Application of deep learning

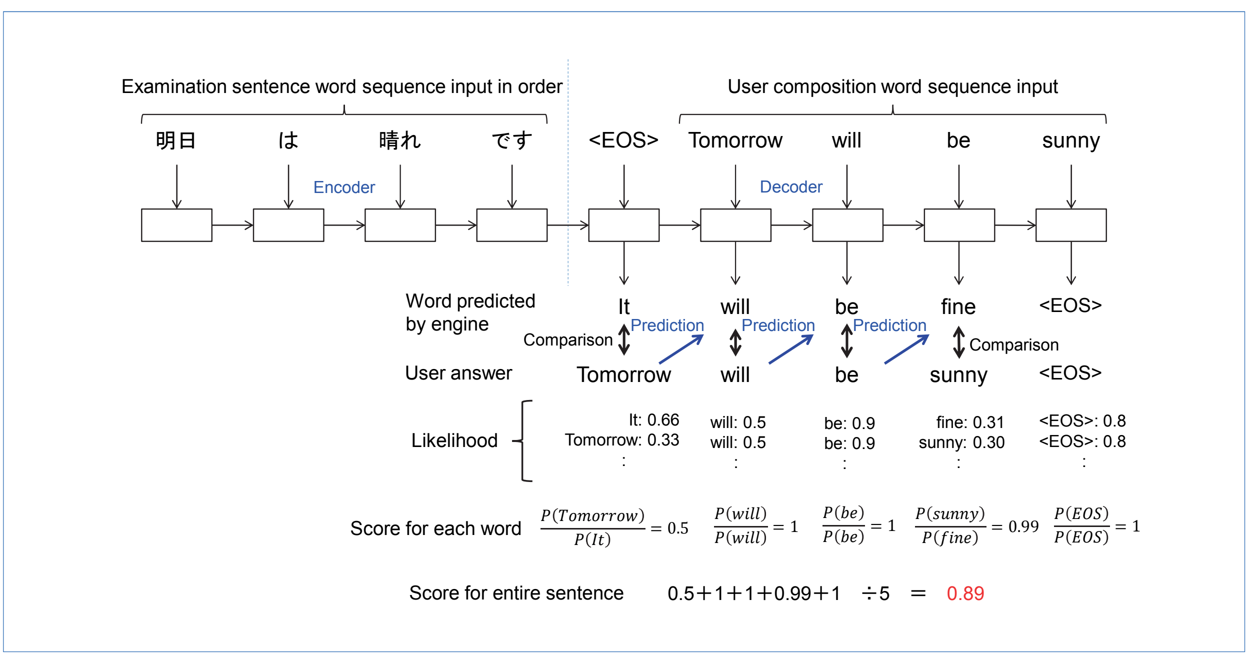

Figure 2　Grading method

*5　Recurrent neural network: A method of neural networking that entails a recurrent network structure in which the output of the intermediate layer is the input of the next step in a time series.

*6　Encoder/decoder model: A recurrent neural network structure that generates time series data from some time series data input.

divided into “明日,” “は,” “晴れ” and “です,” and then input in order into the encoder of the encoder/decoder model. Following, an End Of Sentence (EOS) symbol to indicate the end of the sentence is first input into the decoder section. Then, English translation of the examination sentences, and the first word of the predicted English text is output from the decoder. In the decoder, grading is performed by comparing each word of the user's English composition input into the decoder with the predicted word. The decoder also outputs the next predicted word.

At first, triggered by <EOS> input, “It” is output, the first word of “It will be fine tomorrow,” which is the English translation of “明日は晴れです.” Here, if the user's answer is “Tomorrow will be sunny,” the probability that the first word “Tomorrow” is output from the decoder first is calculated. If the likelihood*7 of the first word output from the decoder is 0.66 for “It” and 0.33 for “Tomorrow,” the likelihood of “Tomorrow” divided by the highest likelihood of “It” is 0.5, which is the score awarded for the word.

Next, the first input of the user's answer, “Tomorrow,” is processed as the next decoder input. The decoder fixes the first word to “Tomorrow” and predicts the next word, and “will” is the word with the highest likelihood. Since this matches the user's answer, “1” obtained by dividing the likelihood of “will” by the likelihood of “will” becomes the score for this word. The calculations are performed in the same way up to the last word, and the average of the scores for all the words is used for the resulting grade of the entire sentence.

Grading is thus done by inputting the user's answer sentence one word at a time into the decoder, predicting the next best word using the user's answer, and comparing that word with the next word of the user's answer. Accordingly, even if the user's answer is expressed differently from the sample answer, the decoder creates a continuation of the English sentence based on the expression used by the user and compares that English sentence with the user's answer, which enables handling of diverse expressions.

Moreover, if the user wasn't able to complete a sentence, the decoder can write the rest of it. Correction is enabled by replacing erroneous words in the user's answer with words with the highest likelihood and proposing subsequent text to improve the user's answer.

Deep learning and a large-scale bilingual corpus make it possible to evaluate English sentences while understanding the meaning of Japanese examination sentences. The more data for pairs of examination sentences and answers, the more accurate grading and correction can be performed. Although there may be multiple answers depending on the question, bilingual pairs are created for each answer example, and making the English translation model learn with deep learning makes it possible to respond to a variety of answer examples. It's also possible to grade and correct examination sentences that don't exist in learning data, which we believe will be useful for learners' selfstudy.

4. Grading Indicators and Grading Examples

In the English composition grading of this technology, the scores of 0 to 1 awarded by the decoder are multiplied by 10 to give a grade out of 10

*7 Likelihood: A numeric value that expresses the probability of guessing some result.

points. **Table 1** shows rough indicators actually created from scores for some questions and example answers.

Following is example of grading using this technology. The Japanese text of the examination sentence and the English text of the sample answer are as follows.

Examination sentence: このバスに乗れば，駅に着きます。

Sample answer: If you take this bus, you will get to the station.

Figure 3 shows this sentence with various example answers and their scores.

Sentence (1) "If you take this bus, you will get to the station." is exactly the same as the sample answer, and is awarded 10 points, and evaluated at level 5. Sentence (2) "This bus will take you to

Table 1　Grading indicators

5-grade evaluation level	Description	Score from grading
5	Meaning correctly conveyed. A fluent sentence in the native perspective.	9.0～10.0
4	Meaning correctly conveyed. Some improvements could be made from the native perspective.	8.0～9.0
3	Meaning mostly correctly conveyed. Improvements required.	7.0～8.0
2	Meaning may not correctly be conveyed. Contains a lot of unnatural language.	5.0～7.0
1	Meaning not correctly conveyed. Not a proper sentence.	0.0～5.0

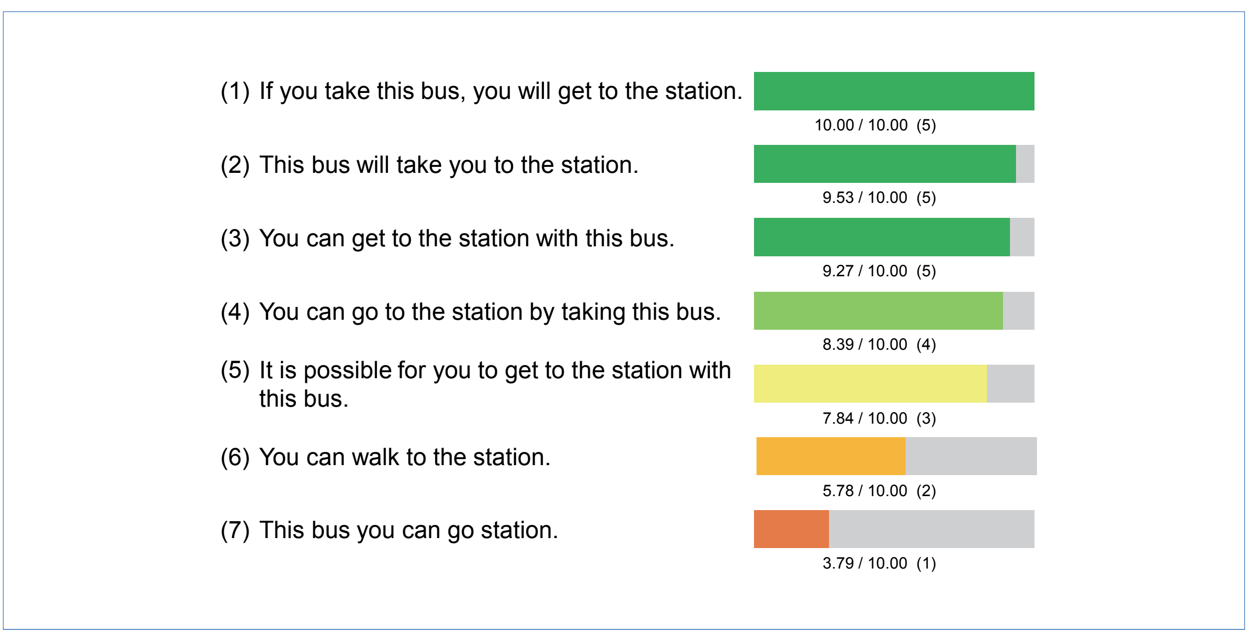

Figure 3　Example of grading

the station." has the bus as the subject, but correctly conveys the meaning, and is awarded 9.53 points and evaluated highly at level 5. In this way, a high grade can be awarded if the meaning is the same, but the sentence structure has been completely changed. Sentence (3) "You can get to the station with this bus." is also in a different form but the meaning is the same and so it is awarded 9.27 points with a high evaluation of level 5, while sentence (4) "You can get to the station by taking this bus." is not incorrect, however, the construction "by taking this bus" is not fluent in the native perspective. Therefore, the sentence is awarded 8.39 points and an evaluation of level 4. Similarly, sentence (5) is awarded 7.84 points and evaluation level 3 for its wordy construction. Sentence (6) "You can walk to the station." uses "walk" instead of "bus", and is therefore wrong, and is awarded 5.78 points and an evaluation level 2. Sentence (7) "This bus you can go station" is just a random attempt at stringing together the words used in the sample answer, and is not a proper sentence and thus is evaluated at level 1. In this way, even if the same words as the sample answer are used, if the meaning is not conveyed the sentence is given the low evaluation. Grading is thus done by understanding the structure and meaning of sentences.

In conventional English education, we hear that these Japanese to English translations are often marked as either correct or incorrect depending on whether they match the sample answer. However, this technology enables evaluation by enumerating fluency and conveyance of meaning, which we believe is an effective method of measuring the extent that meaning has been conveyed even if there are some errors. We also believe this system will be very useful for learners' self-study because it can provide corrections and feedback for creating better answers based on the user's answers.

5. Conclusion

This article describes development of a grading and correction technology that focuses on the meaning of Japanese to English translations. We believe that AI grading and corrections are useful in practicing the large number of Japanese to English translations required to master English composition. Going forward, we also intend to develop technology to handle free English compositions such as essays, etc. for tests such as The Eiken Test in Practical English Proficiency and the Test of English as a Foreign Language (TOEFL).

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NTT DOCOMO
Technical Journal Vol.21 No.4

Editorship and Publication
NTT DOCOMO Technical Journal is a quarterly journal edited by NTT DOCOMO, INC. and published by The Telecommunications Association.

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NTT DOCOMO Technical Journal Editorial Office
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