Beyond 5G/6G White Paper

ver. 2.0.1

KDDI Corporation

KDDI Research, Inc.

Oct. 2021

How can technology help us realize a more exciting future?
To find an answer to this question, KDDI has been working toward the goal of "creating a reliable information-oriented society.”

The safe and secure information-oriented society will be realized by seven technologies, Security as a core technology, as well as Network, IoT, Platform, AI, XR, and Robotics. People will feel comfortable and secure. Such a reassuring feeling increases the possible things in the world.

The massive data conveyed over ultra-high speed networks between physical and cyber spaces, will connect people, economic mechanisms, and social systems together. This will lead to the realization of optimal lifestyles and a new world full of vitality.

KDDI will flexibly build a communication infrastructure to meet the needs of individual users. KDDI will also understand their personality and situation, and propose the optimal actions accordingly.
Such schemes will lead to the self-realization of individuals and the resolution of social issues.

Rather than people needing to be compatible with technology, we will develop technologies compatible with them.
Toward the goal of creating the next exciting moments, we will continue to refine our reliable technologies.

Creating an exuberant future with reliable technologies.

Table of Contents

1. Introduction

In Japan, the number of people infected with COVID-19 began to increase around the same time that 5G became commercially available in March 2020, changing people's lives, economic activities, and the nature of society in a moment. Even before the spread of COVID-19, people were aware of the need for digital transformation ("DX"), and the "with-Corona" (coexisting with COVID-19) and "post-Corona" (post COVID-19) eras, also known as "the new normal," there is an urgent need to accelerate DX to support people's lives and economic activities. On the other hand, to protect our earth from global warming caused by the growing economic activity, there is a need to reduce greenhouse gases and aim to promptly achieve a "decarbonized, carbon-neutral society." In other words, there is a need to achieve a new social infrastructure that strikes a good balance between enriching people's lives, stimulating the economy, and protecting the environment.

There are various definitions of DX, but in a nutshell, based on the Ministry of Economy, Trade and Industry's document [1-1] , and taking into account the issues set out above, it can be defined as "the creation of new businesses and the transformation of organizations and social infrastructure by utilizing data obtained using information and communications technology (ICT)." Data obtained using ICT is acquired from the physical space in which we exist, with safety ensured through various devices, before being sent to cyberspace via wired and wireless networks, where it is then processed. Using the various data gathered in cyberspace, information and data useful in physical space can be created in cyberspace, then conveyed to people and the objects related to them within physical space via networks. The information and data obtained from physical space can be used to improve daily life, economic activities, and social activities, and then, data newly acquired in this process is sent to cyberspace again. Within this cycle, new businesses are created, and organizations and social infrastructure are transformed.

This is precisely the "Society 5.0" that Japan has set its sights on, and we believe that the prompt realization of Society 5.0 will lead to the advance of DX. Based on this, in August 2020, KDDI and KDDI Research Inc. ("KDDI") announced "KDDI Accelerate 5.0," a "next-generation concept for society," and set out the need to realize a Society 5.0 world promptly [1-2].

4G and 5G are essential to realizing Society 5.0, but as mentioned above, more advanced versions of 5G, or "Beyond 5G and 6G" ("B5G/6G"), will be required for the creation of new businesses, promoting the transformation of society and social infrastructure. ICT is required for the advancement of DX due to COVID-19, and achieving carbon neutrality. It is further essential to collaborate with partner companies, universities, and research institutes—both in Japan and overseas—in various aspects, such as the creation of new business models, R&D of new technologies, and the construction and operation of systems.

As to mobile communication systems, much attention has been paid to the progress of mobile communications technology, beginning with 1G and now reaching 5G. This is because the advance of mobile communications technology has had a significant impact on people's lives and economic activities. Going forward, it will be increasingly necessary to integrate not only mobile communications technology, but also various other technologies to support new, environmentally conscious social infrastructure, improve people's living standards, and stimulate the economy. Rather, we may be approaching an era in which it is other technologies that enable us to make the most of mobile communications technology.

Based on these assumptions, KDDI views "B5G/6G," the next generation of 5G, as a system encompassing mobile communications technology and other technologies. Therefore, KDDI Accelerate 5.0 sets forth technologies in seven fields ("seven technologies"), including network technologies such as mobile communications technology, to accelerate the realization of Society 5.0.

As set out above, we believe that the world of 2030, around about the time when B5G/6G will be implemented, will have taken a very different direction from the world of the past. In this white paper, we present lifestyles and use cases for the year 2030, and introduce the constituent technologies that constitute the seven technologies required to realize those lifestyles and use cases.

2. Lifestyles in 2030 and B5G/6G Use Cases

When Society 5.0 comes into being, all people and things will be connected through the development of IoT and AI (the Internet of Things and artificial intelligence), all kinds of knowledge will be shared, and unprecedented new value created. This is expected to overcome various issues in which we are currently embroiled. In September 2015, the General Assembly of the United Nations adopted “Transforming Our World: The 2030 Agenda for Sustainable Development” as a definite course of action to overcome current challenges. In response to this trend, KDDI has established "FUTURE GATEWAY," a co-creation scheme for a collaboration with progressive consumers who maintain progressive lifestyles that have yet to become popular. This plan also entails the utilization of the knowledge that KDDI obtains through researching how people live, as well as how their environments and attitudes change as ICT advances over the years.

2.1. "FUTURE GATEWAY" Co-Creation Scheme with Progressive Consumers

In December 2020, KDDI established the KDDI research atelier, a research base that proposes "future lifestyles." Then, in August 2021, KDDI began initiating the FUTURE GATEWAY plan, a collaborative scheme with a variety of partners, most of whom include progressive consumers who lead advanced lifestyles. The goal of FUTURE GATEWAY is to contribute to the development of medium- and long-term solutions to societal problems. To this end, people who lead progressive/advanced lifestyles, i.e., who live with the intention to contribute to solving societal problems, were targeted for inclusion as references. A more comprehensive description of this plan is as follows.

First, a discussion with progressive consumers is initiated to obtain feedback about advanced lifestyle practices that are purposed to lead to solutions to societal problems; the discussion also covers technologies and/or projects with applied research subjects that may pose an obstacle to the generalization of such advanced lifestyle practices. Next, together with various partners who have a desire to solve the target problem, the optimal solutions are socially implemented by utilizing advanced technology. Then, the popularization activity for the purpose of the extension of the habitant who practices the new lifestyle is carried out in the form in which the advanced habitant leads.

This plan was also purposed to continue with the expansion of social infrastructure to significantly contribute to the realization of the lifestyle modification of many consumers by 2030, as well as to contribute to the development of solutions to societal problems. In summary, FUTURE GATEWAY constitutes a plan to collaborate with progressive consumers to minimize the harmful effects of societal problems in the future as well as to co-create future social infrastructure with partners.

The progressive habitants who facilitate FUTURE GATEWAY implementation are referred to as “transboundary runners,” because they are people who actively and intentionally transcend the constraints and boundaries of the world. Once this designation was established, community development began. Discussion with the collaborative progressive consumers has led to the establishment of the new lifestyle of 2030, which has been projected to encompass security, safety, and comfort for the people. In this chapter, we divide these into two categories: those involving material needs that form the basis of our lives, and those satisfying psychological needs based on our relationships with others, and then separate scenes of life corresponding to the fulfillment of those needs into several themes.

It is expected that by 2030, with the acceleration of the identification and “data-fication” of things and actions across all aspects of society, we will live in a multilayered environment consisting of real physical space and digital cyberspace. Based on this premise, we extracted “food,” “purchasing,” “health,” and “lifestyle” from among material needs, and “learning,” “play,” “communication,” “work styles,” and “rest” from psychological needs, as the things that are expected to bring about significant changes to our lives through the evolution of ICT, and described each lifestyle and life scene [2-1].

The development of use cases is also extremely important to the commercialization of B5G/6G. KDDI has developed use cases for B5G/6G, and has launched a project to create a “social good” lifestyle for the 2030s. In this project, we co-created use cases for the era in which B5G/6G becomes widespread with cooperation from parties outside of KDDI. By gathering signs of change in the various lifestyles and life scenarios, and deepening the questions, we drew up use cases from aspects of physical needs, such as “meals,” “shopping,” “payments,” “body,” “home,” and “living,” together with use cases from psychological needs, “construction work,” “cyberspace,” “mobility,” “primary industry,” “watching sports,” and “walking.” KDDI has formulated “KDDI Sustainable Action: Our power to make connections will help create a brighter future for all” to express its determination to continue working to solve various social issues through its business. The main purpose of each lifestyle and use case presented here is to achieve each of the 17 Sustainable Development Goals (SDGs) established by the United Nations (Figure 2-2), which underlies the “Sustainable Action” described above [2-2].

Figure 2-1: The 17 SDGs (source: [2-2])

Going forward, we plan to study lifestyles other than those shown above, while observing changes in conditions, both in Japan and overseas, and consumer trends.

2.2. Realizing the Fulfillment of Material Needs

The following are situations in which we aim to satisfy the material needs that form the basis of our lives: “changes in food,” “changes in shopping,” “changes in healthcare,” and “changes in lifestyle.” The economic growth that enabled us to develop comfortable, rich, civilized lives in 20th-century style has led directly to burdening the global environment, and has destroyed both environments and ecosystems. However, the new social system for 2030 for which we are aiming should bring about a sustainable world in which the global environment and economic growth can coexist without causing environmental destruction or resource depletion. The various technologies described here that facilitate “food,” “shopping,” “healthcare,” and “lifestyle,” which satisfy people’s material needs, are developed not simply by achieving physical satisfaction, but through the coexistence of both the environment and the economy.

2.2.1. Changes in Food

At present, families often eat meals from the same menu, but with the development of AI and IoT, it is expected that by 2030 each individual in a family will be able to eat according to their preferences and health conditions. For example, it will be possible to provide meals that match the physical condition of the person or family member on that day, what they had for other meals, their degree of hunger at the time of their meal, etc., so food waste is expected to be reduced.

In addition to taking into account the family's health status, an AI system will be able to consider the refrigerator's inventory, which it monitors constantly, as well as past meals, to automatically suggest the most suitable meals at the time. In addition, it is expected that even if all family members share the same menu, they will be able to enjoy optimal meals because the recipes will take into account any reductions in salt or sugar to suit each family member's own health situation.

The concept of meals will change dramatically in the B5G/6G era. By sharing cooking data over a network, for example, family members who do not live nearby, such as grandparents, can enjoy the same meal.

In addition, virtual restaurants using food printers will open, and physically separated people will be able to enjoy popular three-star restaurants together, without making a reservation, in cyberspace. When looking at a menu, you will be able to smell the food, and an AI system will be able to suggest meals you have never experienced before based on your dietary history. It will also be possible to use food printers to recreate foods that have become extinct, or are not available locally. People who cannot enjoy certain foods because of food allergies will be able to enjoy those meals in cyberspace by reproducing the taste of those foods without reproducing the allergen using a food printer.

To achieve these new kinds of foods, it will be necessary to develop high-speed, low-latency networks able to send and receive meal image data without delay, image compression technologies to enable smooth data communications, and AI technologies to facilitate optimal personal recommendations.

2.2.2. Changes in Shopping

At present, people check their supplies before purchasing products, but in 2030, with the development of AI, IoT and robotics, it can be expected that domestic inventory management for convenience products and daily necessities will be automated, and products will be ordered automatically based on users' rate of consumption and inventory.

For example, sensors installed in refrigerators and pantries in the home will automatically reorder products, foods, and daily necessities according to stock levels, the rates of past consumption, and prices at stores.

Furthermore, automatically ordered products will be delivered to homes using delivery robots, able to deliver products 24 hours a day; you will be able to choose how and when you receive the products, according to your convenience.

The concept of stores will change dramatically in the B5G/6G era. For example, the clothing stores of the future will offer virtual store experiences, such as the on-the-spot, customized trying-on of clothing. For example, users will be able to try on clothes virtually which checking the feel and texture, and will be able to call friends for consultation using holographic communication. An AI system will quantify the functionality of clothing for purposes such as sleep or exercise, and will suggest clothes that suit the individual; users will be able to try on samples, produced on the spot by a 3D printer, test the functionality of that clothing, and make changes depending on the price. An AI system will judge the lifespan of pieces of clothing, and will refurbish clothing in your home using other clothes in your possession. The clothes you buy will be delivered to your home by a delivery robot. You will be able to receive products that suit you anytime, anywhere.

The concept of payment will also change dramatically in the B5G/6G era. You will be able to directly transmit biometric data to automatically purchase products offered as personal recommendations by an AI system. For example, when using car-sharing services, your driver's license information will be authenticated using biometric data, and the seat height will be automatically adjusted to suit the individual. An AI system will pore through vast amounts of past purchase data, together with your mood and emotions at the time, to recommend needed products at the optimal time. By the time you wish to purchase something, payment will already have been made, freeing you from the hassle of making a payment or forgetting to buy something.

Realizing these new modes of purchasing will require a system to monitor inventory in real time, AI technologies to calculate the appropriate timing for orders, and a high-speed, low-latency network to facilitate the smooth movement of robots. The FUTURE GATEWAY and Life Delivery projects were designed with the aim of minimizing the burden on the consumer. To this end, these projects were designed to evaluate and apply low-involvement solutions to processes such as inventory management, and order placement, delivery, and receipt of the products. Once the demonstration for the KDDI employees is completed, the solution will be applied in the field with the relevant partner (see Section 11.3 for details).

2.2.3. Changes in Healthcare

With the evolution of wearable devices, it is now possible to monitor metrics such as heart rate in daily life. With the development of IoT and AI, in 2030, it will be possible to understand various data in real time, and as a result, it will be possible to provide optimized healthcare to each individual, enabling them to maintain their health easily and with peace of mind, resulting in enduring independent living.

For example, previously cumbersome measurement of vital data and dietary nutrition will be automated using wearable devices and sensors installed in the home, providing real-time information about the health status of individuals 24 hours a day. As a result, it is expected that it will become possible to propose exercise and dietary habits tailored to individuals' health and physical condition based on that data.

With the development of advanced networks and cross-reality (XR) technology, it will become possible to consult physicians from home, and to take necessary steps before a disease becomes serious, enabling people to continue living independently indefinitely.

The concept of physical disability will change dramatically in the B5G/6G era. It will become possible to expand possibilities using powered suits to strengthen the body. For example, these suits will be able to copy physical functions from the vital data of others, making it possible to enjoy sports and activities. It will become possible for the physically disabled to freely cook, drive, practice calligraphy, paint, photograph, dance, etc. By reducing limitations of physical functions, and adding vitality to life, people will be able to enjoy the "era of the 100-year life."

Realizing this new healthy lifestyle will require a monitoring system that can obtain vital data in real time, AI technologies that can give advice based on accumulated data, and a high-speed, low-latency network to facilitate smooth online medical treatment. Hoppin Sauna, which is a mobile sauna FUTURE GATEWAY subproject, entails the use of automation and vital sensors. The latest 5G technology will be applied to enable dispersion via water circulation to yield an automated sauna that can optimize the state of the mind and body of the user.

2.2.4. Changes in Lifestyle

In recent years there has been a migration to rural areas and a growing interest in "workations" (working vacations), and it is expected that by 2030 it will be possible to live in a place that best suits one's personality, values, health, and situation at the time without being limited by location. When visiting a city for the first time, it is expected that AI systems will support serendipitous enjoyment and comfortable, trouble-free living, enriching everything from work to private life.

It will be possible to work and study comfortably without feeling dissatisfaction or a sense of lack, regardless of location, and there will be no distinction in location between home, work, and school. When traveling by car, automated driving will make vehicle interiors to be like private rooms where we can develop our ideas and rest. They will also provide information during the journey that will allow the user to move about with ease once they arrive at the destination.

In realizing such a lifestyle, trends toward the enjoyment of nature and an emphasis on aspects of our private lives, such as self-fulfillment and hobbies, will strengthen, and it is expected that spending time in unusual ways will become the norm.

The concept of place of residence will also change dramatically in the B5G/6G era. For example, it will be possible to transmit touch, scent, texture, and taste, enabling us to connect with faraway family members anytime in cyberspace. A father posted overseas for work can enjoy lunch with his distant family in cyberspace by wearing a suit that can send and receive inputs corresponding to all five senses. Without moving so much as a finger in physical space, we can move ourselves within cyberspace to connect with faraway family members using all five senses, as though we were spending time together in the same room, strengthening family ties despite being far apart.

The concept of living will also change dramatically in the B5G/6G era. You will be able to work in your favorite place, surrounded by your favorite scents, without a fixed place of residence. For example, by directly transmitting to the brain the sensory data corresponding to the five senses, we can create a world without any cognitive discrepancy. A physical space can be transformed into your ideal space using realistic information; you can hold meetings with remote colleagues via hologram, while brainwave communication, in which what you imagine is transmitted directly to your colleagues, will produce the best performance (See Figure 2-2).

Figure 2-2: Remote conference via hologram transmission

Realizing these new lifestyles will require the recommendation of AI technologies that make it possible for people to travel around a city they are visiting for the first time without getting lost, together with behavioral adjustment AI technologies to enable people to respond optimally to situations in that city.

2.3. Realizing the Fulfillment of Psychological Needs

The following are situations in which psychological needs—those based on our relationships with other people—are satisfied: “changes in workstyle,” “changes in learning,” “changes in hobbies and entertainment,” “changes in rest,” and “changes in communication.” Despite creating abundant wealth, the development of the global economy in the latter half of the twentieth century also led to the widening of economic disparity and social fragmentation due to the entrenchment of social hierarchies. The world of 2030 that we should aim for must be an inclusive society that recognizes individuals’ diversity and allows everyone to live autonomously, freely, and with dignity. The various technologies that facilitate “working,” “learning,” “hobbies and entertainment,” “rest,” and “communication,” which will bring about the fulfillment of the psychological needs discussed here, will be developed by honoring the diversity among individuals and achieving freedom.

2.3.1. Changes in Workstyle

Job-based employment has been becoming prevalent in Japan in recent years, and by 2030, it is expected that individuals will create their own job opportunities that match their dreams and values by utilizing their skills, abilities, and experiences. To this end, AI-based matching will be used to provide venues to meet with business partners that promote optimal projects and co-creation ventures. Moreover, with the spread of machine translation, language barriers will disappear, and global working styles will become more prevalent among individuals.

On the other hand, labor-intensive, low-productivity jobs will be replaced by AI systems and robots, and it is expected that many people will become able to engage in rewarding work, leading to the realization of their self-worth. At the same time, administrative tasks such as data collection, document creation, scheduling, and information support will be automated using AI systems, resulting in free time that can be spent on creative activities such as developing ideas. The AI systems will also suggest ways to supplement technology and professional skills to support these creative activities. It will also provide opportunities to connect with professionals and peers who can provide appropriate advice.

The concept of construction work will change dramatically in the B5G/6G era. Heavy manual tasks such as clearing snow will be automated. It will be possible to carry out construction work requiring advanced technology, such as lunar surface terraforming and construction, remotely from a safe place from the remote by extending the range of feasible mobile communications to the space. Sensory data from a construction robot will be analyzed using its digital twin, and administrative applications for changing construction plans will be filed automatically. Users can learn the skills of expert robot teleoperation through direct physical experience using a specialized suit. Skills learned through this physical experience will be learned synchronously by the robot in real time. The training data from one robot can be automatically linked to hundreds of other robots, eliminating the need for hard manual labor and labor shortages in regions where the physical environment is hard (See Figure 2-3).

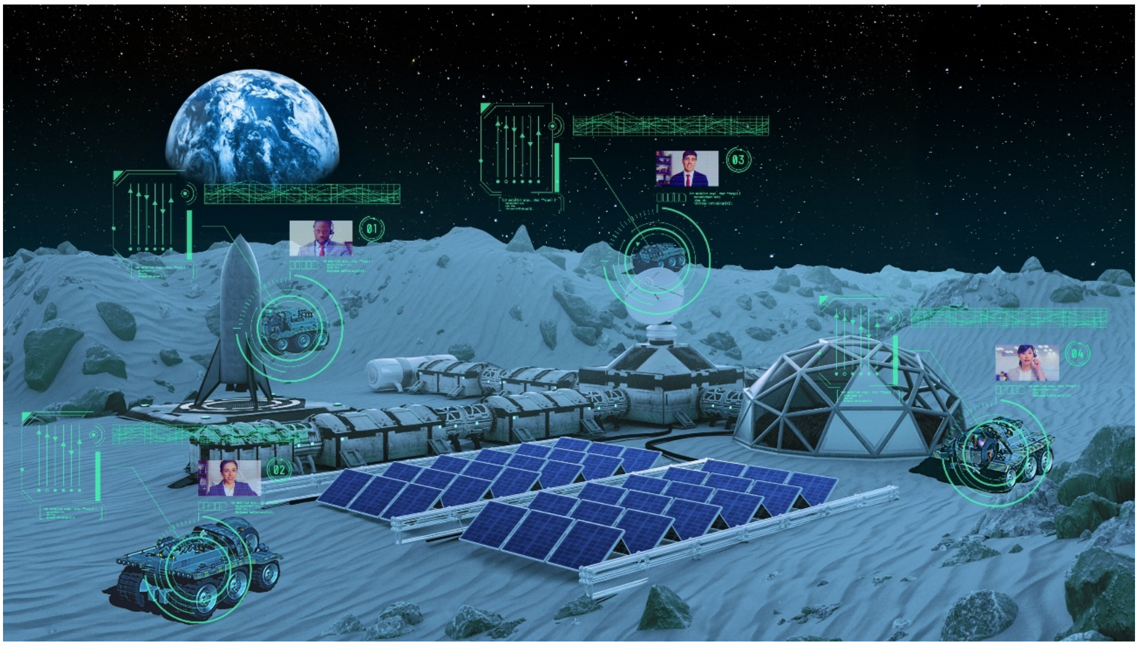

Figure 2-3: Simulation of construction on the moon

These new modes of working require AI technologies that are able to match individuals to the most suitable jobs, high-speed; low-latency networks that facilitate the smooth transmission and reception of data anywhere; and technologies that replicate physical space to produce realistic online meetings (see Chapter 10).

2.3.2. Changes in Learning

The spread of COVID-19 has led to the rapid uptake of online classes. In 2030, the development of XR technology will create a new era for education by optimizing individuals' learning so they can improve not only their academic performance in school, but also efficiently acquire the skills required to achieve their goals and dreams.

Moreover, the expansion of online communities will allow students to connect to trustworthy teachers who can provide pertinent advice and connect them to peers for mutual development, resulting in a deeper learning experience. In this context, in addition to learning from others, by sharing one's own skills and knowledge, anyone can teach and anyone can be taught, and the choices for learning will expand.

The learning content will include the skills required to realize students' dreams and goals, such as ICT knowledge and languages, as well as the learning methods that are most suitable for each student. In addition, the most appropriate program will be applied according to each individual student's progress.

The concept of time in our daily lives will change dramatically in the B5G/6G era. We may be living in an age where microchips are implanted in our brains before we are even born, through which our brain's data is constantly uploaded to cyberspace. Day and night do not matter in cyberspace, and you can enjoy a second, different life, and gain twice as much life experience or more. For example, you can pursue your dream of being a musician while working as a sushi chef, and by synchronizing your experiences in cyberspace with those in physical space, you will be able to live as though there were 48 hours in a day.

In addition to a high-speed, low-latency network facilitating the exchange of large amounts of data, and better image compression technology, a monitoring system that makes it possible to gauge levels of understanding and satisfaction among students in real time will be needed for online learning to become even more valuable.

2.3.3. Changes in Hobbies and Entertainment

As the work-life balance concept spreads, more people in Japan are devoting time to their hobbies and leisure activities. By 2030, it is expected that the spread of AI and robots will make it possible to work efficiently in less time, and the trend in pursuing one's own hobbies and leisure activities will strengthen.

The barriers of language and physical distance will disappear with the advancement of ICT, and people will be able to easily find instructors to learn the skills necessary to improve their hobbies, and will be able to receive optimal instruction through two-way communication. In addition, an AI system can also provide total professional support for everything from training plans to health management and body care, allowing players to improve their skills to the level they desire. It is expected that events and interactions indistinguishable from those in the real world will be available in cyberspace, and that people will be able to have fulfilling experiences in the comfort of their own home without restrictions from weather or location.

Through AI matching, users can connect with friends whose skill levels and interests match their own, and can have fun competing with one another and improving each other's skills. In addition, an AI system will provide new ways to enjoy daily hobbies and games, and users will be able to discover new attractions and enjoy more fulfilling time. As a result, it is expected that many people will be able to achieve self-fulfillment through devoting themselves to their hobbies, and that many will acquire professional-level skills.

The concept of mobility will change dramatically in the B5G/6G era (See Figure 2-4). Purpose-driven journeys will be transformed into journeys that bring new learning along the way. An AI system will suggest experiences, using VR[1] that fit into one's travel plans. For example, if you are travelling to Kyoto, the AI system will be able to recreate the construction of Kinkakuji Temple in a realistic manner. It will be possible to recreate aerial spaces with virtual flying cars, enabling passengers to fly with the birds, and users will be able to enjoy delicious meals prepared by food printers. Comfortable spaces will be created using passengers' biometric information, so passengers will be able to enjoy their travel time without boredom.

Figure 2-4: Example of VR-based purpose-driven experience

[1] Virtual reality

The concept of primary industry will also change dramatically in the B5G/6G era. It will become possible to choose optimal environments for crops, and manage the growth of the crop with all possible data. For example, mobile farms may automatically move to areas where crops can grow well based on weather forecast data of sunshine, temperature, rain, and wind. The management AI will not only collect various data, but also automatically control the operation of the agricultural machinery, manage soil bacteria, filter rainwater, and manage crop watering, and will notify farmers of the next crop that should be grown based on expected future market prices and weather forecasts. In this way, it will become possible for anyone to become a primary industry player as though enjoying game.

Making hobbies and games more fully realized, professional, and sophisticated will require AI-powered matching technology; XR technology and body sensor technology to evoke sensory experiences in cyberspace across all five senses; and high-speed, low-latency networks to facilitate the transmission and reception of large amounts of data.

2.3.4. Changes in Rest

Due to the growing interest in work-life balance in recent years, the number of people wanting to spend their time off in more fulfilling ways is increasing, and by 2030, it is expected that people will be able to use technology to make the most of their time off. By letting AI systems and robots replace household chores and menial tasks in the things we enjoy, we can create ideal vacations where we can immerse ourselves in what we really want to do.

If you wish to challenge yourself with something new, it will be possible to simulate it in advance by testing your preconceptions in virtual space, or superimposing them over real space. In this way, it is expected that the range of possibilities available to us will expand, and we can draw closer to our ideal selves every time we enjoy time off.

The concept of watching sports will change dramatically in the B5G/6G era. Through cyberspace, we can share space with friends who are physically far away from us, stimulating our five senses as though we are sitting in a stadium with our friends. In addition, it will become possible to watch games from any point with 360-degree view, and it will also be possible to check player information in real time. Moreover, by having players teach sports directly in cyberspace, watching sports will be transformed from a passive experience to an active one where spectators can experience the sport for themselves (See Figure 2-5).

Figure 2-5: Example of real-time and engaging experience with active content

In addition to developments in robotics, the realization of these new modes of rest using robots will require, high-capacity image analysis technology and high-speed, low-latency networks that facilitate various simulations in cyberspace.

2.3.5. Changes in Communication

People's interaction styles have changed dramatically with the increase in the number of users of social networking services resulting from the spread of smartphones. By 2030, technology is expected to eliminate hurdles that have historically prevented people from community participation, resulting from differences in ability, including physical characteristics, physical distance, and language, not to mention differences of race and gender. It is expected that an advanced virtual community will emerge, one that can be enjoyed by all. In such a place, we will be able to communicate with anyone however we wish, without being bound by time or place. While assisting in creating new encounters suited to everyone by identifying individual tastes, values, and physical abilities, it is expected that it will be possible to exclude malicious individuals from the community, and to express yourself as you are.

By optimizing each person's interaction in this way, communication can be established with safety and at scale, and it will be possible to create "ideal friendships" and business relationships.

The concept of walking will change dramatically in the B5G/6G era. A threedimensional (3D) space will be reproduced with an ultra-high-resolution drawing from a vast amount of sensor data from real cities, making it possible for users to take a stroll through streets of the past. For example, it will become possible to explore history together with our bedridden grandfathers through cyberspace. Information about physical space is reflected in cyberspace, such that a granddaughter walking through Reiwa-era streets, and a grandfather walking through Meiji-era streets (streets in the early 20th century) can enjoy a walk together while sharing different time periods. New communications that transcend generations will emerge.

Realizing this new communication will require XR technology to achieve communications within a virtual community, and AI technologies with matching capabilities that can introduce individuals to the most suitable people.

We have presented several lifestyles that are expected to emerge by 2030, but many other new lifestyles are also likely to emerge in other aspects of life. For example, many people are expected to pursue lifestyles that make valuable contributions to the global environment and earth's ecosystems, promoting ecology, zero waste, and carbon neutrality. KDDI aims to build a culture and society in which everyone can effortlessly participate and contribute to the world by introducing advanced ICT into the various scenes of life involving these lifestyles.

The realization of such a society will require precise and real-time control using ICT, for which the widespread adoption of B5G/6G is a prerequisite. Moreover, since it will handle large volumes of personal data, a higher level of security will be required. Therefore, in the next chapter, we set out a national-level concept for B5G/6G, and KDDI's next-generation social concept, KDDI Accelerate 5.0.

3. A Concept for B5G/6G

In this chapter, we describe the national movement toward B5G/6G, and KDDI Accelerate 5.0, a concept that envisions the future in 2030 which is expected to be when B5G/6G is implemented, formulated by KDDI.

3.1. A Strategy for the Advancement of Society 5.0 and Beyond 5G

Society 5.0 was proposed in the Fifth Science and Technology Basic Plan as the model for the future society that Japan should aspire to. Following on from hunter-gatherer society (Society 1.0), agricultural society (Society 2.0), industrial society (Society 3.0), and the information society (Society 4.0), it is described as “a human-centered society that balances economic advancement with the resolution of social problems by a system that highly integrates cyberspace and physical space” [3-1].

The society envisioned in Society 5.0 will overcome these challenges and difficulties by connecting all people and things via IoT, sharing knowledge and information, and creating new, never-before-seen value. Moreover, AI systems will provide necessary information when it is required, and technologies such as robots and automated vehicles will overcome issues such as declining birthrate and an aging population, the depopulation of rural regions, and the disparities between rich and poor. Social reform (innovation) in Society 5.0 will achieve a forward-looking society that breaks down the existing sense of stagnation, a society whose members have mutual respect for each other, transcending the generations, and a society in which each and every person can lead an active and enjoyable life.

The 6th Science, Technology and Innovation Basic Plan [3-2] , which covers the five-year period from FY2021 to FY2025, inherits the concept of Society 5.0. This basic plan was created to serve as a concrete strategy for overcoming rapidly changing circumstances, both in Japan and overseas, such as the spread of COVID-19, and received approval from the Cabinet in March 2021. The plan summarizes Society 5.0, the society that Japan should aspire to, as “a society that is sustainable and resilient in the face of threats and uncertain circumstances, that ensures the safety and security of its citizens, and that enables each and every individual to realize well-being on many levels,” which is in line with the SDGs adopted at the UN Sustainable Development Summit in 2015. The 6th Science, Technology and Innovation Basic Plan positions Beyond 5G as requisite next-generation infrastructure and technology for the creation of new value through the convergence of cyberspace and physical space, toward transformation into a sustainable and resilient society that can ensure the safety and security of Japanese nationals. The plan stipulates that the Ministry of Internal Affairs and Communications plays a central role in promoting its establishment, research, and development.

On the basis, in January 2020, the Ministry of Internal Affairs and Communications held the “Beyond 5G Promotion Strategy Roundtable” to discuss expectations for telecommunications infrastructure in the society of the 2030s, when Beyond 5G is expected to be introduced, and the direction of policy to realize those expectations. The “Beyond 5G Promotion Strategy—Roadmap towards 6G” was published in June 2020 [3-3] based on the “Proposals from the Beyond 5G Promotion Strategy Roundtable” [3-4], compiled by the roundtable meeting.

The “Beyond 5G Promotion Strategy” lists “an inclusive society where everyone can play an active role,” “a sustainable society, growing sustainability and efficiency,” and “a dependable society where safety and security are ensured,” as the expected image of society in the 2030s, and holds that these will be achieved in the Society 5.0, in which physical space and cyberspace converge (a cyber–physical system, or CPS).

To realize these, Beyond 5G must provide four new functions: “Autonomy,” “Scalability,” “Ultra Security and Resiliency,” and “Ultra-low power consumption,” in addition to the further refinement of 5G’s characteristic functions “Ultra fast and large capacity,” “Ultra-low-latency” and “Ultra numerous connectivity” (Figure 3-1).

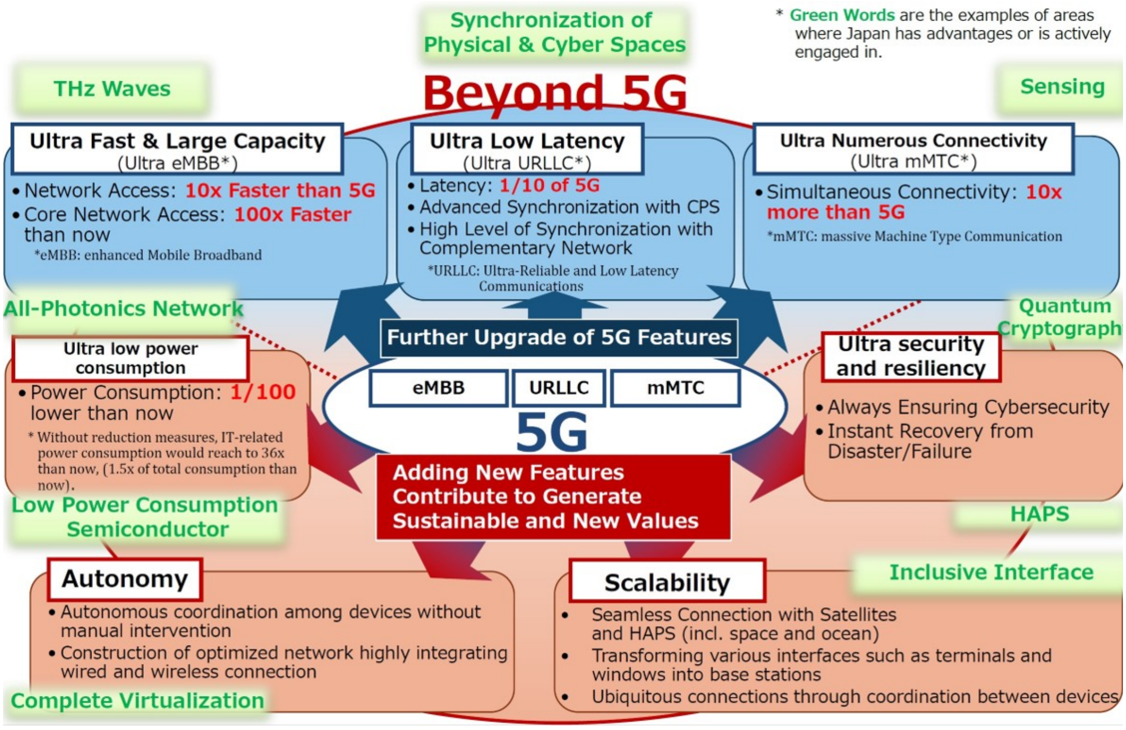

Figure 3-1: Key features for Beyond 5G (source: [3-4])

The Beyond 5G Promotion Strategy also describes an R&D strategy, an intellectual property and standardization strategy, and a deployment strategy, taking (1) “global first,” (2) the creation of an ecosystem for generating innovation, and (3) intensive resource investment as its basic policies. The R&D strategy is to realize an environment for the world’s highest levels of R&D through intensive investment in the latest technologies, and the bold opening up of the radio spectrum; and to establish constituent technologies in turn, beginning around 2025. As to the intellectual property and standardization strategy, the aim is to achieve at least a 10% share of standard-essential patents of Beyond 5G by promoting strategic openness and *de facto* standardization, and to make game-changing developments by collaborating with strategic partners overseas. The deployment strategy aims to achieve a Beyond 5G-ready environment by deploying 5G and optical fiber networks across society, and promoting industrial and public use through demonstrations of 5G solutions.

To promote the strategy strongly and positively, the Beyond 5G Promotion Consortium was established in December 2020 through industry-academia-government collaboration. Moreover, the Beyond 5G New Management Strategy Center was established in the same month to strategically acquire and standardize intellectual property and standardization strategy for Beyond 5G [3-5]. Meetings will be held from 2021, and activities are underway toward the Beyond 5G Strategy Promotion–Roadmap toward 6G.

3.2. A Concept that Envisions the Future in 2030: KDDI Accelerate 5.0

As set out in Chapter Introduction, KDDI believes that the prompt realization of Society 5.0 is necessary to promote DX in Japan, and to accelerate this using 5G, has conceived the KDDI Accelerate 5.0 concept for next-generation society, published in August 2020 [3-6].

In “KDDI Accelerate 5.0”, KDDI pledges to work with a wide range of partners ranging from large corporations to startups both Japanese and foreign, updating the environment in three layers that will form the basis of new social infrastructure: networks, platforms, and businesses. Moreover, we will promote the R&D of seven technologies that support evolution, and will orchestrate them to achieve an advanced convergence of physical and cyberspace that makes it possible for any and all consumers to enjoy the benefits of technology in safety and without conscious effort. In so doing, we aim to create a resilient future society that balances the creation of new lifestyles for people through economic development and solving social issues in Japan.

3.2.1. Upgrading the Environment in Three Layers

(1) Network layer

We aim to establish and continuously develop advanced, robust domestic ICT infrastructures through the quick rollout of 5G networks based on the latest world-class advanced technologies.

Specifically, we plan to establish approximately 50,000 5G base stations by March 2022. We will also accelerate the prompt nationwide 5G area coverage by sharing infrastructure for early expansion in local regions.

(2) Platform layer

We aim to create new value offerings, economic mechanisms, and social systems by upgrading an open platform environment by introducing the latest technologies from the collaboration with Japanese and overseas companies.

Specifically, we will launch a “personal agent,” which proposes optimal activities and choices for consumers; an “industrial data platform” that realizes optimal economic mechanisms; and a “city OS” that operates social systems to actualize safety and security [3-7] together with various partners.

(3) Business layer

We aim to create new business models by promoting DX through open innovation with a wide range of partnerships.

Specifically, the KDDI Digital Gate, a center for creating new businesses, the KDDI Corporate Division at Toranomon Office, a center for promoting corporate working style DX through the use of diverse work styles, and the KDDI research atelier, a research center for demonstrating lifestyles around 2030, described in Chapter 2, will collaborate with one another to promote co-creation.

This new social infrastructure linking physical and cyberspace will bring real-time, dynamic harmony among consumers, economic mechanisms, and social systems, and will play a role in accelerating the construction of a vibrant society that makes lifestyles optimized for each individual consumer.

3.2.2. Seven Technologies and Their Orchestration

KDDI promotes the R&D of advanced seven technologies to support the activities of the three layers mentioned above. In addition, under the banner of “orchestration,” we will focus on enhancing the linkage between R&D and business. This promotes the circulation of data obtained from consumers, the economy, and society between physical space and cyberspace, and contributes to the realization of a sustainable society in which everyone can live comfortably.

With the expansion of 5G, the integration of physical space and cyberspace will advance, and data from physical space will be collected in cyberspace for various analyses and simulations. As a platform for various life-design businesses with communications as their core, KDDI will strengthen R&D of technologies for secure and convenient data utilization in cyberspace, as well as technologies for providing feedback to physical space, such as AI, XR, and robotics, that encourage changes in behaviors, and accelerate the convergence of the two spaces.

The seven technologies are described in detail in Chapter 4 onwards.

The sustainable, human-centered society that balances economic development with the resolution of social issues that is envisioned in Society 5.0—the goal of KDDI Accelerate 5.0—parallels the goals set out in the Ministry of Internal Affairs and Communications' Beyond 5G Promotion Strategy–Roadmap toward 6G. KDDI will promote the realization of Society 5.0 while contributing to the activities of the national government through the activities of the Beyond 5G Promotion Consortium and the Beyond 5G New Management Strategy Center.

4. The Seven Technologies

Chapter 3 explained that KDDI is accelerating the realization of Society 5.0 sing the seven technologies. This chapter provides an overview of the seven technologies, then introduces use cases to demonstrate how the seven technologies will contribute to realizing the 2030 lifestyles described in Chapter 2.

4.1. An Overview of the Seven Technologies

Figure 4-1 shows the CPS, the Society 5.0 initiative, and a diagram describing the seven technologies involved, with arrows connecting the two spaces.

KDDI believes that collecting data (the left arrow in the figure) from physical space for cyberspace is now becoming a reality thanks to the evolution of networks to 5G as well as evolution and spread of sensor devices. On the other hand, we believe that the feedback (the arrow on the right-hand side of the figure) sent from cyberspace to physical space has yet to be fully realized. If sufficient feedback is provided to physical space, shown by the arrow on the right, and people in physical space perceive the efficacy of such feedback, the volume of data collection, indicated by the arrow on the left, will increase, and the frequency of data collection will increase, resulting in the creation of a positive spiral. Without this positive spiral, it seems unlikely that we will truly realize Society 5.0. In Figure 4-1, the feedback (optimization) arrow on the right is drawn thicker and brighter than the data (collection) arrow on the left to indicate the importance of the arrow on the right.

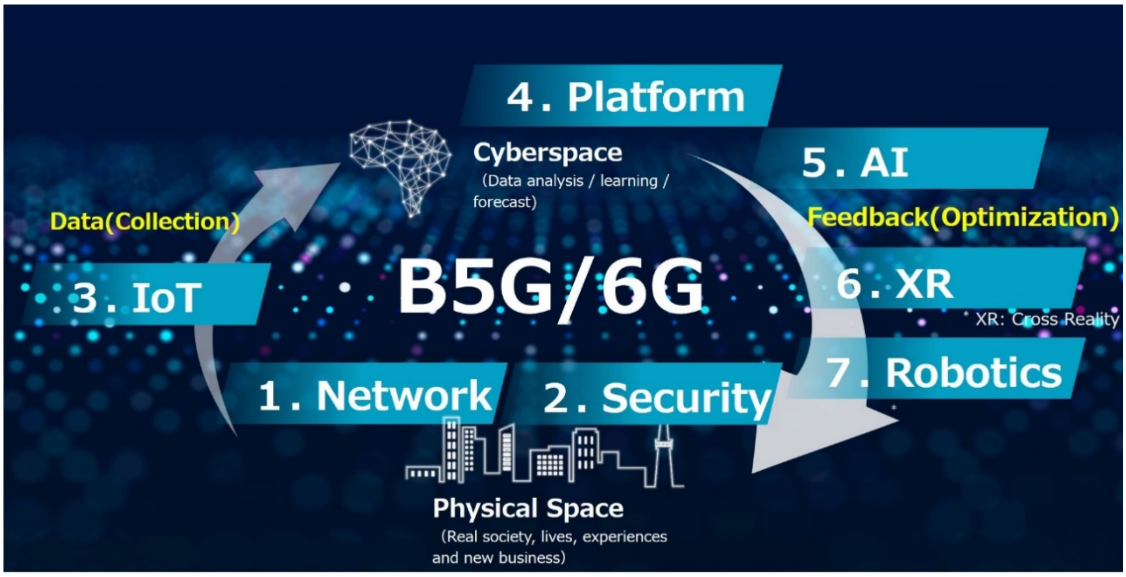

Figure 4-1: The seven technologies contributing to the realization of Society 5.0

On the arrow on the right, the technologies that directly affect people in the physical space are **XR** and **Robotics**. **AI** is responsible for determining what information and data should be sent to these technologies, while **Platform** is necessary for safely managing and manipulating the data to make decisions.

IoT is the technology required to send data from sensors to cyberspace. **Security** is a technology required to securely manage various data that exist not only in cyberspace, but also in physical space. To transmit and receive large volumes of data reliably and with low latency, **Network** is indispensable, and wireless communication is one of the technical fields that create such networks.

4.2. Technologies Support B5G/6G Necessary to Realize the Lifestyles of 2030

Chapter 2 classifies lifestyles into nine categories, and summarizes the lifestyle changes expected by 2030. The realization of these lifestyles requires a variety of technologies. In this section, we show specific examples of use cases and introduce the component technologies required for B5G/6G to make them a reality. As an example use case, we will discuss delivery services, which are easy to envisage given our familiarity with their use in the "with-corona" era. We will then summarize the component technologies required to realize "life delivery" (see Sections 2.2.2 and 11.3)—the future of delivery services to accommodate the 2030 lifestyles set out in Chapter 2.

Let us say that a user wishes to order a variety of foods for a family birthday party. In this scenario, only a limited number of people, including family members, can attend the real party venue. First, appropriate menu options are selected according to the health conditions of each participant at the party, per "Changes in Food" described in Section 2.2.1. It will therefore be necessary to track individuals' health conditions using wearable devices and health management sensors, as described in Section 2.2.3, "Changes in Healthcare." Moreover, as described in Section 2.2.2, "Change in Shopping," sensors like those shown in Figure 4-2 (a) will detect shortages of required beverages and foodstuffs, and these can be purchased automatically. In making automatic purchases, a virtual human (see Section 10.4.1) counsels individual family members based on their health conditions, as shown in Figure 4-2 (b), and allows them to select food and beverage options that consider their health and preferences. Furthermore, when an unusual event such as a birthday party is held, the necessary food and beverages are delivered automatically in advance by delivery robot (see Section 11.3) using sensors as in Figure 4-2 (c). Pre-ordered food and birthday cake, etc., can also be delivered via delivery robot. For those who are unable to attend the birthday party, food similar to that at the party can be delivered by robot to their own homes upon request. In addition to

3D-images based on point cloud data as shown in Figure 4-2 (d) (see Section 10.4.3), tactile information is transmitted so that remote participants can get a sense of being at the real venue (see Section 10.4.2).

(a) Automatic purchase of food and drink using sensors

(b) Counseling by a virtual human

(c) Automatic delivery by robot

(d) 3D animation using point cloud data

Figure 4-2: Example use-case for 2030: Birthday party

The technologies introduced thus far are technologies that can be directly perceived by users through the five senses, but other technologies are also required.

First, to gather information using sensors, it is necessary to place sensors in various locations. Sensors that use batteries face issues with recharging or having to be replaced. In some cases, location data is necessary to send sensor data to cyberspace, but a sensor will lack the functionality to receive GPS signals to obtain location data; even where a sensor has such functionality, it may not be able to obtain a signal from GPS satellites in the location where the sensor is placed. For these cases, energy harvesting technology (see Section 7.4.4) and virtual positioning systems (VPS, see Section 10.3) are needed to create maintenance-free sensors.

All possible measures must be taken to ensure the security of information sent by sensors. However, it will be necessary to develop next-generation cryptography whose information cannot be deciphered—even using quantum computers, which will see widespread use in the future (see Section 6.4.3). Many people also have concerns about all manner of data being sent to cyberspace by sensors. KDDI has developed a technology called Privacy Policy/Preference Manager (PPM) to manage and control the information that users send to cyberspace (see Section 6.4.1). In the B5G/6G era, it will be necessary to improve the PPM to cope with the increase in the types of information handled and changes in user preferences.

Delivery robots are used in the use case set out above, but in the future, it will be necessary to manage and control various types of robots. For this reason, a new function called Robotics as a Service (RaaS) will be required on the platform (see Section 11.4.1). Mobility as a Service (MaaS) will also be required when robots move on public roads by themselves and things are transported by automatic cars (see Section 8.4.2). In addition, a new platform will also require functions to control IoT devices and to link different types of data (see Section 8.4.1). Indeed, the platform must take into consideration the balance among three elements: improving users' quality of life, driving economic activity, and creating active social systems that are conscious of environmental issues such as energy consumption and global warming.

Using a variety of data, AI systems determine the next action in physical space by considering the balance of these three factors determined on the platform. Existing AI technologies, as characterized by image recognition and games, accumulate a large amount of historical data in cyberspace, and uses deep learning technologies to display intelligent results and provide information in games (we will refer to such AI technologies as "cyber-based AI"). On the other hand, because in physical space, the environment around us changes over time, it is almost impossible to reproduce identical environments. Thus, there are limits to the information that can be obtained from the same environment, and this is even true for similar environments. This change in environment differs from person to person, and the data being sought differs depending on personal preferences and one's sentiment at the time. Thus, unlike conventional cyber-based AI, "real-world AI" is required to solve issues particular to physical space, such as those with limited relevant historical data (see Section 9.4.1). Applied to the example of a birthday party above, because the external environment surrounding the birthday celebrant and accompanying well-wishers changes annually, it is necessary to predict the event based on limited data. In addition, to encourage users in the physical space to change their eating habits, exercise habits, and means of transportation based on the results obtained by real-world AI, it is necessary to send information tailored to the personality and hobbies of the target user. “Persuasive AI” is a technology that facilitates such an approach (see Section 9.4.2.2). At the same time, whether a user takes actions such as diet management or exercise to promote his or her health depends, at least in part, on whether the user can trust the AI models or systems. We will therefore also need “trustworthy AI,” technology that provides reasons for the predictions and conclusions made by the AI models or systems (see Section 9.4.3).

These new AI paradigms will determine what information should be transferred from cyberspace to users in physical space through the arrows shown on the right side of Figure 4-1. Here, XR is a technology to express information to be conveyed as sensory information, including visual information using images and video. First, 3D image transmission is required because the 2D images currently used in telecommunications lack realism and impact. One method to achieve 3D imagery is a technology used to display 3D images using a collection of points known as point cloud data, so this requires much higher throughput and transmission capacity than 2D images. A new compression technique is required to compress point cloud data without comprising the quality of 3D images (see Section 10.4.3). High-efficiency, Ultra-low-latency In addition, multimodal interaction transmitting the senses of touch and smell is also necessary to make people feel as if they are sharing the same space despite being in remote areas (see 10.4.2).

In addition to conveying electronic information to physical space using XR, looking to 2030, robots are expected to serve as a means of providing feedback to physical space. KDDI has been working together with TELEXISTENCE inc., which has developed a remote-operated robot, on R&D toward practical applications. One of the outcomes from the joint R&D is an encoding technology that reduces end-to-end delay from 100 milliseconds to 50 milliseconds using the international standard video codec H.265/HEVC (see Section 10.4.3). As shown in the delivery robot example above, we can see cases of having a single robot operate by itself, but in the future, it may be necessary for multiple robots to work in cooperation with one another. In this case, besides delays in video transmission between robots, and in addition to technology for communicating sensory data between robots, it will also be necessary to develop technology enabling robots to determine what action to take based on the information transmitted. To operate multiple robots in a coordinated manner, it will be necessary to standardize the interface for communicating information between robots, as well as the mechanisms for controlling and managing robots used for RaaS as implemented on the platform. Moreover, since the space in which a robot moves may not be a location from which location data can be obtained, technology to obtain location data, such as VPS, will also be required.

Since not only delivery robots but also domestic help robots and robots supporting human activities will become widespread, human and robots must be able to coexist. Thus far, humans have mainly given instructions to robots, but in the future, robots will make suggestions to humans, and directions given by robots to humans when human lives are at stake. As such, in addition to the AI technologies detailed above, technologies relating to human-robot interaction (HRI) will be required. Furthermore, to advance HRI, research into acceptability evaluations is also needed to measure whether people can or will accept robots, and to improve upon them (see Section 11.4.2).

As we have discussed, the contents of communication services will become increasingly diverse, and will include not only large volumes of data such as 3D images, but also data from all manner of devices, including sensors. The traffic characteristics of each service, and their network requirements, are expected to vary tremendously as a result. It will be necessary to reduce delays—not only delays in the network layer, but also delays in the application layer. Moreover, safety is essential not only to self-driving cars, but also for the coming and going of goods, such as those carried by automated delivery robots; a communication network is therefore required to support it.

Until 5G, communication network coverage areas had mainly focused on locations where people are present. Mobile network operators have been adopting cellular-based architectures to efficiently allocate coverage over wide areas. When using cellular architecture however, throughput becomes lower in so called cell edge area, where locations are far away from base stations. It may not be possible to satisfy communications requirements in such locations, even when using the end-to-end slicing technology to be introduced in 5G, which is a mechanism to satisfy the communication requirements of services and applications, such as throughput, delay, and quality. As introduced in the use case above, coverage areas must be provided not only to locations where people are present, but also to locations in which robots move about. KDDI therefore believes that a new architecture named “user centric architecture” is necessary to dynamically create coverage areas, as if multiple spotlights were to shine on places where both people and robots exist (see Section 5.4.1). In user centric architecture, a large number of distributed antennas cooperate with each other to create a coverage area. To achieve this, we can use a technology called Cell-Free massive MIMO (see Section 5.4.1.1).

In the future, in addition to people and sensors, large amounts of data will be transmitted from new devices such as robots. Until 5G, the main focus was on improving throughput performance in downlink, which is the communication link from base stations to user terminals. However, when a robot takes a video of its surrounding environment, moves autonomously, and transmits the video data to a RaaS that exists in cyberspace every time the environment changes, the amount of uplink traffic generated will be extremely large. Until 5G, uplink communications are made by one user terminals and one or more base stations. The uplink throughput is limited by the upper limit of transmission power imposed on user terminals. The idea of “virtualized terminals” will therefore be necessary to achieve cooperative transmission with the multiple devices around one person, such as wearable devices, to improve uplink throughput (see Section 5.4.1.4).

The throughput required for B5G/6G wireless access lines is expected to be even higher than for 5G, assuming that new devices such as robots will be added as subjects for sending and receiving 3D images. Thus, the required capacity of optical fiber lines known as “fronthaul,” which connect antennas to a central base station where radio equipment is located, will increase. Until now, mobile fronthaul has used digital transmission interfaces called the common public radio interface (CPRI) and enhanced CPRI (eCPRI). However, assuming a peak throughput of 100 gigabits per second for B5G/6G, would require an unrealistic terabit-per-second optical fiber line. Thus, a new mechanism will be required to transmit radio signals from wireless devices to antenna sites using analog transmission. KDDI has proposed intermediate frequency over fiber (IFoF) as an enhancement of radio over fiber (RoF) technology (see Section 5.4.2.2). This solves not only the problem of fronthaul optical fiber capacity, it also has the advantage of reducing the size and weight of equipment at antenna sites and reducing power consumption, since analog transmission eliminates the need for digital-to-analog and analog-to-digital conversions at antenna sites.

With regard to network-related technologies, we believe that new technologies will be required not only for wireless and optical communications technologies, but also for flow control technologies, to efficiently accommodate a wide variety of applications and services; technologies to accommodate large numbers of devices; as well new systems technologies with device movement management functionality—that is, a mobile core network—and the ability to serve as a gateway for packet transmissions (see Section 5.4.3).

Thus, even when celebrating a birthday party in 2030, for example, it can only be achieved by making full use not only of networks, but also the various component technologies in the seven technologies. These technologies are introduced from Chapter 5 onwards, so please refer to those sections.

Of course, as we study further, we will find other component technologies not introduced in this white paper. We hope for cooperation with companies, universities, and research institutes, both Japanese and foreign, on these unexplored and as-yet-undeveloped component technologies. Through the prompt realization of Society 5.0, we hope to work together to construct a next-generation social infrastructure that brings to fruition “a social system that improves people’s lives, stimulates the economy, and is environmentally conscientious.”

5. "1. Network"

5.1. The Role of Network Technology in B5G/6G

With the spread of the Internet, an online cyberspace has appeared and our lifestyles and economic activities today have become increasingly dependent on this cyberspace as well as the physical space of the real world. By 2030, CPS is expected to become even more advanced through the cooperation of the seven technologies. KDDI calls this cooperation “orchestration,” and network technologies will play an important role in connecting physical space to cyberspace.

For example, in 2021, increasing numbers of users are using online services such as streaming services to enjoy music rather than buying CDs or other media. This has been achieved by linking the action of listening to music in physical space to cyberspace using a network.

This trend will have further accelerated by 2030, and it is anticipated that many of the events, objects, and data in physical space will be uploaded to cyberspace. Various processing will be performed in cyberspace by leveraging AI technologies and Big Data. The results of the processing will be fed back to users in physical space through XR, robotics, etc.

It is expected that the flow of this feedback will be accelerated by improvements to the quality and capability of networks, and thus the barrier between physical space and cyberspace will be eliminated. It is expected that CPS will advance by forming a society that transcends time, space, and physical constraints, with all objects and actions moving back and forth between physical space and cyberspace as digital data.

5.2. Network Technology Goals

The most important networks are wireless communication networks. In March 2020, 5G services were launched in Japan. Thus far, wireless communication network technologies have been evolved with an emphasis on transmission data rate. 5G mobile technology offers higher performance through lower latency and larger numbers of simultaneous connections as well as a higher data rate.

We aim to further enhance these three features — “high data rate,” “low latency” and “large numbers of simultaneous connections”— in B5G/6G. Since creating CPS will require the transfer of a large amount of data to reproduce physical space as-is in cyberspace and then, to take the cyberspace information, generated and processed based on the transferred data, and reproduce it in physical space using technologies such as high-definition 3D images and holograms. There will therefore be a need to transfer vastly greater volumes of data than at present. In addition, transferring data from physical space to cyberspace and back with low latency improves real-time experience, and the simultaneous transfer of information by large numbers of users will create a sense of unity, such that users existing in physical space will be able to experience the reality of information generated and processed in cyberspace.

Around 2030, 3D holography and full sensory communication, indistinguishable from the real thing, will be achieved through the real linkage of physical space and cyberspace, delivering excitement everywhere. However, implementing 3D holography will require the ability to transmit one terabit-class data instantaneously [5-1]. This is because vast quantities of data will be exchanged between cyberspace and physical space, for which ultra-high-capacity optical fiber communications offering high-capacity, high-speed (low-latency) data transfer between the two spaces will be essential. With multi-core optical fiber transmission technology that enables the construction of petabit-class ultra-high-capacity optical networks, and RoF transmission technology, which connects a huge number of base station antennae and radio aggregation stations with high capacity and high efficiency, resilient fiber optic communication networks with higher capacity and lower power consumption than ever before become available, making it possible to have real connections with distant family members, colleagues overseas, and friends on the other side of the world.

In addition to leapfrogging the requirements for high capacity, low latency, and large numbers of simultaneous connections to be achieved by 5G, the mobile core network in the B5G/6G era will be required to achieve power savings, autonomy, safety, reliability, and expandability [5-2]. The following describes the high-capacity, low-latency communications that the mobile core network needs to equip.

Regarding high-capacity (broadband) communications, the mobile core network must simultaneously achieve two goals: accommodating the high-capacity communications, and reducing the duration for which a mobile terminal reaches to the max-throughput. Additionally, such high-capacity communications should be achieved for all the online mobile terminals accommodated in the same base stations and/or gateways (the equipment delivering user data to the mobile terminals) in the mobile core network (see Figure 5-1).

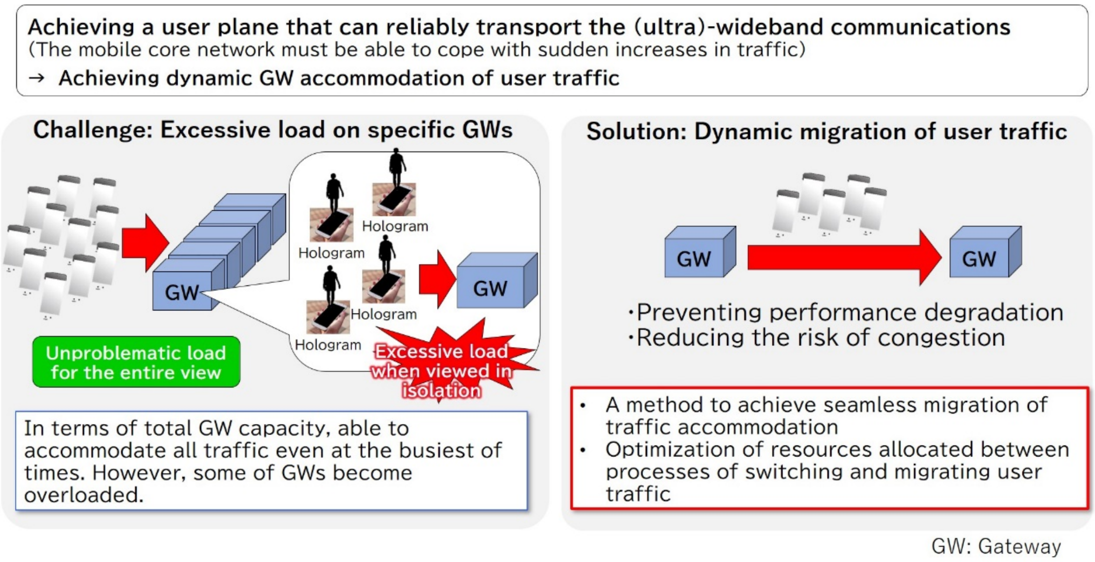

Figure 5-1: Examples of issues with high-capacity (broadband) communications: Accommodating user communications

With respect to low-latency communication, in addition to low latency in the time required to transmit data, the key is to reduce the time required to begin communications for user data transmissions. In most cases, the mobile communications system releases radio resources when the mobile terminal has no communication, and it takes a certain amount of time, corresponding to round trips of several signals, for making its communication ready. By reducing this time, it is possible to achieve low-latency communication from the beginning of the communication (Figure 5-2).

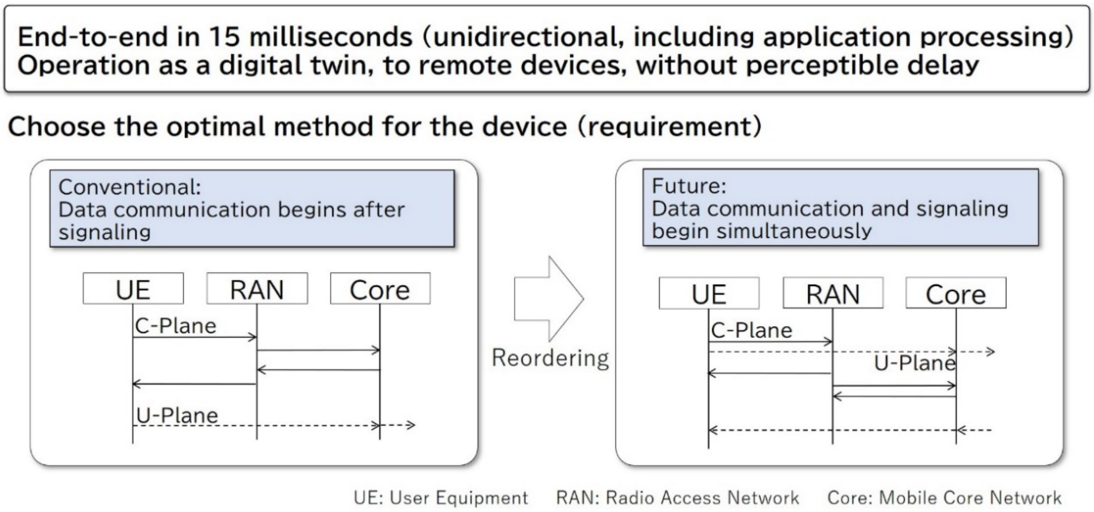

Figure 5-2: An example of issues in low-latency communication: Reducing the time required to begin communication

Moreover, automation of network operations is expected to become more advanced toward the advent of B5G/6G, and as shown in Table 5-1: Definitions of Operational Automation in Networking, we are aiming for its development in stages.

Table 5-5-1: Definitions of Operational Automation in Networking

	Overview	Decision-maker
Level 0	**Operation by human operators** Human operators perform all tasks	Operators
Level 1	**Automation of a part of operation tasks** Automated execution of commands using scripts	
Level 2	**Automation of the operation process flow** Partial automation using rule-based decision-making (e.g., thresholds)	Operators (main) System (sub)
Level 3	**Automated decision-making in operation processes** Partial automation of decisions by the system	System (main) Operators (sub)
Level 4	**Full automation in specific environments** Specialized, full automation for specific tasks and networking performed by the system	System
Level 5	**Full automation** All operations and networking are automated by the system	

Defined in stages from Level 0, where all tasks are performed by human operators, to Level 5, where all tasks and networks are automated by the system, we are aiming to achieve Level 4 to Level 5 automation of operations in the B5G/6G era. Dynamic reconfigured slicing is anticipated for the BG/6G era, requiring flexible design changes during service provision, and dynamic controls such as the reallocation of network resources to suit a given situation. The complexity of network requirements is expected to increase, and new technologies like multi-access edge computing (MEC) will be incorporated into services; IoT networks will also expand further, increasing the number of items to take into consideration during design stages. The increase in the number of available choices, combined with existing design patterns, will result in a huge number of design patterns.

5.3. Global Situation

Various efforts to implement B5G/6G have already begun in many countries. The telecommunications division of the International Telecommunication Union (ITU), the ITU-T, has launched the ITU-T Focus Group on Technologies for Network 2030 (FG NET-2030), to examine existing network technologies, platforms, and standardization, and to identify gaps and challenges in the requirements for the networks of 2030 [5-3]. FG NET-2030 compiles issues from all aspects of Network 2030, such as the vision, requirements, architecture, new use cases, methods of evaluation etc., publishing these issues as white papers [5-4]. In response, the ITU-R, the wireless communications division of the ITU, has begun to prepare technical reports listing the key technologies required for the B5G/6G era. This technical report is expected to be released around 2023, and will be used by 3GPP and other organizations to develop technical standards. ITU-T Study Group 13 has established a focus group on autonomous networks to address the automation of network operations [5-5], and it intends to develop technical reports and specifications for autonomous networks, including considerations for future network evolution. Moreover, the TM Forum, a leading standardization organization for network technologies, has launched the Autonomous Networks Project [5-5], which proposes an AI-based architecture that enables networks to perform operational tasks autonomously. Specifically, in an architecture divided into four layers, network equipment, network, orchestrator, and customer portal, it aims at overall automation across network domains with a total of four loops: three closed loops (a series of automated task cycles), and a closed loop between the top and bottom layer.

In Europe, the 6Genesis project, supported by the University of Oulu, Finland, was designated as a flagship program project of the Academy of Finland in June 2018, and has begun early-stage research. The main goal of the project is to support future industry by supporting the evolution of 5G, developing the basic technologies required to implement B5G/6G, and accelerating the digitalization of society. The results of the project were published in September 2019 as “Key Drivers and Research Challenges for 6G Ubiquitous Wireless Intelligence.”

In the US, New York University and the Defense Advanced Research Project Agency (DARPA) have launched ComSenTer, a research center for wireless and sensor technology, to carry out R&D of wireless communications primarily in the terahertz band (roughly 100–1,000 GHz). The University of California’s Santa Barbara, Berkeley, and

San Diego campuses, together with Cornell University and the Massachusetts Institute of Technology, are also participating in this project, for which R&D is conducted by four teams: Systems, Integrated Circuits, Devices, and Demonstrations. The Alliance for Telecommunications Industry Solutions (ATIS) has established the Next G Alliance, which is working to formulate a roadmap for B5G/6G.

In Japan, B5G/6G is expected to further accelerate the development of CPS advanced by 5G, and to serve a core function as a backbone to Society 5.0 [5-6]. The Beyond 5G Promotion Strategy–6G Roadmap [5-7], published in June 2020, lists the seven major requirements for B5G/6G as (1) Ultra Fast and Large Capacity, (2) Ultra Low Latency, (3) Ultra Numerous Connectivity, (4) Ultra low power consumption, (5) Ultra security and resiliency, (6) Autonomy, and (7) Scalability.

Optical fiber communications that support backbone and backhaul networks have achieved a dramatic 30,000-times increase in capacity over the past 30 years or so through advances in optical signal multiplexing technologies such as time division multiplexing, wavelength division multiplexing, and digital coherent optical transmission (for example, the capacity of optical submarine cables had increased from 560 megabits per second in 1989 to 15 terabits per second/fiber by the late 2010s). However, the limits of these multiplexes are approaching [5-8]. Because there is a limit to the amount of optical power that can be input into existing single-mode fiber due to nonlinear degradation and the fiber fuse[2] phenomenon that occur in optical fiber, and it is difficult to increase capacity by more than 10 times current levels (about 100 terabits per second) using conventional multiplexing technology alone. Innovative technology that can realize sustainable increases in capacity is therefore indispensable.

KDDI has been working on a new optical fiber communication technology, space division multiplexing (SDM) to break through the conventional limitations described above. Spatial multiplexing technology was first discussed at the IEICE Technical Committee on EXAT [5-9] in 2008, and KDDI has actively participated in the committee as a key member since its creation, and has achieved many research results. Major achievements are shown in Table 5-2. In particular, in 2017 we succeeded in building the world’s first multi-core multimode fiber (19-core, six-mode fiber) transmission at 10 petabits per second, corresponding to 1,000 times the transmission capacity of current optical fiber communication systems. This was opening the door to optical communications in the ten quadrillion bit era [5-10]. This achievement received high praise at one of the world’s leading international conferences, with the official press

[2] A phenomenon in which an optical fiber is degraded by light.

release from the conference offering praise: “In a heroic effort, researchers from Japan have managed to break the current record by a factor of five.” This demonstrates the high scalability and potential offered by SDM technology. However, the transmission distance remains short (about 10 km), and further studies are needed to extend the transmission distance. In recent years, multicore fibers (MCFs) with a standard cladding diameter of 125 micrometers have been gathering attention for their practical use because of the manufacturability and mechanical durability of MCFs. Investigation of their practical use has been accelerated by the creation of technical reports on SDM by the Telecommunication Technology Committee (TTC) [5-11] and ITU-T SG15, and by the launch of NICT commissioned research “R&D for accelerating the practical use of multicore fiber” (2018–2022) [5-12].

Table 5-5-2: World’s First Achievements by KDDI in Multicore Fiber Transmission Technologies

Year	World first results	Reference
2012	Success in a trans-oceanic multicore fiber transmission experiment	[5-13]
2013	Success in a 1 exabit x kilometer ultra-long-haul MCF transmission experiment	[5-14]
2015	Successful MCF transmission experiment at 2 petabits per second	[5-15]
2017	Successful MCF transmission experiment at 10 petabits per second	[5-10]

Technical development of mobile core networks includes the ongoing examination of implementation architectures to reduce processing, or to secure new processing. For example, an approach to reduce signaling traffic and the signaling process by an integrated implementation of the functions specified in the mobile core (3GPP Standards TS23.501 [5-16], TS23.502 [5-17], TS23.503 [5-18]), and an approach to deploy mobile core network functions on peer-to-peer (P2P) infrastructure that utilizes on-device processing has been proposed [5-19]. In addition to reducing delays in the transmission of user data (communications data from applications running on the terminal) using MEC, the number of studies into reducing delays in signal processing has been increasing. The main approach used thus far has been to reduce the number of signals by integrating functions [5-20][5-21], but approaches such as a fast signal message conversion process (serialization) [5-22] have also been proposed. Note that none of these proposals address the capability requirements of the mobile core network itself for B5G/6G. Moreover, since it is essential to deal with multiple simultaneous connections—a result of the increasing numbers of devices—there is a need to carefully scrutinize the capability requirements of the mobile core network.

5.4. Technologies Required for 2030

In this section, we summarize the technologies that will support networks in the B5G/6G era, i.e., from 2030 onward, from wireless, optical, network, and operations perspectives. We will also touch on white-boxing (general-purpose equipment) and hardware/software separation, which are expected to widely spread in all network devices in the future.

5.4.1. User centric Architecture

To implement B5G/6G, it is important to implement user centric networks in which a communication area is formed for each user according to the communication environment and individual communication requirements. In wireless communications, mobile communication devices, such as smartphones, communicate with base stations by wireless connection.

Conventional wireless communication is built on the concept of providing communication services with high performance requirements over as wide an area as possible by deploying base stations across a plane. As shown on the left side of Figure 5-3, the area to which each base station provides communication services can be likened to a cell, and this kind of network configuration is known as "cellular architecture."

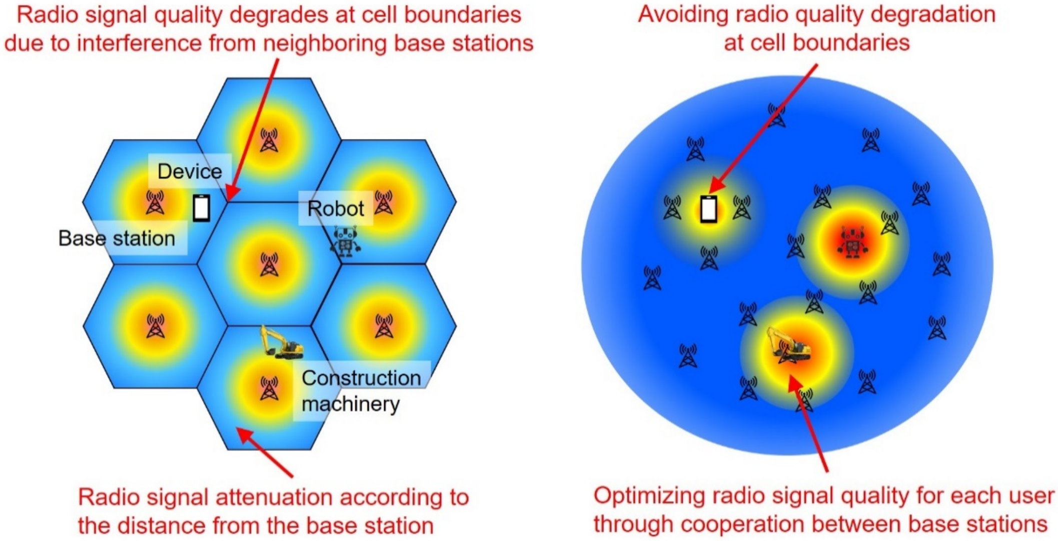

Figure 5-3: Cellular architecture (left) and user centric architecture (right)

In cellular architecture, base stations are deployed according to the distribution of users and traffic, but the radio signals from base stations are attenuated by distance around the base station, especially at the cell boundary. Moreover, at the cell boundary, radio signal quality is greatly degraded by interference from neighboring base stations.

In 5G, high-frequency bands such as the millimeter-wave bands are exploited to achieve ultra-high speed and high-capacity communications. This trend is expected to become even more pronounced in B5G/6G, but as frequencies become higher, this will give rise to issues such as communication loss due to blocking, resulting in unstable communications.

KDDI believes that the introduction of “user centric architecture” like that shown on the right of Figure 5-3 will be an effective technology to solve this issue. In user centric architecture, instead of a specific base station providing services to users in a specific area, multiple base stations work together to provide services for each user. This will provide an optimal communication environment to meet the diversifying communication requirements of the B5G/6G era. For example, for users who wish to send large amounts of data such as high-quality 3D movies, the data transmission rate is an important indicator of communication quality. For such users, it is possible to provide high-capacity communication services without interference between base stations by having nearby base stations cooperate to send and receive radio signals. On the other hand, if we wish to monitor the trajectory of movement in real time, we do not need high speed communications, since the volume of data involved in GPS positioning data is small compared to that of 3D movies—but we must be able to send and receive data with low latency to avoid disruption of communication. It becomes possible to provide stable, uninterrupted communications to such users, despite their movements and changes in the surrounding environment, by implementing redundant connections with multiple base stations simultaneously providing communication services to devices. This ensures the same level of connectivity in the mobile wireless environment as in a fixed-line environment.

Thus, in user centric architecture, every user can enjoy stable, optimized communications services in a variety of environments, and in doing so, it is expected that physical space and cyberspace will become linked to the extent that we are no longer aware of the boundary between the two spaces.

In the following, we show the component technologies required to implement this architecture (Figure 5-4).

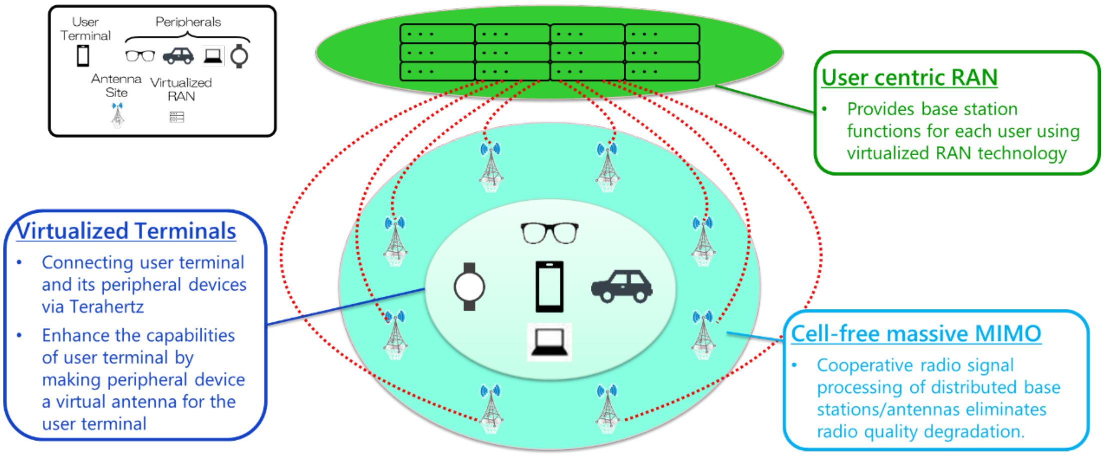

Figure 5-4: User centric architecture and its constituent technologies

5.4.1.1. Cell-Free massive MIMO

KDDI believes that Cell-Free massive MIMO will be an effective component technology for implementing user centric architecture. Cell-Free massive MIMO has been studied since late 2010s, and is positioned as a combination of distributed MIMO and massive MIMO technologies [5-23]. As shown in Figure 5-5, large numbers of base station antennas are densely deployed and each base station antenna cooperates with the others to provide service to individual users. Applying massive MIMO technology at aggregation stations, interference between users can be suppressed, and radio quality degradation at cell boundaries—an issue in conventional cellular architecture—can be reduced. This can increase the number of concurrent connections and can improve throughput, reliability, and energy efficiency per user.

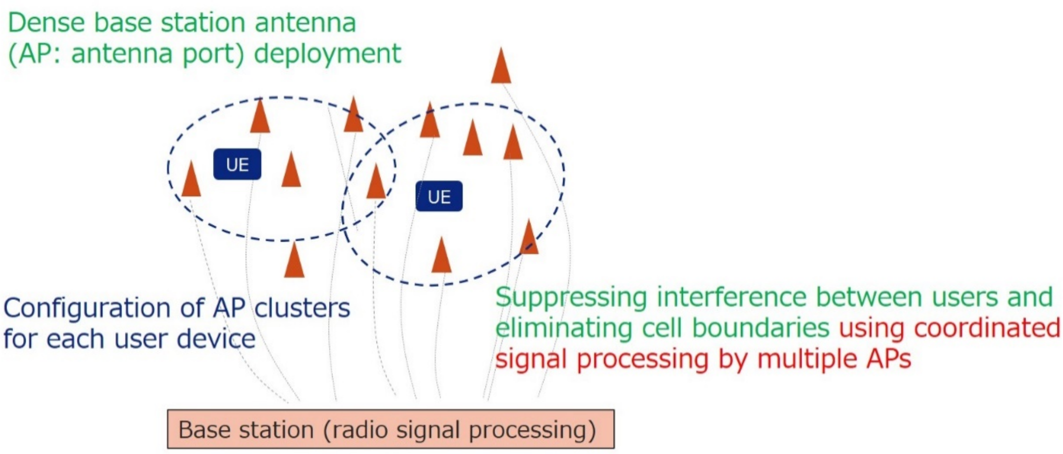

Figure 5-5: Cell-Free massive MIMO

The effects of Cell-Free massive MIMO are strongly dependent on the distribution of the base station antennas that are to be operated by aggregation stations [5-24][5-25]. For example, as shown in Figure 5-6, the spectrum efficiency is dependent on the number of base station sites (L) and the number of antennas installed at each site (N) when the total number of base station antennas is fixed. The results of computer simulations indicated that the spectrum efficiency in the semi-distributed case (center of the figure) is significantly higher than that in the centralized case (left of the figure) at the same level of one of the fully-distributed case (right of the figure) [5-26].

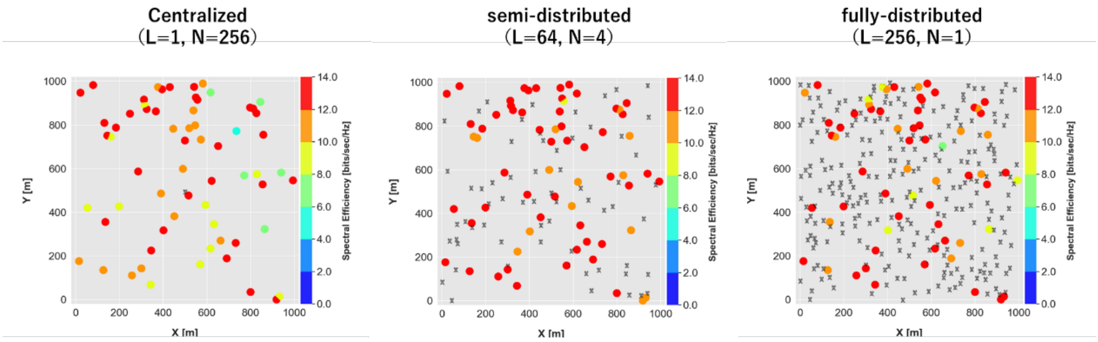

Figure 5-6: Spectrum efficiency (centralized / semi-distributed / fully distributed)
L : the number of base station sites
N : the number of antennas at each site

The deployment of mobile fronthaul to a large number of distributed antenna sites is also very important for the deployment of Cell-Free massive MIMO. In the case of Cell-Free massive MIMO, a large number of high-capacity mobile fronthaul systems is required to transmit a large amount of traffic, e.g., radio waveform information, between antenna sites and an aggregation station. KDDI believes that optical fiber wireless multiplex transmission that employs radio-over-fiber (RoF) technology, as shown in Section 5.4.2.2, has the potential to reduce the high-capacity mobile fronthaul installation costs. To verify the feasibility of Cell-Free massive MIMO deployment using RoF technology, a millimeter-wave radio communication environment was created by connecting a 5G base station simulator and two millimeter-wave band (28 GHz) antennas with multicore optical fibers. The following three conclusions were made [5-27]:

(1) Inter-antenna site interference can be eliminated, and high throughput can be obtained anywhere.

(2) Stable throughput can be obtained to eliminate adverse effects by obstacles.

(3) High radio quality can be maintained even when the placement of the distributed antenna sites is changed.

5.4.1.2. User centric RAN

We believe that the user centric network implementation will require an unprecedented architecture of radio access network (RAN) to realize flexible networks per users. Figure 5-7 shows the historical evolution of RAN architecture. Figure 5-7 (a) illustrates the configuration of a conventional base station, and the base station functions are defined for each base station site. Base station functions have long been implemented using hardware, but the use of software and virtualization for base station functions has increased in recent years.

Figure 5-7 (b) shows an assumed architecture for 5G advanced on the 2025s [5-28]. In this architecture, signal processing functions (distributed unit, DU) and packet processing functions (central unit, CU) of a base station will be virtualized. The placement of the DU and CU, and the assignments of radio and computer resources will be dynamically controlled according to user service quality requirements, such as ultra-low latency and ultra-massive connections.

Figure 5-7 (c) shows a user centric RAN architecture [5-29]. To provide a cell-free radio environment per users with a Cell-Free massive MIMO, the RAN architecture requires more flexible network control using virtualization technology. The significant difference between this architecture and that of 5G advanced is the expansion of the virtualized target to include the backhaul of the mobile communication network and the radio link between a base station and terminals, because logical networks per users are provided. A radio processing unit (central processing unit, CPU) and a radio unit (access point, AP) are placed for each user by using a virtualized method, and these units perform distributed processing of the radio signals between APs. Those provides mobile communication networks per users by the evolved RAN architecture, because it can place and control base station functions for adaptation both the radio environments and communication services that are different per users. To implement this RAN architecture, a construct method of physical networks is required. The method needs to consider how to place computers for CPUs, transport links and APs. A control method to make logical networks per users from the constructed networks is also required. The method includes an assignment procedure of physical network resources such as computers and APs to logical networks. The procedure is required to perform on the minimum order of milliseconds, because the logical networks per users will satisfy required communication quality to adapt both the radio environments and communication services that are different for each user. In addition, the constructed and control methods are required a scalability for a mobile operator network.

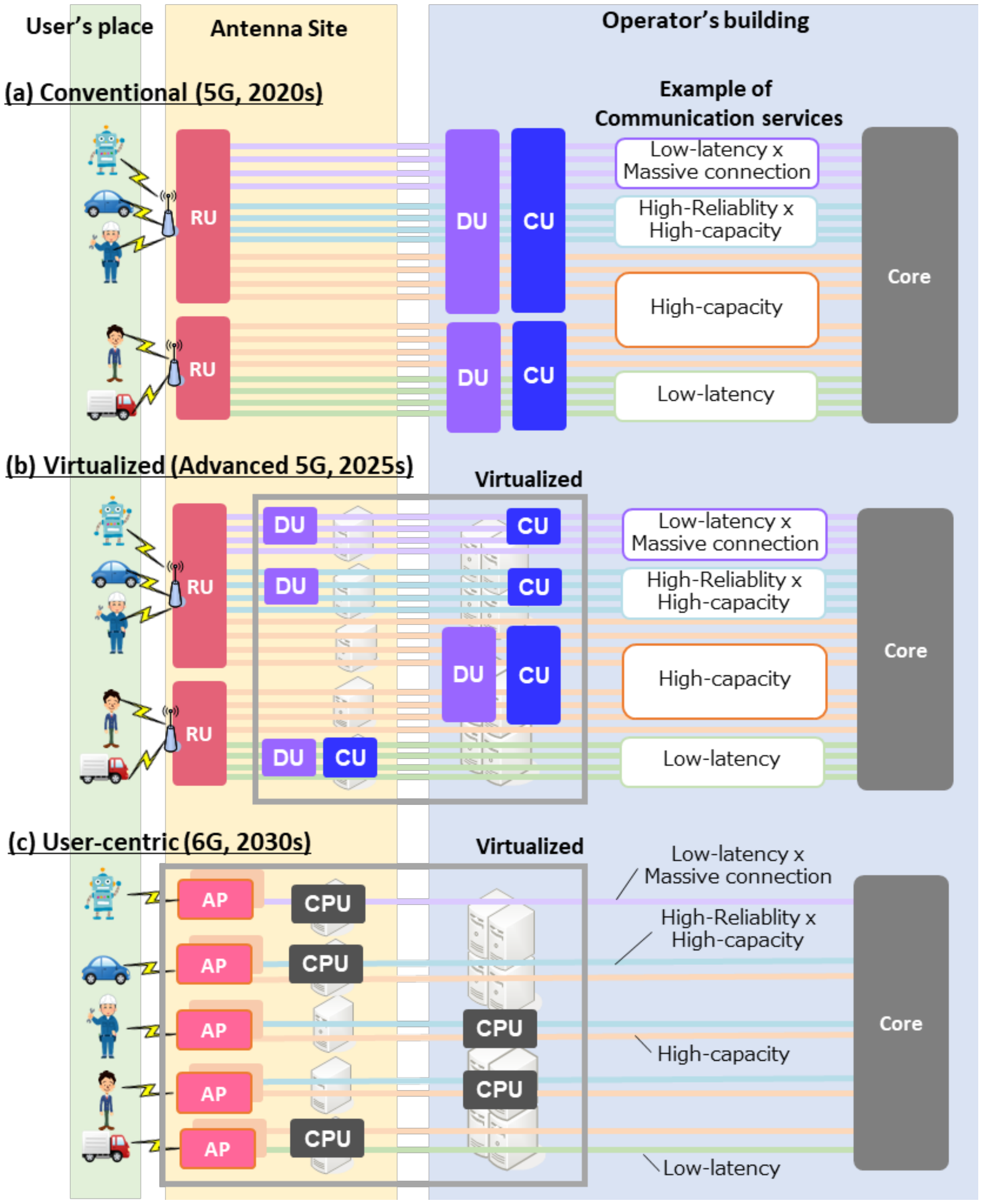

Figure 5-7: Changes in RAN architecture

5.4.1.3. Intelligent Reflecting Surface

To implement user centric architecture, i.e., to satisfy the required service quality for each user, it is necessary to deploy base stations densely, and to have multiple base stations providing seamless coverage to each user. Because 5G makes full use of the millimeter-wavelength spectrum, radio signals with short wavelengths make it difficult to provide wide service areas due to the strong linearity of the radio waves. This results in areas with poor radio signal quality, known as coverage holes, produced by shielding from buildings, trees, vehicles, and people. This issue is likely to become one of the challenges in implementing user centric architecture as the use of higher frequency bands increases moving toward B5G/6G. The use of reflectors has been drawing attention as a means to solve this issue. In particular, investigations into meta-surface reflectors, which reflect radio waves in non-specular directions, have been carried out making use of meta-surface technology, which can generate unnatural electromagnetic properties of radio waves and light by means of fine artificial surface structures, as shown in Figure 5-8.

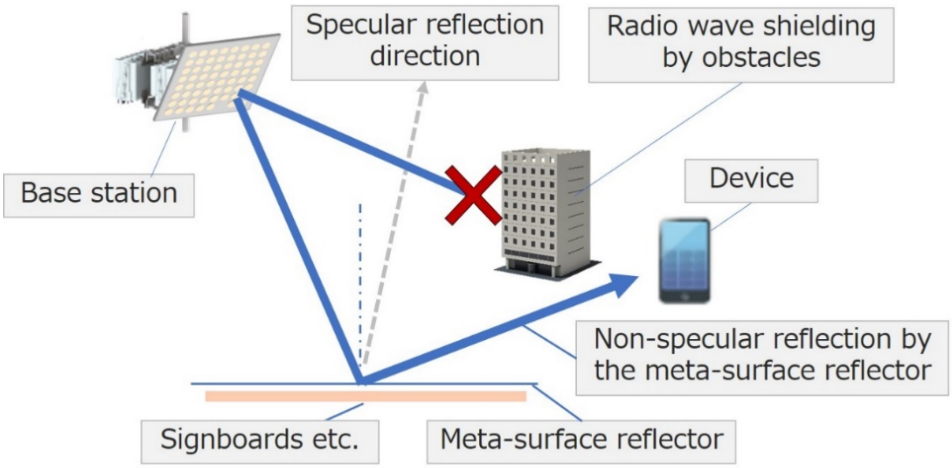

Figure 5-8: Meta-surface reflector

For example, we present an optically transparent meta-surface reflector consisting of a meta-surface reflective element, arranged for each of multiple frequency bands, using a conductive thin film and supported by a transparent resin plate [5-30]. Figure 5-9 and Figure 5-10 show the appearance of the optically transparent meta-surface reflector and the structure of the reflective element, respectively. Reflectors using transparent and invisible materials can be installed on the walls of buildings or urban structures without spoiling the scenery, and are able to provide wireless connectivity from various locations around users.

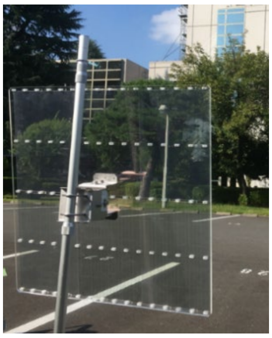

Figure 5-9: Optically transparent meta-surface reflector appearance

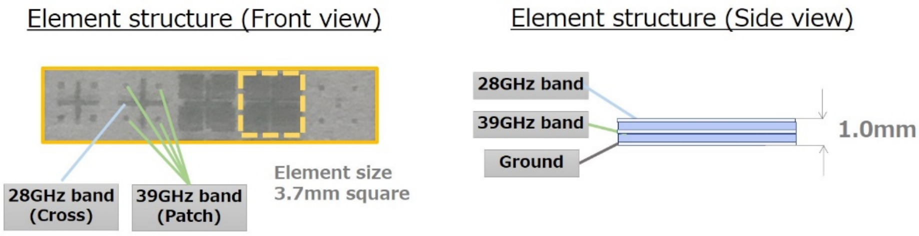

Figure 5-10: Reflector Element Structure

The directivity characteristics of the reflected wave created by the optically transparent meta-surface reflector are uniquely determined by the shape of the reflective element corresponding to each frequency band. The direction of reflection therefore cannot be changed according to a user's location or their movements. On the other hand, users need communication services at various locations within physical space, and their location and surrounding environments change over time. It will therefore be necessary in the B5G/6G era to establish intelligent reflecting surface (IRS) technology, a reflector technology that makes it possible to freely change the directivity characteristics of reflection according to a user's location and movement, while maintaining transparency and permeability to keep their placement from spoiling the scenery.

For example, we present a direction-variable liquid crystal meta-surface reflector that can electrically induce reflected radio wave directional change by applying the liquid crystal used in displays to control radio waves [5-32]. Figures 5-11 and 5-12 respectively show the appearance of the prototype sample and structure of the reflector element of the direction-variable liquid crystal meta-surface reflector. By incorporating a liquid crystal layer between the reflecting element and the ground and applying a voltage using the reflecting element as an electrode, the electrical characteristics of the liquid crystal can be controlled. This makes it possible to electrically induce reflected radio wave directional change. Furthermore, by using this reflector, it is possible to provide a wireless connection regardless of the user's location or environment. This reflector is expected to enable the development of IRS technology that can achieve high-quality wireless connection via high-speed tracking of user movement.

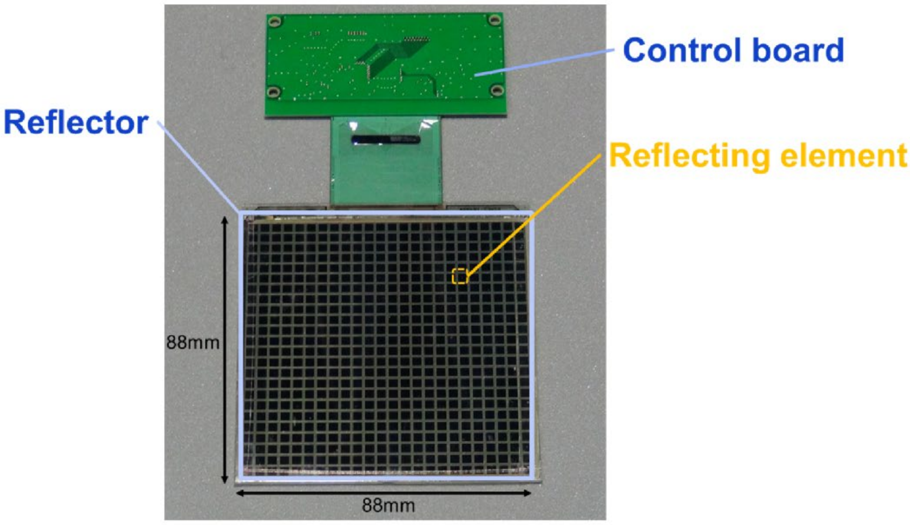

Figure 5-11: Direction-variable liquid crystal meta-surface reflector prototype

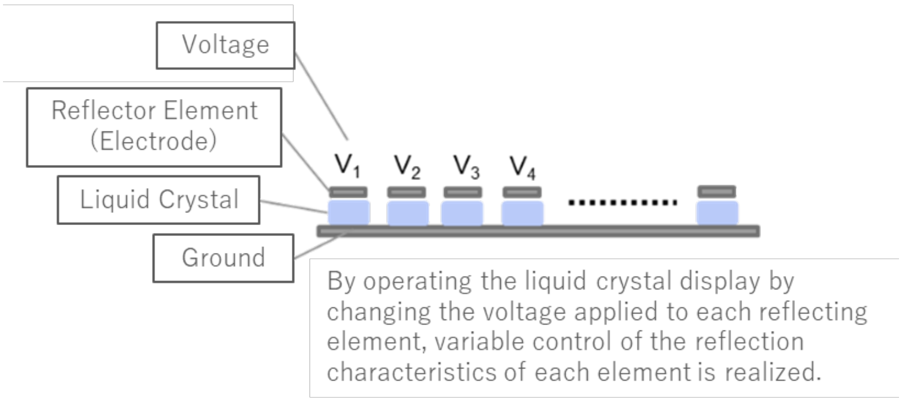

Figure 5-12: Components of the direction-variable liquid crystal meta-surface reflector

5.4.1.4. Virtualized Terminals and Radio over THz Technology

In the wireless communication networks of the 2030s, user devices themselves will also need to evolve to meet individual users' high-communications performance requirements. For example, while mobile phones and smartphones, the most popular user devices today, have evolved in terms of weight and shape, their capabilities as radio devices have not significantly changed since mobile phones first appeared 40 years ago.

In achieving the exchange of information between cyberspace and physical space with the quality and quantity high enough to meet individual users' diverse requirements, user devices present significant limitations in terms of their size, which limits the number of integrated antennae and their maximum transmission power. It is not practical to increase the size of smartphones to alleviate constraints such as the number of antennae, and the performance of uplink communication from user devices to base stations is vastly inferior to downlink communications from base stations.

We are introducing the concept of user centric architecture to the environment around users to resolve these user device limitations. Specifically, through cooperation between various devices that communicate with user devices, it becomes possible to solve issues arising from the constraints caused by a single user device, such as power transmission and the number of integrated antennae.

Figure 5-13 presents a concept for a virtualized terminal. For examples, devices around the user, such as PCs, watches, glasses (smart glasses), or self-driving cars, can become wireless devices and cooperate with one another, making it possible to overcome transmission power constraints in a single user terminal, and to virtually overcome limitations in the number of antennae. When riding in a car with a smartphone, the antenna on the car can also be used virtually as the smartphone's antenna to improve communications performance.

Here, communication between a user terminal such as a user's smartphone and a peripheral device such as a watch or pair of glasses requires a short-range but extremely wideband signal transmission. Since the capabilities required for wireless signal processing are limited in small devices such as watches and glasses, complex wireless signal processing should be avoided in such devices. Thus, in the virtualized device concept, the user's smartphone is responsible for wireless signal processing as a terminal; the smartphone and peripheral devices connect via terahertz broadband radio, while for peripheral devices simply convert the terahertz radio into frequencies for connecting to base stations (e.g., the millimeter wave bands and the sub-6 gigahertz band). This concept can be referred to as "radio over THz" technology, which is an issue for future study. The use of terahertz radio has long been investigated for use in fixed and long-range radio applications such as wireless backhaul [5-33]. However, it is expected that the terahertz radio application could also be disseminated in the form of these short-range use cases.

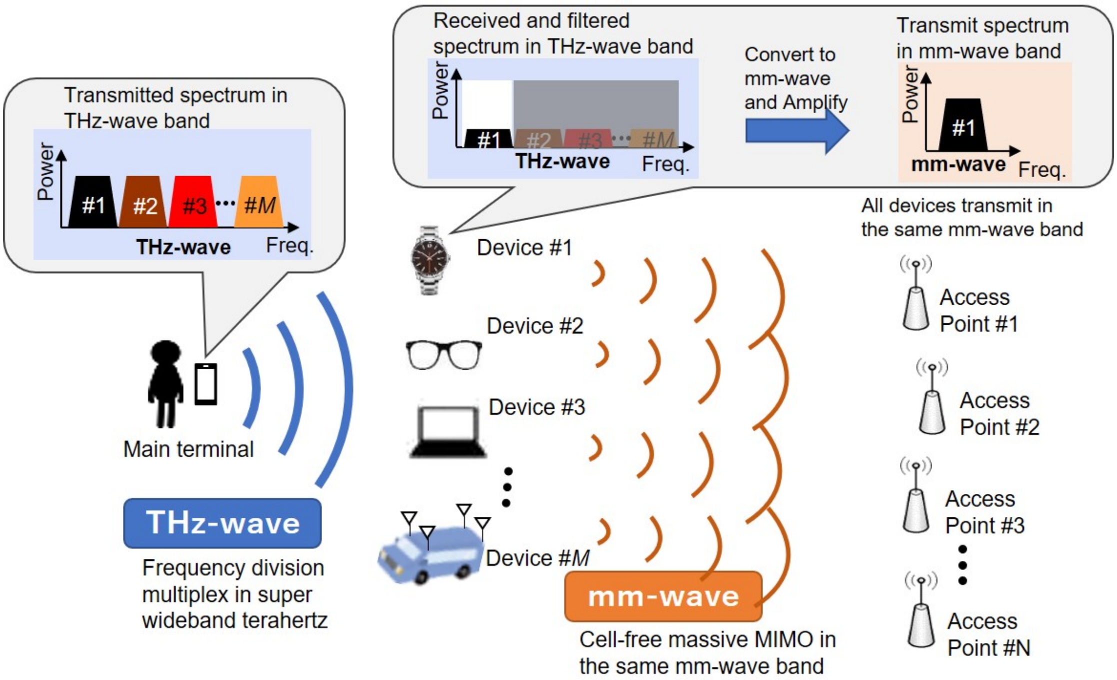

Figure 5-13: A virtualized terminal concept

5.4.2. An Ultra-high-capacity Optical Fiber Network

The capacity required for networks in the 2030s will be more than 100 times the current capacity, i.e., terabit-class capacity for access networks, and petabit-class capacity for core networks. However, to realize the three “links” based on KDDI Sustainable Action [5-34], it is not enough to simply increase the capacity of the network by increasing the number of facilities: an ultra-high-capacity optical fiber network is required that is both sustainable going forward, and fully satisfies energy and space saving characteristics. In this section, we introduce “multi-core fiber transmission technology” and “radio over fiber (RoF) technologies”, which will be necessary for constructing networks in the B5G/6G era.

5.4.2.1. Multi-core Fiber Transmission Technology

Advances in the R&D of multi-core fiber (MCF) transmission technologies will facilitate the construction of petabit-class optical fiber networks that would be difficult to achieve with only conventional technologies, enabling ultra-high-capacity data transmission between physical space and cyberspace. This also enables to achieve realistic spatial reproductions such as holographic communication and full sensory communication. Between now and 2030, the traffic demand of hyperscalers such as Google and Facebook will have further increased; additionally, by 2030, optical submarine cables and interconnections between data centers that support global communications will require significantly higher-capacity optical networks, and research and development is expected to be conducted worldwide. MCFs and their transmission technologies are expected to be a fundamental technology for ultra-large capacity optical networks in the beyond-5G/6G (B5G/6G) era. For example, if a single optical fiber has four light paths (i.e., four cores), the space utilization efficiency can be increased by a factor of four, making it possible to increase the transmission capacity of the entire cable by a factor of four under the conditions of using the existing optical cable. KDDI, in collaboration with a fiber manufacturer, has succeeded in developing an ultra-low-loss, ultra-low-crosstalk, standard-cladding, uncoupled four-core fiber (4CF) with the same characteristics as the fibers used in conventional optical submarine cables; this was achieved by optimizing the fiber structure and manufacturing method. In addition, KDDI successfully performed the world's first standard-cladding 4CF transmission experiment by applying wavelength-division-multiplexed optical signals at a bitrate of approximately 100 Gbit/s over a transmission distance of 12,000 km, which is longer than the 9,000 km that is required for trans-Pacific transmissions (see Figures 5-14 and 5-15 for images of the optical submarine cable and cable structure, respectively) [5-35].

To further increase the transmission capacity through the use of spatial-division multiplexing (SDM) technologies, it is necessary to increase the spatial multiplicity according to the number of cores and modes. However, MIMO digital signal processing (MIMO-DSP) is necessary to achieve ultra-dense SDM processes, such as coupled MCF transmission and mode-division multiplexing (MDM) fiber transmission, as MIMO-DSP will eliminate the inter-core coupling and mode coupling that occurs between cores and modes. Table 5-3 summarizes the pros and cons of SDM transmission technologies. Although uncoupled MCF transmission does not require MIMO-DSP, coupled MCF transmission and MDM fiber transmission should be considered because they have the potential to significantly increase capacity of spatial multiplicity in the future. To realize real-time MIMO-DSP, it is necessary to 1) understand the behavior of spatial inter-core and mode coupling, and 2) create real-time MIMO signal-processing algorithms with high noise tolerance. Thus, KDDI has been investigating real-time MIMO-DSP technology, and has recently developed a real-time MIMO signal processing system using FPGAs [5-36]]. KDDI has consequently successfully conducted the world's first transatlantic-class, ultra-long-haul coupled MCF transmission experiment using real-time MIMO-DSP circuits [5-37]

Additionally, to realize the development of SDM transmission systems and subsequent deployment as a network, it is necessary to research and develop various peripheral technologies, such as compact and power-saving optical repeaters (optical amplifiers), optical switches, and monitoring devices for SDM networks. KDDI is also in the process of developing 1) a cladding-pumped multicore erbium-doped fiber amplifier (MC-EDFA), which is purposed to allow a single laser to simultaneously pump multiple cores, and 2) novel optical devices that can pump a multicore erbium-doped fiber (EDF) core by core and monitor the optical signal power core by core without a fan-in or fan-out devices [5-38]. In July 2021, KDDI began the research and development of SDM optical network node technologies (e.g., SDM optical switching nodes and optical repeaters) as fundamental technologies for ultra-high-capacity backhaul and backbone optical networks. This research is being performed in collaboration with other research institutes under the name "Research and Development of Space-Division Multiplexed Optical Network Node Technologies to Support Beyond 5G Ultra-high Capacity Wireless Communications" , which has been commissioned by the National Institute of Information and Communications Technology (NICT) as part of the Beyond 5G R&D Promotion Project [5-39].

Toward the B5G/6G era, in addition to the research and development dedicated to increase the capacity of existing optical fiber networks [5-40][5-41], KDDI will continuously accelerate the research and development of MCF transmission technologies in order to ensure the reality of ultra-high-capacity data transmission between cyber and physical spaces in the future.

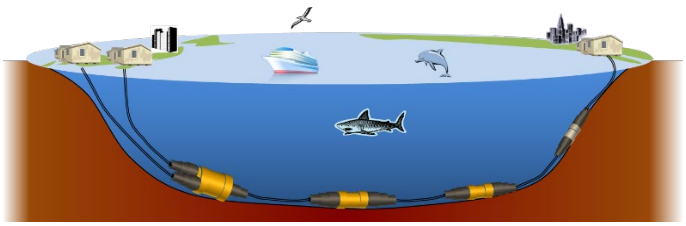

Figure 5-14: Image of submarine optical cable system

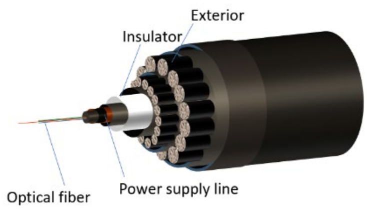

Figure 5-15: Structure of submarine optical cable

Table 5-3: Advantages and disadvantages of space-division multiplexing (SDM) transmission technologies

	Multi-core fiber (MCF) transmission		MDM fiber transmission
Fiber	Uncoupled MCF	Coupled MCF	MMF, Strongly-coupled FMF
Multiplexing	Core Low inter-core crosstalk	Core Large inter-core coupling	Mode Large mode coupling
MIMO DSP @ Spatial channels	◎ Not required	△ Required	△ Required
High capacity ＝Large spatial multiplicity (SM)	△ Standard-cladding MCF, maxSM：～4,5	○ Standard-cladding MCF, maxSM：～12	○ Standard-cladding MMF, maxSM:～45
Long-haul transmission	○	○ Low SMD	○ Large DMD

MDM:Mode-division multiplexing, MMF：Multimode fiber, FMF：Few-mode fiber, DSP:Digital signal processing, SMD：Spatial-mode dispersion, DMD：Differential mode delay

5.4.2.2. Radio over Fiber (RoF) Technology

In the B5G/6G era, the data rate of wireless communication system is expected to reach the sub-terabit level, which is 10 times faster than 5G. It is assumed that the frequency bands higher than the millimeter wave band will be utilized in B5G/6G to realize such a high-speed communication. However, propagation loss becomes much higher compared to the frequency bands used before 5G, so the installation of vast numbers of base stations and antennas will be required. Therefore, it is essential for networks accommodating these wireless systems to be low in power consumption, space-saving, and cost effective, in addition to having the ability of conveying large volumes of data.

As in the user centric architecture concept set out in Section 5.4.1, close cooperation between large numbers of distributed antenna ports is a precondition for realizing high-capacity, high-quality wireless communications, and it will be necessary to transmit radio signal waveform between central stations and antenna sites. Digital transmission methods such as CPRI [5-42] and eCPRI [5-43] are widely used in conventional centralized radio access networks (C-RAN) for the mobile fronthaul interface between central stations and antenna sites. In this scheme, the temporal waveform or physical layer information for modulating and demodulating radio signals is transferred as digital signals, and a transmission speed of about five to 16 times larger than the user throughput is required for mobile fronthaul network [5-44]. If we assume that the user throughput will increase to more than 100 gigabits per second in the B5G/6G era, terabit-class communication will be required for mobile fronthaul, and it will be extremely difficult to achieve such high speeds. Thus, novel mobile fronthaul technology that is not bound to conventional technologies will be required.

Based on the above, KDDI is working on the research and development of radio over fiber (RoF) technology, which can achieve both accommodation of large-capacity wireless communication systems and a configuration of C-RAN architecture at the same time. In the RoF system, the modulation and demodulation of wireless signals are performed at the central station, and the radio signal waveform is transmitted “asis” over optical fiber in the mobile fronthaul section. This obviates the need for modulation and demodulation of radio signals at the antenna sites, which resulting in significant improvement of the space and energy efficiency. Furthermore, as shown in Figure 5-16, KDDI is investigating intermediate frequency-over-fiber (IFoF) as one form of RoF technology which, rather than sending a single radio channel at a time, multiplexes wireless signals in frequency domain for vast numbers of antenna sites and transmits them over a small number of optical fibers and wavelengths. In 2017, in anticipation of the 5G era, the world’s highest capacity signal transmission experiment was successfully conducted [5-45], and completed feasibility studies from the large-capacity and high signal quality points of view. Recently, in a joint study with other organizations, we have succeeded in the world’s first RoF transmission experiment with large capacity and superior installability for a use case bringing millimeter-wave wireless signals into enclosed spaces such as indoors [5-46]. In addition, by exploiting the four-wave mixing phenomenon that occurs in optical fibers, KDDI was able to develop and successfully test a new transmission method that was purposed to increase the signal-to-noise ratio (SNR) of optical signals that are input to an optical fiber by nine times before it reaches the optical receiver . This method is expected to be adopted as a technological basis for RoF transmission quality improvement [5-47].

The creation of new mobile fronthaul technology is essential for realizing B5G/6G, and further development of RoF-based mobile fronthaul is expected in the future for cost reduction, operation and maintenance. Furthermore, configuration of antenna sites can be simplified, i.e., “optical/electric (O/E) conversion + antenna,” which is expected to save power and space of antenna sites in the B5G/6G wireless systems utilizing millimeter-waves or higher. With the aim of further developing such mobile fronthaul technology, KDDI has also began the research and development of ultra-high-capacity wireless fronthaul technologies that converge THz waves and optical wireless signals. This research is being performed in collaboration with other research institutes under the name "Research and Development of Radio and Optical Converged Wireless Communication Systems for Beyond 5G Ultra-high Capacity Wireless Networks" [5-48]; this research project has been commissioned by NICT as part of the Beyond 5G R&D Promotion Project.

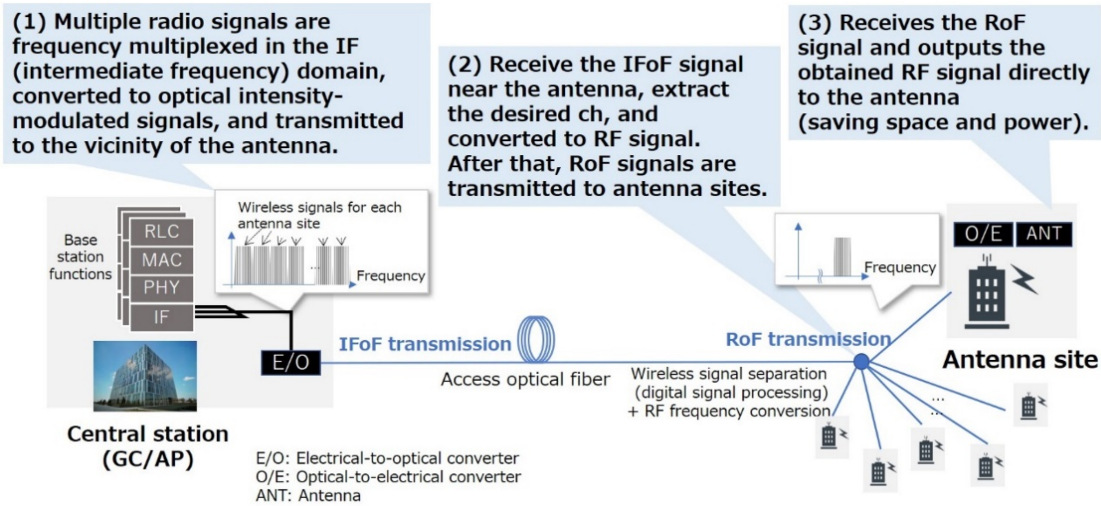

Figure 5-16: An example IFoF transmission system

5.4.3. Mobile Core Network

This section discusses the technologies that are expected to be utilized to implement the various requirements of mobile core network, including the requirements described in Section Network Technology Goals.

5.4.3.1. Technology to Realize High-capacity Communication

For high-capacity communications, in addition to supporting higher speeds in the wireless section, it is expected that multi-session communications using multiple communication connections simultaneously, and explicit congestion notifications will be used in accelerating communication throughput and controlling communication flows, respectively (Figure 5-17). In using these technologies, the mobile core will be responsible for controlling the number of flows and maximizing the communication speed of each flow by sufficient interworking with terminals and the radio access networks.

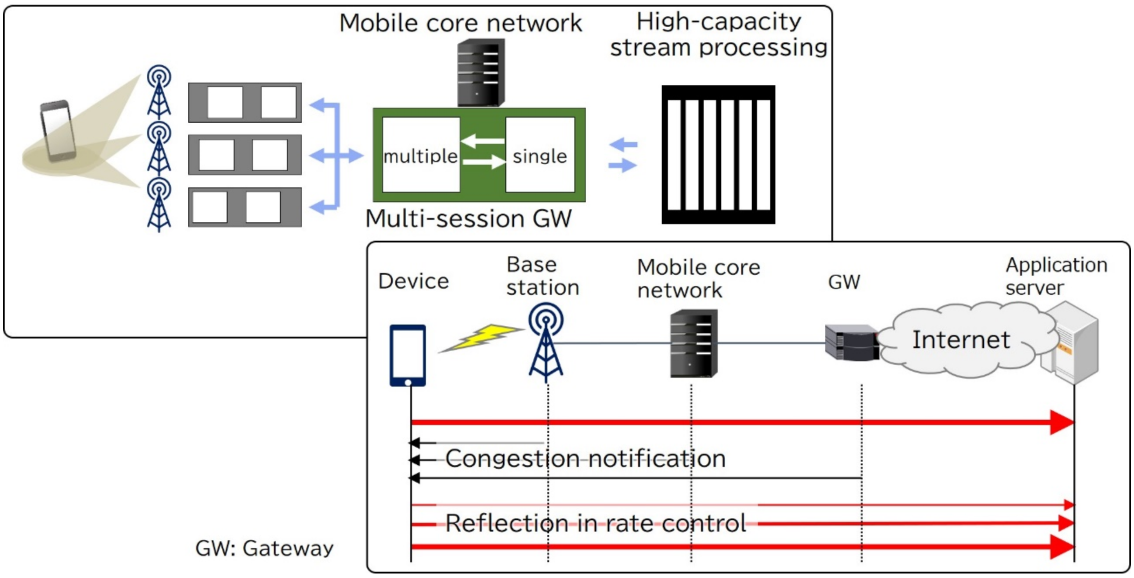

Figure 5-17: Multi-session communication (upper left) and explicit congestion notification (lower right)

5.4.3.2. Technology to Achieve Low-latency Communication

The key to low latency communication is reducing the time to begin communication. As shown in Figure 5-2, there is a need to establish a method of device registration and bearer management that can achieve user data delivery without waiting for signal processing to establish a communication bearer.

5.4.3.3. Technology to Achieve Massive Multiple Simultaneous Connections

For massive multiple simultaneous connections, it is necessary to simplify the management of terminals without registering the location of the terminals in the mobile communications system (Figure 5-18). In the conventional mobile communication systems, once a mobile terminal is powered on, the mobile core network registers the mobile terminal. When the mobile terminal does not communicate, the connection to the wireless section is released, but the mobile core network track the position of all the mobile terminals[3]. Because the number of IoT device connections is expected to increase dramatically in the B5G/6G era, following the current location management of mobile terminals leads to bringing bloated facilities.

The challenge when omitting the location management is that the mobile core network

[3] To be precise, tracking area data is defined by the carrier.

enables the mobile terminals to begin their communications despite that they are not unregistered, and it is further necessary to provide a means to begin the registration process originated by the communications begun by the mobile terminal more quickly than before. Note that there are many round-trip signals in conventional mobile communication systems, and the registration process takes a certain amount of time. If we can resolve these two problems and achieve a means of connecting terminals without location management, it will be possible to reduce the processing load of mobile communication systems, and to avoid the bloating of facilities.

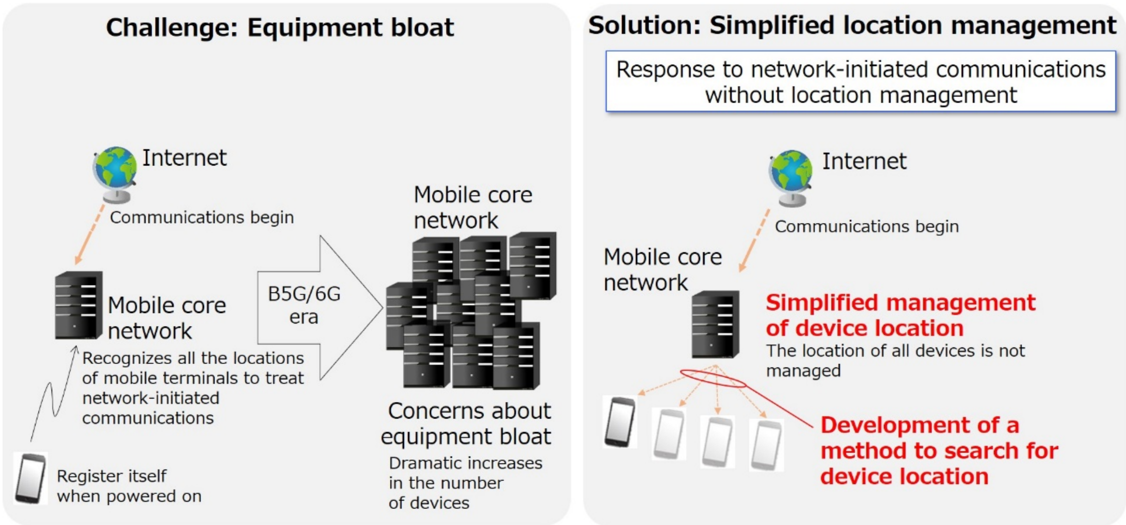

Figure 5-18: Responding to a dramatic increase in devices: Simplifying device location management

5.4.3.4. Technology to Achieve Autonomy in Mobile Communications Systems

The key to autonomy is operational automation using AI technologies, as described in Section 5.4.4. Achieving the autonomy of mobile communication systems will enable them to predict and avoid network failures in advance. In addition, it can be expected to maximize the effects of high-speed communication, with low-latency, multiple simultaneous connections by adjusting the mobile terminals accommodation and network configuration.

In predicting network failures, it is important to understand trivial changes from various network states. Since various slices are provided in the B5G/6G era, various communications characteristics should be achieved accordingly. It is therefore important to be able to appropriately extract information concerning the network state, which results in the predictions of network failures, depending on the slice.

5.4.3.5. Technology to Achieve Safe and Reliable Communication

Secure, end-to-end secrecy of communications and continuity of connectivity are required to improve the security and reliability of communications (Figure 5-19). Security of communications requires the realization of end-to-end confidentiality for IoT devices that require low power consumption. Continuity of connectivity will require a means to completely eliminate the conventional wireless communications characteristic of "occasionally being interrupted because it is wireless." It is therefore necessary to utilize multi-session control using multiple base stations simultaneously, and to develop a means of monitoring the state of the network to identify areas that can continue to be connected, and those that cannot.

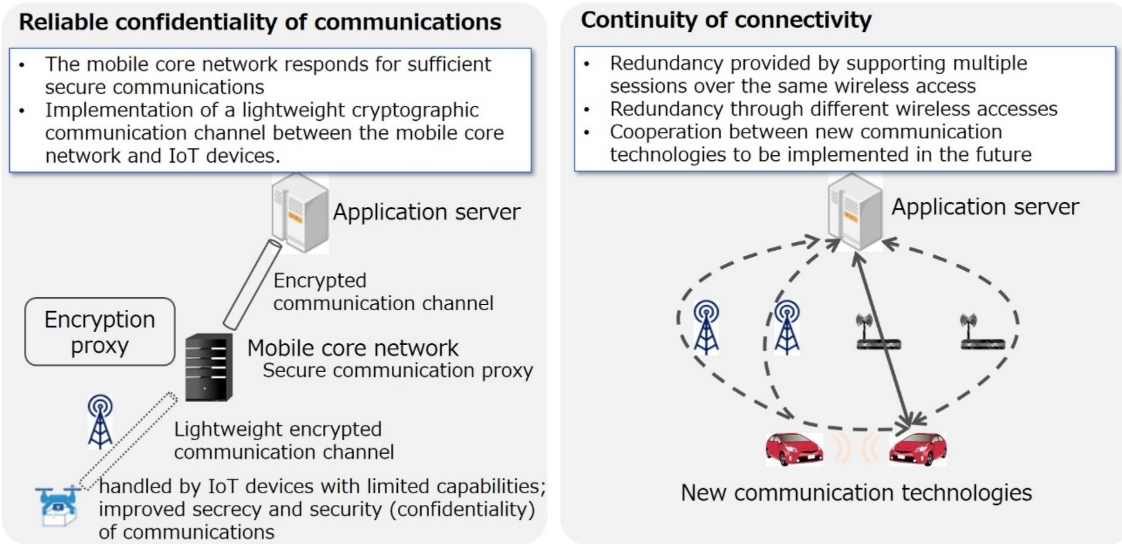

Figure 5-19: Delegation of secret processing of communication and communication session redundancy

5.4.3.6. Technology to Achieve Scalability in Mobile Communications Systems

For scalability, it is necessary for the mobile core network to handle multi-hop communications resulting from cooperation between the mobile terminals, and to manage them efficiently in environments with vast numbers of base stations. Multi-hop communications are a complementary measure to ensure continued connectivity, which may be considered together with methods to ensure reliability (see Section 5.4.3.3). In this multi-hop technology, one terminal carries the communications of another, and so a power-saving method of communication is important for its widespread use. A flooding time synchronization protocol has been developed as a technology to achieve this [5-49]. Although further technical innovation is required to apply this to high-speed communication, it is expected that a low-power method of multi-hop communications can be implemented.

A very large number of base stations will be used. It is of significant importance to avoid location management following conventional mobile communication systems. This will dramatically increase the frequency the location registrations of mobile terminals are updated, and leads to raising the processing load of the entire mobile communication system. It will be necessary to re-design the mobile core network with more sophisticated location management or without the location management as discussed in Section 5.4.3.3.

5.4.3.7. The Direction of Mobile Core Network Architecture

Based on the requirements in Sections 5.2 and 5.4.3, it is expected that the mobile core network will handle diverse communications in the B5G/6G era. In the conventional mobile core network, which deals with various communication requirements uniformly, the expansion of management data is expected to cause the mobile cores themselves to become bloated, resulting in a deterioration of their operating efficiency. For example, in the transformation from 4G to 5G systems, the component functions of mobile core networks have almost doubled, from six or seven functions to twelve or fourteen. If functions expand by the same factor in B5G/6G mobile communication systems, processing power consumption will need to increase dramatically, together with an increase in connected terminals. It is therefore essential to revamp mobile core network architecture, including re-designing the location management (see Section 5.4.3.3).

The architecture of conventional mobile core network systems has been designed with a focus on improving treating management data (information elements), and almost all functions (accessing or refreshing managed data) are used in response to changes in the state of mobile terminal communications. In reforming the system architecture, it is desirable to reduce signal processing, i.e., to keep processing to the minimum necessary when the communication state of mobile terminal changes.

Considering the mobile core network architecture should also incorporate the adoption of software implementation techniques. In terms of software implementation methods, there have been various studies on methods to improve reusability and methods to make rapid modifications. In the latter context, the concept of micro-service architecture has been proposed as a means to treat the diversity [5-50]. In this micro-service architecture, various permutations of micro-services (components) are prepared, and the components maintain a weak relationship while they cooperate with each other (Figure 5-20).

It is necessary to carefully consider how to define components when introducing a micro-service architecture in the mobile core network. The important question is understanding processing relationship between designed components from the behavior of the mobile core network in order to keep the components to have a sparse relationship. Once the components are properly defined, the processing load on the entire mobile core network can be reduced. Because exchanges of management data become sparse, the processing load on them may be kept at a certain amount of variation, and this may bring that processing capacity can easily be estimated based on the number of terminals and their communication requirements.

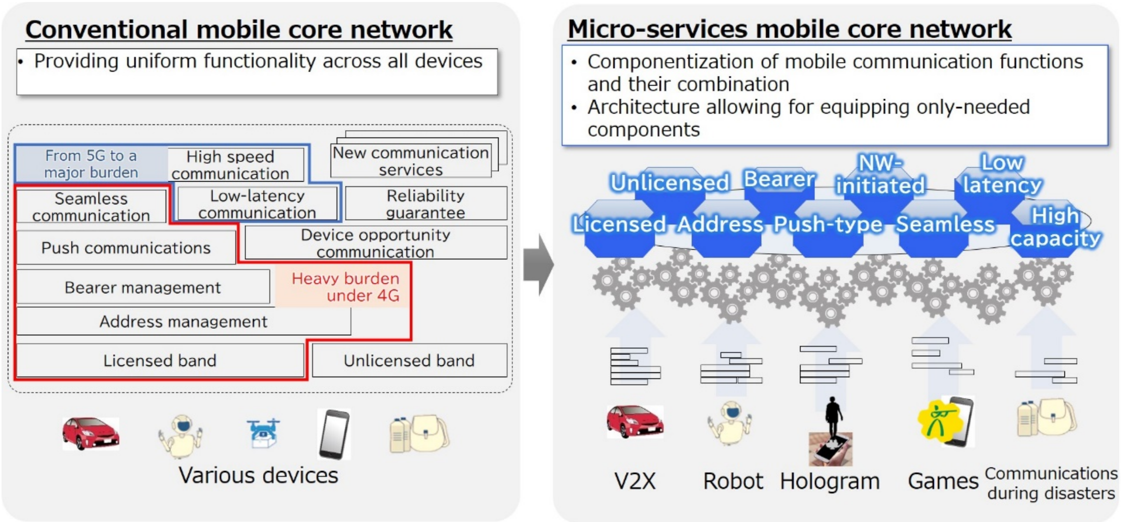

Figure 5-20: Provision via microservice architecture to satisfy necessary communication requirements: An example of mobile core network architecture

5.4.4. Operation

KDDI is carrying out various R&D efforts toward implementing operational automation.

5.4.4.1. AI-based Operational Automation

The use of “5. AI”, one of the seven technologies of KDDI Accelerate 5.0, is being promoted in various fields, and its use is also being considered in the network operations field. With the further development of network virtualization and dynamic changes in network segmentation, known as slicing, in the B5G/6G era the task of constructing and operating networks will become more complex than before. Thus, since operational tasks are also increasing, efficiency is required.

AI technologies are used to analyze information obtained from networks to make necessary decisions in network monitoring, such as detecting failures, determining causes, and selecting the recovery procedure. As stated above, networks consisting of virtualized hardware and microservice-based applications have a huge number of targets to monitor, and the data obtained from that monitoring is also vast. Moreover, in the B5G/6G era in which network configurations will change dynamically, there will be limits to the number of rule-based decisions that can be made based on that vast and changing information. Overlooked failures or incorrect implementation of recovery measures beyond those limits may hinder communication between physical space and cyberspace. For this reason, KDDI is carrying out R&D of technology to automate network operation monitoring tasks by using AI technologies to repeatedly learn data such as logs and alarms generated from faults.

Furthermore, it is expected that the technology used for network virtualization will shift from virtual machine-based technology to container-based, cloud-native technology. The software quality of cloud-native technologies, which have thus far mainly been used in the ICT field, has been enhanced in the online service field by DevOps and canary releases. In carrier networks, it is necessary to satisfy service level agreements (SLA) for all traffic. KDDI has therefore been carrying out R&D to ensure that cloud-native infrastructure satisfies carrier quality requirements. Specifically, as described in Section 5.4.3.4 , we are defining datasets that enable the predictive detection of network faults, and we engaged in the R&D of technology to obtain metric data from container data [5-51].

5.4.4.2. Operations Robots

"7. Robotics," one of the seven technologies in KDDI Accelerate 5.0, is also being considered for use in network operations. Hardware operations are not eliminated even in virtualized networks, and physical tasks, such as periodic patrols and responding to faults, are still required. It will be of benefit to use robots to complete these physical tasks, which are currently performed by people.

Floor surfaces in data centers are flatter than those in outdoor environments, and it is easy to operate robots in them because they contain few uneven surfaces such as gravel paths. In conjunction with security functions to manage entrance and exit, the environments are designed to facilitate the movement of robots while maintaining security. Considering these advantages, it is possible for robots to automatically patrol rooms in a data center and to automatically notify users of any detected abnormalities. It is also possible for a human to remotely operate a robot to open rack doors and replace a failed unit within a server. By utilizing robots to support this kind of physical work, it is possible to provide stable hardware resources for network function virtualization (NFV).

5.4.4.3. Operational Automation using Open-source Software

There are also various open-source software initiatives for network operations. There are several advantages to using open-source software. Although it depends on the policy of the community managing the open-source software for network operations—the interface with the virtual network function (VNF) to be controlled and monitored, together with its management system—the software is often compliant with typical standard specifications such as 3GPP and ETSI, which is advantageous for multi-vendor configurations. Moreover, open-source projects often include not only formulating specifications but also software implementation in their scope, making it easy to proceed with operational validation, and where it features a desired specification or function, this can be reflected by participating in the community and providing source code.

Within open-source software for network operations, the Open Network Automation Platform (ONAP) is one of the most reliable from the perspective of the companies participating the project, which is reflected in its presence and the frequency of releases. ONAP is a platform that automates the operation of carrier-grade virtualized networks, comprised of DESIGN-TIME (the part for designing networks) and RUN-TIME (the part for monitoring networks). ONAP is promoting the creation of an ecosystem through smooth linkage with external systems. For example, the project jointly with O-RAN ALLIANCE, a community making an Open RAN specification, is formulating an interface with a non-real-time controller to support network slicing feature providing SLA assurance service and flexible function deployment.

In this way, open communities and standardization organizations are actively collaborating and complying with one another’s specifications. By strategically adopting examined standards and software, it will be possible to efficiently advance the automation of operations using software that applies expertise from its various stakeholders in a global manner.

5.4.4.4. Autonomous Networks

Autonomous networks are a concept in which the network itself operates automatically, and is able to perform necessary configuration and fault handling automatically. The ITU-T, ETSI, and TM Forum have been working on their respective projects under this name, and there is growing interest in expanding the possibilities for operational automation in the future.

KDDI is working on the R&D of autonomous networks in the form of cooperative AI technologies for inter-domain collaboration, extending the AI-driven network operations described above, and to broaden the scope of application of operational automation.

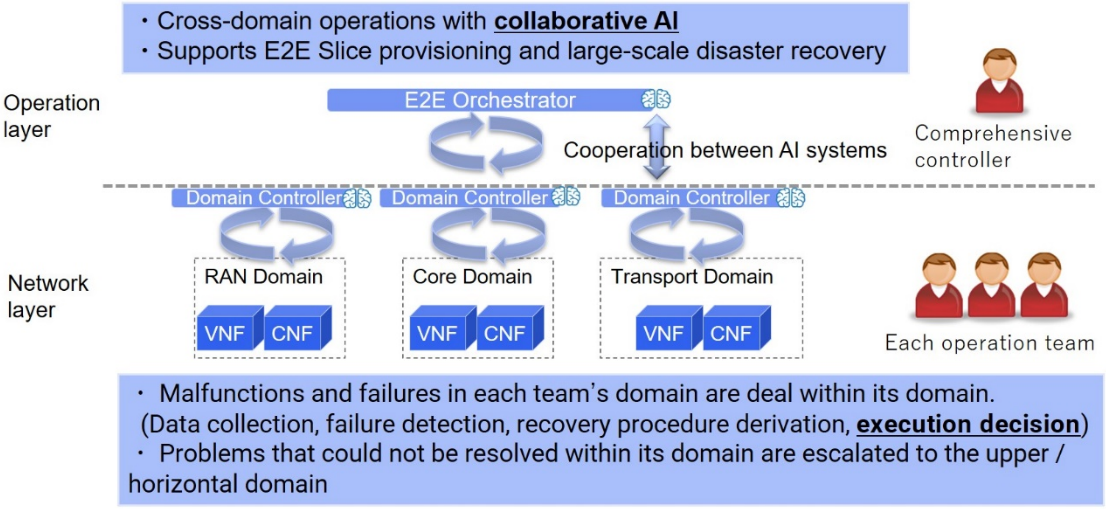

Figure 5-21: Automation using autonomous networks

Figure 5-21 shows an example of automation by autonomous networks. The AI automation in Section AI-based Operational applies to a single network domain such as RAN or mobile core, and responds to faults within the networks. In actual practice, however, the effects of operations or faults may extend beyond the domain, or the location in which a fault occurs may differ from the location of a recovery action, so it is necessary to coordinate and address failures across domains. By learning the results of workflow execution and optimizing these adjustments, the impact of events such as failures and planned work can be minimized and operational tasks can continue. This cooperative AI technologies can be used to control events spanning multiple domains, such as RANs and mobile core networks, to accommodate end-to-end automation.

5.4.5. The White-boxing of Systems and Technology to Separate Hardware from Software

The white-box development approach, which separates hardware from software (which are historically integrated), is expected to make further progress in communication systems going forward to accelerate innovation and improve upgradeability, respectively. The expansion of the ecosystem is important to promoting the development of white-box technology. To contribute this expansion, KDDI established the Telecom Infra Project (TIP) Community Lab (TIP-CL) in Tokyo in 2020, and continues to be active through the creation of projects to conduct basic validation and interoperability testing of base station aggregation gateways, to open up high-capacity routers (DOR: Disaggregated Open Router), and to promote study of RAN slicing in O-RAN ALLIANCE.

Cloud-native networks are currently receiving attention as a new trend for white-boxing communication systems. The original white-box approach uses a virtual machine (VM) to implement network equipment on non-specific computers. However, such simple white-boxing will not maximize the benefits of virtualization, because the costs of development, operation, and management will remain the same. In contrast, cloud-native networks have been proposed as a tool to extract the benefits of hardware-software separation to optimize development, operation, management, and scalability. Cloud-native networks use container technology instead of a VM to separate network functions into small units, called microservices, for flexible control. Such cloud-native frameworks based on microservices are widely applied in the development and construction of modern large-scale web services; these frameworks ultimately enhance the efficiency and scalability of development, operation, and management processes. Such frameworks do not constitute a simple replacement of VMs with containers, as they entail the re-design of network functions, such as those related to resilience, manageability, and observability. Furthermore, the application of a cloud-native framework to a communications system requires that the problems specific to cloud-native networks, such as the need to improve the throughput of inter-container communication, be solved in advance.

Power consumption is a key concern for future technologies, because it increases with increasing traffic. It should also be taken into consideration that it will be difficult to maintain the conventional growth rules for processing technologies that have underpinned innovations in virtualization technologies to date [5-52]. In order to cope with this difficulty, it is necessary to utilize general purpose and energy-efficient chips such as GPUs, FPGAs, and smart NICs as communication accelerators, rather than relying only on chips and processors such as ASICs and CPUs (Figure 5-22). Additionally, we study a network domain-specific architecture (DSA) which optimizes chip configurations, including accelerators with promoting clustered and networked architectures [5-53].

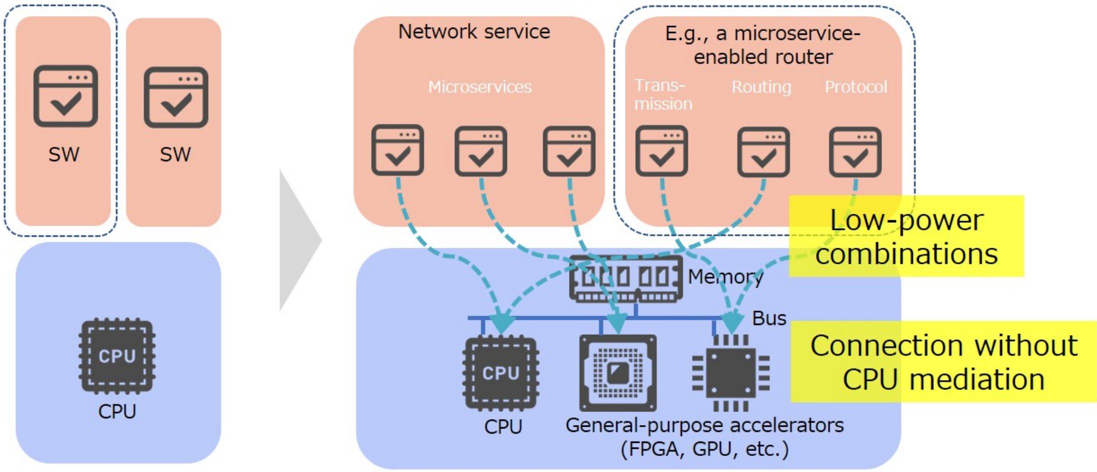

Figure 5-22: Conventional virtualization infrastructure and virtualization software configuration (left) and the use of accelerators in future virtualization infrastructure (right)

5.4.6. Communications in space

To expand communication coverages for seas and mountainous areas that are typically not covered by mobile communication services, the 5G Non-Terrestrial Network (5G NTN) is developed to provide communication services without terrestrial base stations. Figure 5-23 shows a realization form of 5G NTN, and it is through base stations in the space/sky secure communication coverages, such as low-earth orbit (LEO), geosynchronous (GEO) satellites, and high-altitude platform stations (HAPS). KDDI has also begun to utilize LEO satellites, and a business collaboration with SpaceX to use Starlink for backhauls of the au network is underway [5-54]. KDDI are also considering various aspects of 5G NTN initiatives.

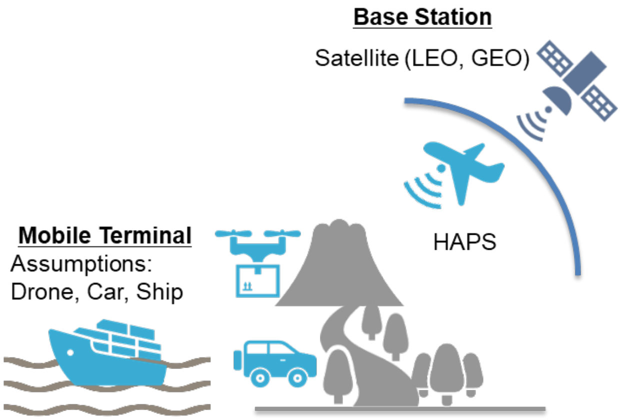

Figure 5-23: Applications for 5G NTN

Assuming around the 2030s, B5G/6G communications are expected to be prevalent, and the scope of mobile communications is expected to be extended not only across the earth, but also to space. One of the prospective goals for space is to establish mobile communications on the lunar surface. Achieving this goal will require lunar exploration and surface development, and those support by both the government and private sectors has been steadily increasing in recent years. The Artemis program, which is led by the United States and has Japan as a participant, includes a plan for a lunar base by the 2030s [5-55]. In addition, NASA has been studying LunaNet [5-56] to provide interconnection networks between the earth and moon, such as the Internet. Regarding the roles in LunaNet, NASA will handle the standardization, and the private sectors will construct and operate the communication networks. In NASA's Lunar Surface Innovation Initiative Technology Demonstration, a demonstration of LTE construction on the moon is being promoted by NOKIA [5-57]. In Japan, lunar communications are also discussed at the strategic program for accelerating space development and utilize (called as stardust program), and at the Space ICT Promotion Initiative Forum [5-58] which was launched by NICT and JAXA and was participated by KDDI and KDDI Research [5-59]. Regarding the private sectors, a lunar transportation service by iSpace planned in 2023, and SKY Perfect JSAT is studying communications between the moon and earth via GEO satellites.

To establish B5G/6G communications on the lunar surface, three technical challenges are addressed in Figure 5-24. The first challenge is the area-planning technology on the lunar surface. Mobile communications area planning on the earth is achieved by applying various conventional methods by mobile operators. However, a radio propagation on the moon may be different from that on the earth. Because the lunar surface has a metallic component called regolith, it may have different reflection characteristics. In addition, it is necessary to consider the lunar topography and the fact that radio propagation cannot be measured as easily on the moon as it is on the earth. To overcome the first challenge, the characteristics of radio reflection which are influenced by regolith must be understood. Then, wide-area radio propagation estimation methods from sky-based images and a small amount of radio propagation measurement will be developed [5-60]. The second challenge is the network-control technology between the moon and earth. Because the distance between the moon and earth is over 380,000 km, there is a communication delay on the order of minutes. This is a different order from that for satellite communication links, which has a delay of approximately 500 milliseconds. The satellite communication links are often used as mobile communications backhaul links for base stations on the earth’s surface. To manage delays that exist on the order of minutes, flow-control and congestion-control technologies based on store and forward communication. In addition, construction method of the mobile communication backhaul with the store and forward communication links will be required. The third challenge is optical wireless technology that connects the moon and earth, and the earth surface and satellites. The technology is expected to be applied to space communications, because it does not require a frequency band, and it is suitable for large capacities. Utilization of the technology requires a digital signal-processing method to stabilize the communication links, an interference control method for the lasers when there are many optical wireless communication links, and a QoS control method. One-to-one communication is a prerequisite for current space communications technology, but the optical wireless technology enable simultaneous n-to-n communications.

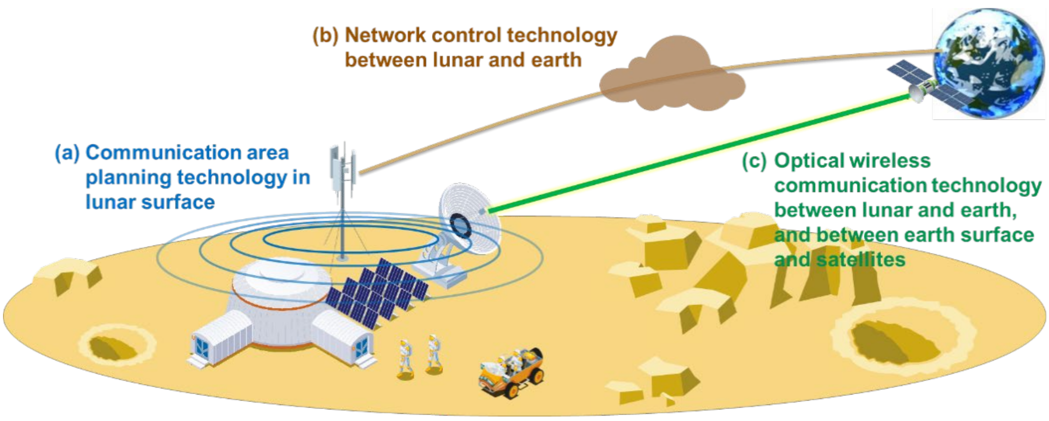

Figure 5-24: Technical challenges to establish a B5G/6G communication in the lunar surface

KDDI has been collaborating on the HAKUTO project. As a part of the project, we studied the application of antennas and radio propagation on the lunar surface [5-61]. By utilizing the knowledge in the HAKUTO project and efforts to overcome the three above-mentioned challenges in Figure 5-24, KDDI will realize mobile communications on the lunar surface with the same level of quality as that on the earth surface in 2030s, when B5G/6G is expected to be applied.

6. "2. Security"

6.1. The Role of Security Technology in B5G/6G

The communication infrastructure that will support DX society is not limited to network facilities in physical space such as base stations and core networks, but also includes functions that allow data acquired from physical space to be stored and processed in cyberspace, including systems such as authentication systems for various services, and Big Data processing systems for industrial data platforms. It will further develop as a foundation for CPS that feeds analyzed results from cyberspace into physical space. Various functions required in the B5G/6G era will be added to communication networks that incorporate virtualization technology enabling the flexible configuration of networks, simultaneous access by large numbers of IoT devices, and new technologies that enable ultra-low-latency communication. New features and increased network complexity will create new security concerns, however. Ensuring the security of the ultra-high speed and low-latency communication specified by B5G/6G, will require cryptographic techniques that can operate on a variety of devices at high speed and with low computational complexity. If future technological advances succeed in creating a general-purpose quantum computer, existing cryptographic schemes will be vulnerable to attacks by the quantum computer, potentially creating a foundational threat to communication secrecy. It is therefore necessary to implement communication technologies that remain secure in the face of quantum computers. Cyberattack targets will increase even further, due to the massive connectivity and diversification of use cases that are expected in the course developing B5G/6G as well. It is therefore essential to adopt and operate security technologies appropriately to maintain a highly reliable communication network. The implementation of appropriate security technologies in communication networks is a critical issue to implementing highly reliable, ultra-secure communication networks. Furthermore, the reliability of the systems used in the communication network must be ensured by verifying the hardware and software. Although there is much clamor over a shortage of security technicians, and the training of security technicians is an urgent issue so far, it will take even more time to train security personnel who understand the diversified and complex technologies of the B5G/6G era. Thus, there is a potential need to simultaneously consider security measures premised on reducing amounts of human resources, and the importance of AI-driven automation will increase in the cybersecurity field.

6.2. Security Technology Goals

6.2.1. Security Technologies Embedded in Next-generation Communications Networks

Advanced security technologies are required to ensure the stable operation of communication networks and protect network services from all manner of cyberattacks in the B5G/6G era. In addition to configuring networks with secure hardware and software, security verification and privacy protection mechanisms should be provided as basic functions on the network. Moreover, while security has conventionally focused primarily on boundary measures, either at end points or at gateways, in the B5G/6G era, functions will be distributed across the network, and since the creation of networks using virtualization technologies will expand the range of aspects requiring security measures, it will be necessary to implement security measures that can be applied efficiently to the virtualized systems. In which communication networks will be more closely integrated into various social activities, it will become more important for people to take appropriate security measures, and efforts to support those actions will be required.

6.2.2. Protection of Next-generation Communication Networks

There are various technical challenges to the use of AI learning in the cybersecurity field, including learning to attack events—which occur far less frequently than normal events—effectively while amassing vast quantities of learning data; training AI models in the knowledge of advanced security personnel, such as analysts working at the Security Operations Center (SOC); and ensuring that AI models are able to keep pace with changing attack surfaces and methods. In particular, the efficient creation/collection of training data, and the improvement in the quality and quantity of training data, are essential requirements for performance improvement, and so collaboration with multiple organizations will be of benefit. The key to the security measures in B5G/6G is therefore to promote broad collaboration in the cybersecurity field, and to accelerate the development of AI-driven security technologies by uniting an abundance of data with knowledge from a variety of people and organizations. It is also important to apply homomorphic encryption, which enables arbitrary operations (addition and multiplication) while remaining encrypted, so that data from multiple institutions can be aggregated in an encrypted state, and analyzed in combination without disclosure to other parties.

6.2.3. Encryption Technology Supports Next-generation Communications

B5G/6G communication speeds exceed 100 gigabits per second [6-1], and fast and lightweight encryption schemes that can meet this speed requirement on a variety of devices will be required in B5G/6G era. The Shor algorithm breaks current RSA public key encryption and elliptic curve cryptography, and mutual authentication and end-to-end encrypted communication will require the replacement of public key cryptographic algorithms such as key exchange schemes and digital signatures with post-quantum encryption.

6.3. Global Situation

Today's 5G networks feature a mechanism to provide network-side functions to external users provided by network exposure function (NEF). Scenarios in which security functions are provided by communications carriers, and in which an external user incorporates security functions, have been proposed as an application [6-3]. At present, firewalls, IDS/IPS[4], etc., are installed in the network, but there is also a need to develop new security features for the advanced functionality of B5G/6G. Moreover, while the skills required for security are becoming more sophisticated, the technology for implementing people-adjacent security measure support has yet to be sufficiently studied.

On the other hand, the application of AI technologies to cybersecurity measures has been progressing rapidly in recent years. AI technologies are being studied for use in a variety of cybersecurity products and services, including intrusion detection, attack risk auditing, and threat information analysis , but this has produced many false positives when compared to signature-based methods of detection, issues with explaining the reason for detection, and reliability issues with the AI itself, so it is being used in combination with traditional methods.

Efforts to establish next-generation standard public key algorithms have also begun. In 2017, anticipating the possibility that existing public-key cryptography will be broken by quantum computers around 2030, the US National Institute of Standards and Technology (NIST) launched a project, NIST-PQC, to define US standards for public-key cryptography that will be secure against quantum computers [6-5]. In this project, cryptographic schemes in two categories—encryption/key exchange, and digital signature—have been selected, and as of March 2021, seven final candidate schemes have been released. The selection of a US standard is scheduled to be completed around 2023, and the migration of cryptographic schemes is expected to proceed in turn.

6.4. Security Technologies Required for 2030

6.4.1. Security Functions for Communications Networks

The following technologies are being researched and developed as advanced security

---

[4] Intrusion Detection System/Intrusion Prevention System.

functions required in future communication networks. There is a project on design of a mechanism to prevent intrusion by unauthorized users by quantifying the trustworthiness of people and devices using the service, and controlling connection to the network based on a trust relationship. Another project fucuses on development of a mechanism to accurately detect abnormal or unauthorized communication attempts, even against new types of devices, by using advanced traffic analysis technology, and to enable appropriate controls such as blocking access. A trusted information-sharing platform for supply chains has been developed by utilizing security verification techniques for hardware chips; the PoC is conducted to demonstrate the trustworthiness of the network equipment. In addition, technologies enabling users to control the use of data such as PPM , standardized by ITU-T, serve an important function in protecting privacy, and it is desirable to use the technologies on communication networks as common functions from the perspective of privacy-by-design. By making a default function on communication networks, it will be possible to apply appropriate privacy protection measures based on the user's consent and privacy preferences for each service to achieve appropriate data usage. As shown in Figure 6-1, we aim to provide more extensive security and privacy measures by making these technologies seamlessly applicable to each service on the communication network.

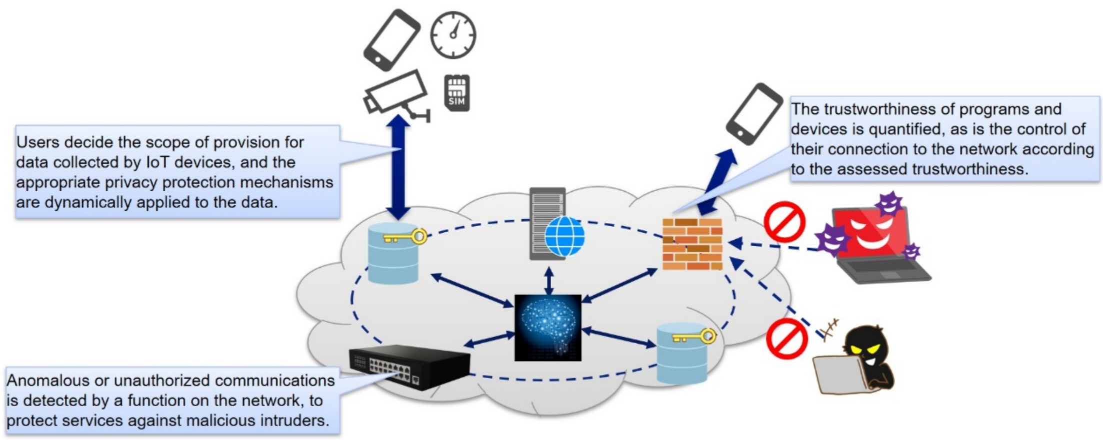

Figure 6-1: Security infrastructure with embedded security and privacy functions

6.4.2. Robust AI-based Security Measures

As shown in Figure 6-2, KDDI has been conducting research and development of attack detection and defense technologies using AI. In the WarpDrive project , which aims for the advancement of online security countermeasure technologies, a large amount of online access data is collected and accumulated, and seven domestic security research organizations are cooperating to build and operate infrastructure for analysis and research, and several innovative results have been produced[5]. KDDI will continue to both accumulate security Big Data and collaborate with other organizations to promote the R&D of cybersecurity measures using AI in B5G/6G. AI technologies will also be used to efficiently verify a vast amount of hardware and software. On the other hand, measures to prevent attacks against AI models are also an important topic in preventing the creation of new vulnerabilities through the adoption of AI technologies. Attacks against an AI model itself have rapidly progressed in recent years, and methods for creating malware that cleverly hide the malware from an AI's detection are becoming increasingly definite. As the use of AI technologies increases, threats from attacks are expected to become more apparent, and KDDI is proceeding with R&D of countermeasure technologies. KDDI is also improving high speed, high performance, next-generation homomorphic encryption for use in integrated analysis to make effective use of AI technologies.

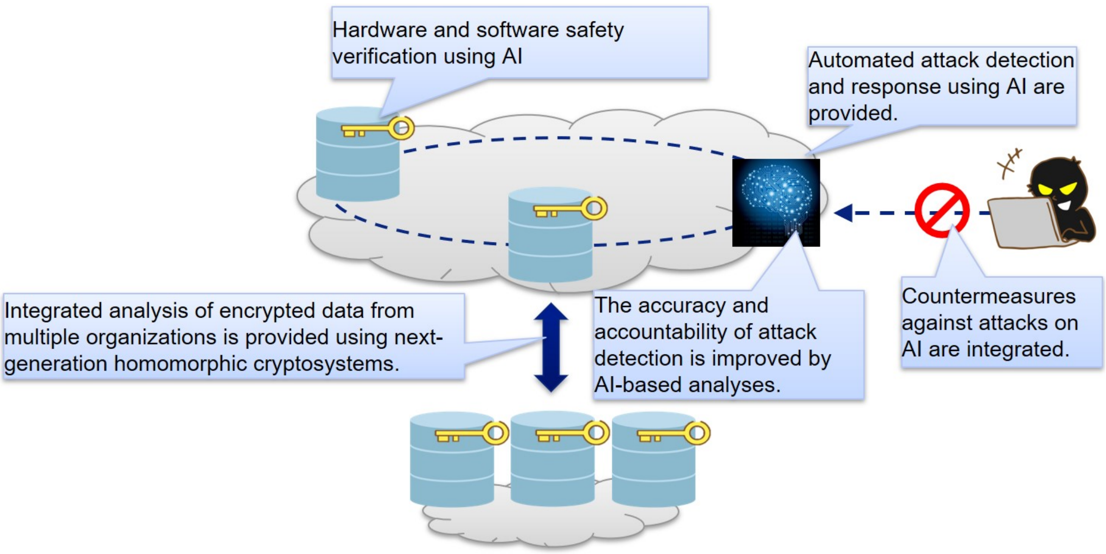

Figure 6-2: AI-driven technologies for attack detection and prevention

6.4.3. A New Generation of Encryption

KDDI is continuing to research and develop a next generation of cryptographic algorithms for the B5G/6G era. In 2020, we succeeded in designing a next-generation digital signature scheme as a post-quantum cryptographic algorithm. This is the first

[5] In particular, WarpDrive (Web-based Attack Response with Practical and Deployable Research InitiatiVE).

scheme in the world to be based on the LWR problem[6]. It has already been proven to be secure in a quantum random oracle model; it cannot be solved efficiently even with a quantum computer, and is about 10 times faster than conventional RSA encryption. We are also designing ultrafast, next-generation encryption algorithms. These feature a focus on assessing the security of post-quantum encryption. The challenge when adopting new cryptographic algorithms is to establish a consensus on the security. In order to contributing to this global challenge, KDDI have been participating in international cryptanalysis contests targeting post-quantum encryption. We have performed parallel optimization of lattice and symbolic cryptosystem decryption algorithms for multi-core environments, and have achieved world records in four different contests , which have contributed to building a matured consensus around secure parameter design. We will continue new efforts to prepare for further paradigm shifts in cryptography to protect the security of communications from advancement of cryptanalysis techniques.

[6] The “learning with rounding" problem: Solving simultaneous equations with rounding errors.

7. "3. IoT"

7.1. The role of IoT technologies in B5G/6G

In recent years, a wide variety of devices, including smartphones, have been equipped with communication functions, and 30 billion devices are said to be in operation as of 2021 [7-1]. These devices are referred to as IoT devices. In the world of 2030, IoT will permeate all aspects of life more than they do today, and all aspects of cities, including homes, cars, buildings, roads, factories, shops, and fields will be “connected,” i.e., physical space and cyberspace are expected to become more closely connected. The "vast number of simultaneous connections" feature of B5G/6G, which is discussed in Section 3.1, also supports this expectation. The series of flows that KDDI Accelerate 5.0 aims to achieve is one in which data acquired in physical space is given value in cyberspace before being fed back to physical space. IoT technology, which makes all things connected, will be important in accelerating this trend.

7.2. IoT Technology Goals

In this chapter, IoT technologies are classified into the following four categories for further discussion:

(1) Technology related to sensing information in physical space

(2) Technology related to communications for transferring sensed information to cyberspace

(3) Technology related to data processing for processing information in cyberspace

(4) Technologies for the design and operation of IoT devices, with consideration for maintenance

KDDI has been utilizing IoT in a variety of use cases [7-2]. In one, we take the automotive field in this section, because the benefits of high capacity and low latency, which are prominent feature of B5G/6G, can be enjoyed to the greatest extent. The automotive field is predicted to become a vast market worth $166.3 billion globally by 2027 [7-3], and discuss the forms of (1) to (3) for which we are aiming. In the near future, vehicles will equip with many sensors such as cameras and LIDAR[7] to monitor road and traffic conditions, and vehicle sensors will acquire sufficient data to reproduce traffic conditions around the vehicle in cyberspace. With the evolution of device technology, the performance and cost of sensors has improved at a rapid pace, but each type of sensor has its own characteristic. Cooperation between multiple sensors, and the consolidation of sensed information, are therefore important. Furthermore, technology is required to implement fast, low-power cooperation between sensors and the consolidation of data.

[7] Light detection and ranging (LiDAR), or laser imaging detection and ranging (LIDAR).

The vast quantities of varied data acquired by these sensors are first processed by the computer in each vehicle, before being transmitted to cyberspace via mobile network. A new network for the B5G/6G era, one capable of handling large quantities of data and large numbers of simultaneous connections, will be essential to the transfer of huge volumes of information from physical space, such as images and point clouds, simultaneously from vast numbers of vehicles. In addition, since the volumes of information from physical space to be handled are expected to increase with this expansion in data volumes, media compression technology will be as important as ever to reducing the volume of bits transferred. Moreover, the cyberspace described above is not constructed within a single server, but in a cloud, or a large number of distributed edge servers. Technology is therefore required to dynamically select appropriate servers and transfer data according to user requests, data type, vehicle location, and service subscriptions. This data transfer includes cases in which processing that cannot be handled by a vehicle's on-board computer due to computational resource constraints is offloaded to a server on the network. In this way, vast amounts of data generated by large numbers of vehicles reach cyberspace, and these data may require ultra-fast processing. This might include, for example, a traffic safety application. Looking to the breakdown of the time delay moving from physical space to cyberspace and back to physical space again, the time required for computation tends to be longer than the time required for communication, although this depends on the content and quantity to be processed. In other words, high-speed data processing technology is extremely important from the viewpoint of reducing end-to-end delay. The establishment of these technologies will bring us closer to the realization of scenarios in which, for example, traffic conditions are completely reproduced in cyberspace in real time; traffic accident risks are instantaneously calculated based on those traffic conditions; and vehicles that are judged to be at high risk of causing an accident are remotely controlled to prevent the traffic accident.

Next, we look at a case applying IoT technology to primary industry, which has requirements that are the opposite of those in the automotive sector—requiring neither high capacity nor low latency—and consider the appropriate form for this technology. In primary industry, large numbers of IoT devices are expected to be installed in forests, fields, and maritime regions, and so power supply and maintainability are extremely important. While it is easy to ensure a power supply when implementing IoT technology in vehicles, it is very difficult in primary industries. Since many devices are installed in locations where physical access is difficult, progress in technologies that enhance maintainability, including battery replacement, will prove key to utilizing IoT in primary industry.

IoT is expected to be a catalyst to increase productivity and revitalize primary industry. In agriculture, the system senses information in physical space, such as temperature, humidity, illumination, crop growth, and soil conditions, and uses this information for predictions in cyberspace about the amount of pesticide to be applied, the planting time, harvesting time, yield, and shipping time, and then feeds the information back to the producer. In the fishing industry, physical environmental information—such as water temperature, speed, direction of tidal currents, and salinity—is sensed, appropriate fishing grounds and bait amounts are calculated in cyberspace and then fed back to the fishing industry workers. In these cases, IoT devices will be battery-powered, so ultra-low power technology for sensing in physical space will be required. Power consumption for communications when sending the sensed data to cyberspace should also be minimized. Furthermore, energy harvesting technology is also important in the use of ubiquitous energy, such as sunlight and vibrations, as a power source for IoT devices. In the absence of these technologies, replacing batteries in IoT devices that are installed deep in the mountains or offshore will incur significant costs. In addition to battery replacement, daily maintenance and tuning are often difficult. The effort required to respond when a problem occurs, such as a decrease in sensitivity or data not being transferred, is also very large. Technologies for the design and operation of IoT devices are therefore required to reduce maintenance costs as much as possible. If maintenance-free devices can be achieved using these technologies, primary industry productivity could be dramatically increased, as set out above, making it a very attractive industry.

In this section, we have discussed an ideal state of IoT technology, taking automobiles and primary industry as examples. As discussed above, the areas of application of IoT technology are extremely broad, and another characteristic of IoT is that there are few technologies that can be used universally across all use cases. Constructing a common platform to increase versatility, and optimizing it for each use case and application through validation in the field, will be an important issue going forward.

7.3. Global Situation

Taking the automobile and primary industries discussed in the previous section as examples, this section provides a bird's-eye view of IoT technologies, as classified into groups (1) to (4) set out in the previous section.

IoT-enabled vehicles are widely known as "connected cars." At present, most self-driving vehicles rely on sensor data from physical space to drive autonomously; however, since Level 3 and greater vehicles will be equipped with remote monitoring and control functions, and will need to both download high-resolution maps and upload sensor data [7-4], these can be regarded as connected cars[8]. With the entry of companies from many different industries, including IT companies in the US and China, business in the connected car field is expected to expand greatly. An ecosystem is being constructed consisting of a variety of players, including not only existing automakers, on-board equipment manufacturers, and semiconductor manufacturers, but also IT companies, ICT infrastructure vendors, mobile service providers, insurers, map providers, and so on.

The application of LiDAR to self-driving vehicle sensors is drawing attention [7-5]. Most self-driving cars being testing in Japan and overseas are autonomous vehicles that operate using point cloud data of surrounding traffic sensed using a LIDAR installed in the vehicle. Prices are expected to fall further in the coming years. A global consortium led by players in the telecommunications and self-driving vehicle industries has been actively discussing communications for self-driving vehicles. KDDI has joined the AECC [7-6] and the 5GAA [7-7] to participate in these discussions[9,10]. Two communication standards, cellular V2X (C-V2X) [7-8], based on cellular communications, and dedicated short-range communication (DSRC), based on 802.11 technology, have been proposed. In Japan ETC2.0[11] is adopting DSRC.

On the other hand, China has decided to adopt C-V2X in the ITS frequency band (5.9 gigahertz band), and the sale of compatible vehicles is expected to begin soon. While US IT companies such as Google, which proposed MapReduce in 2004, have a long lead in the foundations of data processing for self-driving vehicles, the open-source community is also highly active in the field, and the technology is evolving day by day. In both R&D and the business field, the use of open-source software, and the relationship with the community, are becoming very important.

IoT technologies for use in primary industry are known by names such as “smart fisheries” and “smart agriculture,” and some of these are already being put into practical use. Some municipalities are actively supporting the introduction of these systems. For example, KDDI is promoting the R&D of smart fisheries in cooperation with Higashimatsushima City, Miyagi, and has developed a buoy equipped with sensors and communication modules called a “smart buoy.” In a proof-of-concept experiment, these were floated offshore, sensing air temperature, air pressure, water temperature, water

[8] Levels of automated driving are defined by the US Society of Automotive Engineers (SAE), which defines Level 3 as “conditional automated driving.” The driver of Level 3 and greater vehicles considered to be the system, rather than a person.

[9] Automotive Edge Computing Consortium.

[10] 5G Automotive Association.

[11] Electronic Toll Collection 2.0

pressure, salinity, acceleration, etc. This data was sent to a server for analysis via cellular network, and analyzed in combination with past catch performance and weather data to quantitatively predict the catch. Compared with conventional predictions based on intuition and experience, the new predictions based on IoT technology were highly accurate. As discussed above, issues included power supply and maintenance. Since the battery life of the buoy at the time of initial development was one month, it was necessary to replace the battery every month. The buoys also weigh more than 20 kg, creating heavy manual work, and their structural complexity and need for frequent cleaning have laid bare maintenance-related issues. Field experiments are being conducted in various locations, but since use cases and issues differ depending on the industry and people involved, optimal solutions are being developed for each use case.

7.4. Technologies Required for 2030

As described above, the IoT field has a wide range of use cases and issues, and the domain of required technologies is also broad. KDDI is aiming to create technologies to solve social issues by actively promoting collaboration with partners (universities, companies, etc.) and communities (standards developing organizations, open-source communities, etc.) in peripheral fields, while keeping communications at its core. Below, as shown in Figure 7-1, we introduce IoT technologies according to the categories defined in Section 7.2.

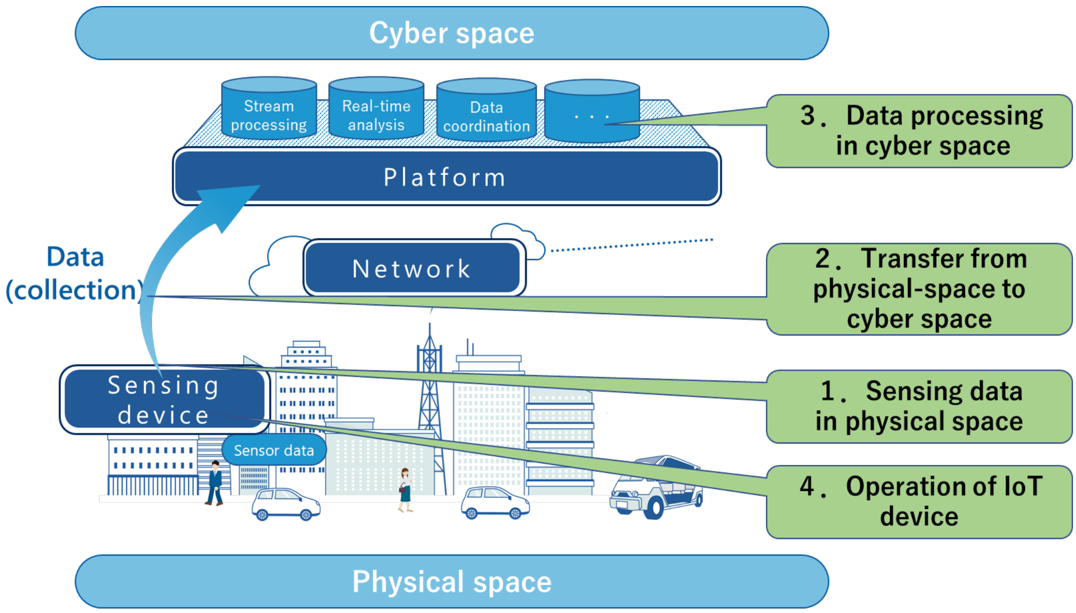

Figure 7-1: IoT technologies

7.4.1. Technologies Related to Sensory Data from Physical Space

When sensing location information in physical space, different sensors will be suitable for different conditions. GNSS[12] is suitable for outdoor use but not for indoor use; video is suitable for clear, daytime conditions but not for bad weather or at night; and fixed sensors such as cameras or millimeter-wave radars can sense only areas with line-of-sight. We are therefore considering approaches to improve sensor accuracy through the use of sensor-fusion technologies, which integrate data gathered by various types of sensor. KDDI has been conducting field experiments to demonstrate sensor fusion technology and advanced location information sensing. As described above, sensor data compression technology is also important. KDDI is actively advancing R&D into video compression and point cloud data compression technology, and has been promoting activities to standardize these technologies. The video compression and point cloud data compression technologies are described in detail in Chapter 10.

7.4.2. Technology Related to Communications for Transferring Sensed Information to Cyberspace

To satisfy diversifying requirements, it is important for packet processing nodes to understand the requirements of IoT devices with a very fine granularity, and process them optimally using data transfer technologies, together with the cloud and large numbers of MEC hosts. KDDI has been actively promoting the R&D of these.

Since current IP-based networks are based on best-effort packet forwarding, a new architecture is required for packet processing nodes to understand application and user requirements in detail. KDDI has therefore been conducting R&D into application-aware networking, a framework enabling appropriate control and resource allocation on the network side by explicitly notifying the network of application quality requirements [7-9].

KDDI anticipates that various IoT devices will be connected to networks, such as self-driving vehicles and dedicated devices for XR, and is investigating how MECs can ensure versatility and interoperability of applications in the face of differences in requirements between applications, and differences in functionality and performance between devices. In environments where mobility and resource utilization are constantly changing, there is a need for each application to select an appropriate MEC host to connect to so that all devices can effectively utilize MEC on an ad-hoc basis to maximize application quality. In addition, KDDI is working on standardization to realize interoperability between MEC systems installed on each operators' network domain. This

[12] Global Navigation Satellite System

technology is necessary when each device connects to each MEC located in different operator's network [7-10].

Furthermore, communication systems with ultra-low power consumption are desirable, particularly for applications in primary industry. We are also studying communication methods that can extend battery life several times longer than under the existing low-power, wide-area (LPWA). Since there is generally a trade-off between communication quality and device power consumption reduction, we will also study methods to flexibly update design and operation according to application and use case.

7.4.3. Technology Related to Data Processing for Processing Information in Cyberspace

Infrastructure for high-speed, efficient Big Data processing is more important than ever. Drawing on the wisdom of the open-source community, KDDI will actively participate in ecosystems that return results to their communities. We have already proposed a scheduling scheme based on Apache Spark that improves resource utilization efficiency [7-11], and a method that reduces latency when loading applications [7-12], and will continue our research going forward.

7.4.4. Technologies for the Design and Operation of IoT Devices with Consideration for Maintenance

We aim to improve maintainability and eventually achieve maintenance-free operation. Achieving this will require not only reducing power consumption as much as possible, but also energy harvesting technology to convert the ubiquitous energy around us into a power source. In the smart buoy example above, the system initially operated for only about a month, but by developing a new communication method and using solar power, it became possible to operate the smart buoys for about a year. Going forward, we will continue to explore the best methods to reduce power consumption, and methods of energy harvesting, that are appropriate for each use case. In addition, hardware, including sensors, must be maintained, monitored, and replaced, limiting improvement to maintainability. We will therefore research technologies to improve maintenance characteristics by increasing the number of functions that can be defined using software.

8. "4. Platform"

8.1. The Role of Platform Technologies in B5G/6G

With the spread of the Internet, cyberspace has appeared as an addition to the physical space of the real world, and now it plays an important role in our lives and economic activities. For example, rather than buying CDs or other media, people are increasingly using online services such as streaming services to access music, and this has been achieved by linking the action of listening to music in physical space to cyberspace using a network.

KDDI predicts that by 2030, CPS will be advanced by the linking of the seven technologies set out above. KDDI calls this linkage “orchestration,” and the platform is at the center.

Platforms play an important role even today. In streaming music services, for example, one cannot provide such services simply by preparing music data. Many functions are required, including digital space for storing data, a server for managing user access, and a billing service. Having a single company develop and provide all functions required for the service would thus require tremendous cost and research, and it would take considerable time to provide the service.

This is where platforms come into play. By using services such as data storage and electronic payment on a platform, music streaming companies can focus on development efforts such as recommending songs to users, and shorten the time to service launch.

8.2. Platform Technology Goals

KDDI is engaged in research on a wide range of platforms (Figure 8-1). These include not only Internet access and payment services, but also social infrastructure such as electricity. By combining many of these platforms, it will be possible to use them for even larger social infrastructure. One example of which is a “city OS,” the Japanese version of smart cities. The various controls provided by a city OS required consideration of three factors: improvements in users’ standards of living; economic activity as a driver; and environmentally conscious activities as a social system, such as those involving energy and global warming.

Today it is often necessary to visit the municipal office to access public services. In other words, this is a system that often centers on physical space. While there are some organizations and fields that are moving toward online systems, in many cases these have adopted specialized systems, making it difficult to reuse them in other regions or to collaborate in horizontal development.

City OSes are being studied as a solution to these problems. A city OS provides service APIs (application programming interfaces) for education, healthcare, energy, mobility, urban planning, and disaster prevention. These can be used to simplify reuse in other regions, and can be developed and introduced inexpensively.

City OSes further provide functions for managing and analyzing data collected from smartphones, IoT devices, and various sensors, as well as functions for personal authentication, payments, and personalization to provide services to users. In so doing, it is possible to construct a system in which the services provided by the city OS are created in cyberspace available for access by residents living in physical space.

City OSes will also introduce IDs and payment functions that will be shared between all services. Since there is no need to create a login ID for each service, services can be accessed seamlessly. Moreover, by using the mobile payment function and associated biometric authentication, payments can be automatically completed at the time a service is used, eliminating the action of making a payment. When you receive a service in physical space, the payment is completed automatically in cyberspace. We aim to realize such a CPS by 2030.

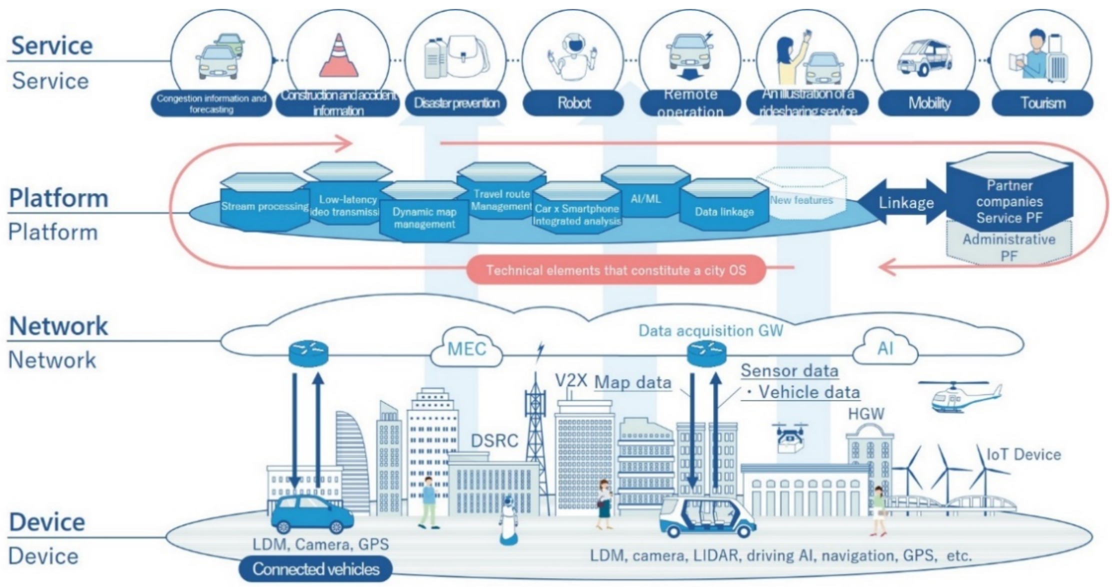

Figure 8-1: A platform concept for 2030

8.3. Global Situation

The movement to solve social problems and design cities by leveraging AI technologies and Big Data in cyberspace are gaining momentum around the world. For example, in Singapore, “Smart Nation Singapore” has been promoted since 2014 as a smart city policy to solve social problems, generate innovation, and improve people’s lives by using digital technology and data [8-1]. In 2014, Dubai in the United Arab Emirates announced “Smart Dubai 2021,” which presented a roadmap for conversion to a smart city by 2021. Many studies are underway, such as a virtual currency strategy using blockchain; efficiency improvements for administrative services using e-government; optimized energy use; etc. One of the themes of Smart Dubai 2021, “smart mobility,” focuses on the development of automated driving to prevent traffic congestion and achieve a safe travel environment [8-2]. In Japan, the “Super City Concept” has been proposed to achieve the world’s most advanced Japanese-style super city by utilizing the national strategic special zone system [8-3]. With regard to MaaS, a time-limited proof-of-concept experiment is underway that includes next-generation mobility built on on-demand and ridesharing, and a fixed-rate service that integrates multimodal transportation, based on the characteristics of each region. Some of these proof-of-concept experiments are being conducted without driver operations, using remote-controlled vehicles in anticipation of the coming shift to automated driving under next-generation mobility. As exemplified by the lifting of the ban on Level 3 automated driving on public roads in April 2020, the evolution of self-driving technology has been accompanied by deregulation in laws and regulations.

8.4. Technologies Required for 2030

8.4.1. Key Technologies for Operating a City OS

In addition to convenience for residents, city OSes have the advantage of operating cities more efficiently. For example, it is possible to predict the movement of people based on information from sensors positioned in each city, and to reduce unnecessary power consumption by appropriately adjusting the amount of power supplied. Thus, by collecting and utilizing user data, we can improve convenience and economy. The issue, however, is how to handle user data gathered in such cases. Moreover, at present, each service has its own terms of service, and consent is required for the data to be collected. PPM (see Section Security Functions for Communications) is a technology that can be applied to the issues above.Security Functions for Communications

PPM features a function to act as a proxy for the management of personal information. It works this way: (1) A user gives a PPM his or her personal information such as an e-mail address or residential address, and a telephone number that can be transferred to a service provider without issue. (2) When a user uses a service, the PPM presents the personal information required to use the service to the user and obtains the user’s consent. (3) The PPM then passes the necessary personal information onto the service provider. By using a PPM, users do not need to provide data they do not wish to give to service providers, and can use the service in a secure manner.

Operating a city OS will require the management and analysis of an enormous amount of data. Moreover, high-speed, low-latency data transmission technology will be essential for sending and receiving that data. AI and quantum computing technologies will be used to manage these vast amounts of data, and both 5G and B5G/6G will be used for high-speed, low-latency data transmission. In other words, a platform alone cannot operate a city OS: it is important that the seven technologies work together.

In so doing, it is important to utilize and manage large volumes of data collected in various ways. This has led to the development of FIWARE, a data utilization platform that can integrate and manage a wide variety of data models. In many cases, traditional city-provided services do not allow for the cross-sectional use of data. The adoption of FIWARE as a standard in the smart cities field will enable the interoperable use of data from various services and the construction of a more flexible system spanning a breadth of services (Figure 8-2).

Message queue telemetry transport (MQTT) has also been developed as a protocol for the efficient transfer of data. This has been developed based on TCP/IP, and the processing involved has been made lightweight so it can work even when the network is unstable or when the device's performance is poor. While smartphones and PCs are becoming more sophisticated, IoT devices often have limited performance, so using MQTT enables stable and reliable data transmission.

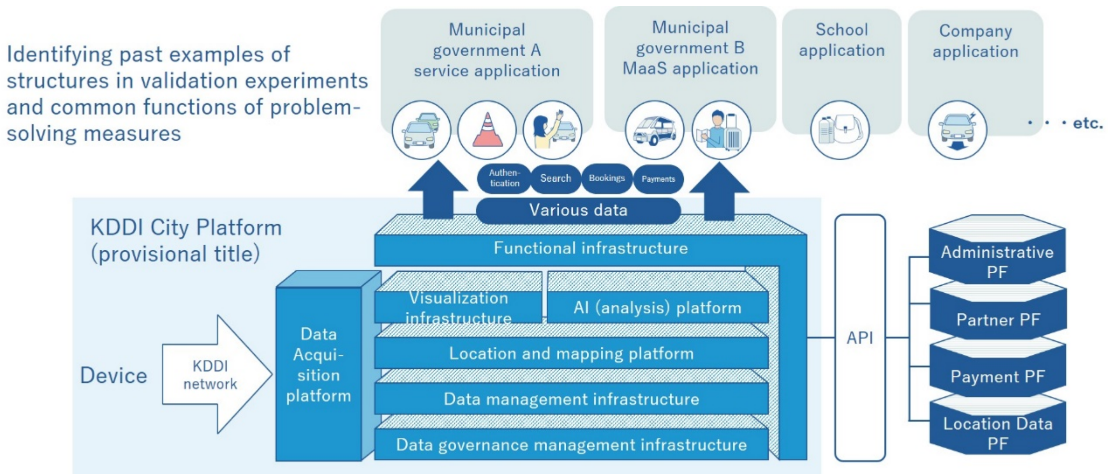

Figure 8-2: City OS architecture and constituent technologies

8.4.2. Opening up MaaS (Mobility as a Service) Using Automated Driving

Besides city OSes, there are other fields where platforms are expected to be used. One example is MaaS, a service that improves the efficiency of transportation by seamlessly connecting various modes of transportation such as public transportation facilities (Figure 8-3).

At present, it is necessary to arrange modes of transportation to a certain place individually. For example, if people travel from their home to the nearest station using bicycle sharing, take a train to the nearest station in the region they wish to travel, and then take a taxi to their destination, they would need to arrange for each individual service separately. MaaS eliminates this hassle and makes it possible to use the services of each transportation system in unison. Platforms are important when making lateral use of services. For example, it is necessary to implement one-stop payments for bicycle sharing, trains, and taxis. To solve this problem, the general transit feed specification (GTFS) format, which is used today for data related to timetables for public transportation and geographic information, can be used for applications and functions such as route searches. In addition, payment services are becoming increasingly platform-based, and it is becoming possible to make payments for multiple services with a single mobile payment. By linking the payments for each service, it becomes possible to provide services such as discounted rates.

MaaS-connected systems are not limited to public transportation; they can also connect to services in cyberspace. For example, it may become possible to automatically book a taxi simply by searching for a destination on one's smartphone and registering the travel route in one's itinerary.

Moreover, if user location data can be obtained, the taxi company can automatically dispatch a vehicle when the user arrives at the station.

MaaS, like city OSes, consists of platform infrastructure and application infrastructure. The application infrastructure has access to platform infrastructure such as authentication, search, bookings, and payment, and it facilitates the rapid development of applications tailored to the needs of each region. In addition to the functions of a city OS such as positioning, mapping, and data management, the platform infrastructure features microservices with MaaS-specific functions, such as route searches and vehicle dispatch calculations, which can be freely combined and used according to the needs of each region via a service API. It may be possible, for example, to use a service API for urban planning and disaster prevention in the city OS, built for the purpose of handling movements of people, to adjust the numbers of taxis or shared bicycles dispatched. MaaS is expected to spread rapidly alongside the development of automated driving technology. Self-driving vehicles can operate more efficiently because the system can manage vehicle arrival and departure locations, boarding and alighting of passengers, travel routes, booking status, the arrangement of ridesharing and automation of route settings Japan Cabinet: National Strategic Special Zones, and connections to other mobility systems

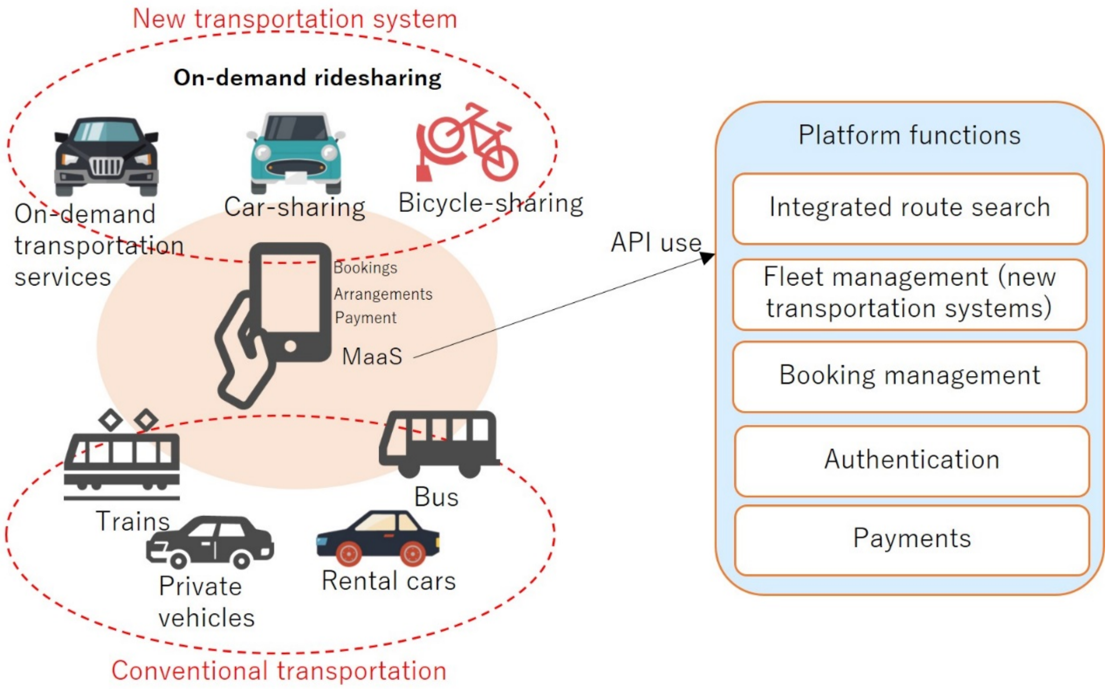

Figure 8-3: MaaS and platforms

8.4.3. Changes in Behaviors Resulting from MaaS

MaaS is a new service to improve the efficiency of transportation, but its introduction is expected to give rise to other, new demands. One of these is a change in user behavior.

Suppose, for example, that a user is using a MaaS to travel using a self-driving vehicle service. When a traffic jam occurs, the MaaS (its automated vehicle service) suggests a detour. In so doing, depending on the time of day, a service separate from the automated driving service can provide a list of restaurants to stop by on the detour.

Thus, through the introduction of MaaS, users can act and move rationally and enjoy further added value, but one of the issues that must be solved to achieve this is a combinatorial optimization problem. For example, when a salesperson tours several cities, they can choose from various routes, but there are only a limited number of efficient routes available. At present, however, it is necessary to consider an extremely large number of conditions and patterns to search for the optimal route, and this takes time to analyze even when using a supercomputer. KDDI is working on technology to provide this processing at high speed (Figure 8-4).

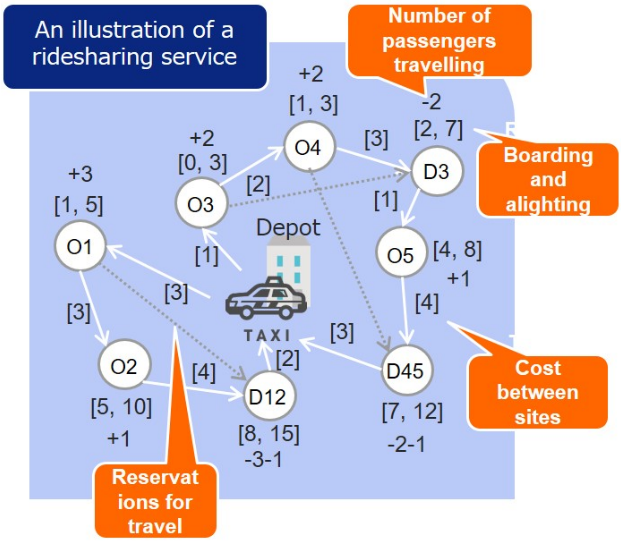

Figure 8-4: The combinatorial optimization problem

8.4.4. Automated Driving

Dynamic maps that reflect real-time information are also important for implementing automated driving (Figure 8-5). Automated driving vehicles are equipped with various sensors including not only camera imaging, but also LIDAR, sonar, etc. By utilizing data gathered in real time using these sensors, seamless automated driving can be achieved. Furthermore, if these data can be reflected on an actual map and used as a dynamic map by other automated vehicles, this will make possible smoother automated driving.

R&D of automated driving technology is underway with a view to 2030. ”Autoware,” open-source software facilitating the development of automated driving, also continues to evolve, making it possible to construct systems simply by using existing vehicles and sensors in the development of automated driving and testing.

AI technologies are also essential for automated driving, and unsupervised learning for automated driving AI is also under development. Using unsupervised learning, an AI engine can be created without drawing on vast quantities of data, which is expected to significantly reduce both cost and time.

Automated driving vehicles themselves have communication functions, and V2X has been formed to enable vehicles to communicate with all manner of objects. However, communication functions are required not only by vehicles, but also by the infrastructure required for driving. For example, if all the objects that come together to form roadways, such as traffic signals, signs, surveillance cameras, etc., are equipped with communication functions, it will become possible to provide more comfortable automated driving.

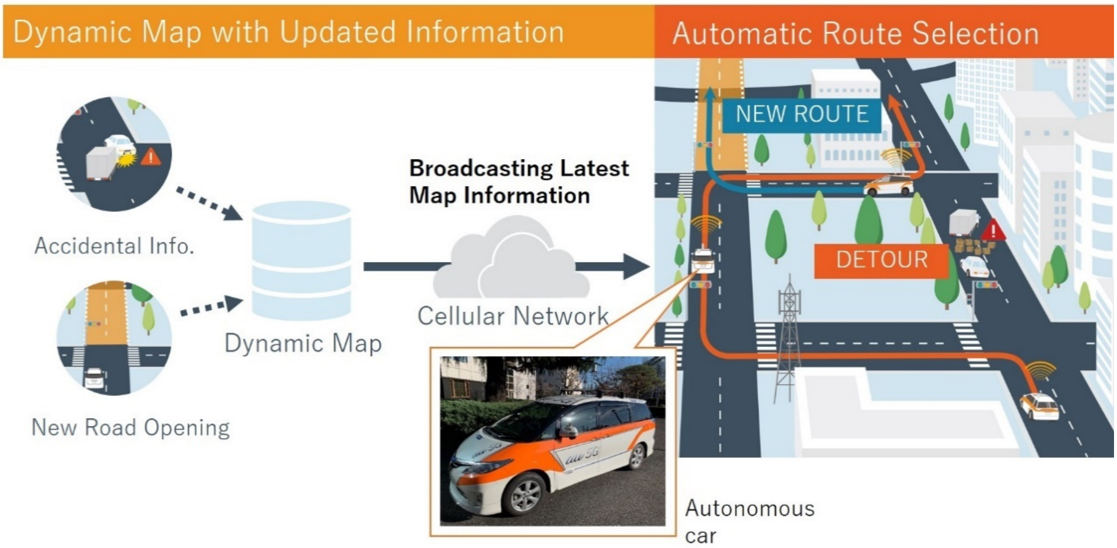

Figure 8-5: Distribution of maps to self-driving vehicles

8.4.5. Quantum Computing

Quantum computers are expected to be able to solve problems that are difficult for classical computers because of computational complexity. A classical computer performs sequential calculations using bits that represent either 0 or 1 states explicitly. Alternatively, a quantum computer uses qubits, which represent probabilistic states of 0 and 1 by applying the concept of quantum mechanics, to calculate superposed multiple information in parallel. Thus, by increasing the number of qubits, a quantum computer can achieve massively parallel computations that are not feasible for classical computers.

The first commercially available quantum computer is a quantum annealing machine that was developed by D-Wave Systems [8-5]. Although it cannot be used for general-purpose calculations, unlike classical computers, its potential as a solver for combinatorial optimization problems, i.e., its ability to quickly find good approximate solutions, is being investigated. In addition, other systems that can be used in the same way as a quantum annealing machine, such as high-performance simulation software [8-6], and dedicated machine implemented in electronic circuit [8-7], have also been developed. These systems are not quantum computers, and are inferior in terms of speed, but they can be applied to solve larger combinatorial optimization problems because of the limited number of qubits in the current quantum annealing machine. Systems that are dedicated to combinatorial optimization problems are called Ising machines, and they include quantum annealing machines.

Gate-based quantum computers are also being developed for more general-purpose calculations. A number of companies, including major players such as IBM and Google, as well as start-ups such as IonQ and Rigetti Computing, have announced the development of gate-based quantum computers. Some of the systems are available via cloud services such as IBM Quantum [8-8] and Amazon Braket [8-9]. Gate-based quantum computers are currently being applied to solve optimization problems, and for simulations, AI, and security, which involve calculation that are difficult or time-consuming for classical computers [8-10].

The concept and use of quantum computing differ from those of classical computing. Ising machines can be utilized by assuming that qubits are the decision variables of the combinational optimization problem to be solved, and by formulating the problem into an Ising model, which is a statistical mechanics model. In the case of gate-based quantum computers, a dedicated algorithm that considers the behavior of qubits (i.e., a quantum algorithm) must be designed for the process to be executed; this algorithm is implemented by a quantum circuit, which is a sequence of qubit operations called a quantum gate. Thus, quantum computing technologies that differ from existing classical computing technologies are required for the effective utilization of quantum computers. Existing quantum computers have many practical problems that need to be overcome [8-11], such as a small number of available qubits and a high rate of qubit errors, which serve to degrade the state of a qubit. However, some Ising machines have already been applied to address these practical problems. It is expected that Ising machines, including quantum annealing machines, will be available for application to various combinatorial optimization problems by 2030. Gate-based quantum computers are also expected to become practical for application in fields such as security by 2030 [8-12][8-13]; the extent of practical applicability is expected to expand thereafter.

KDDI is also investigating the application of quantum computing in various domains, including the seven technologies. We applied an Ising machine to the problem of the dynamic allocation of shared frequencies to operators in order to confirm its utility in a research project commissioned by the Ministry of Internal Affairs and Communications in Japan [8-14][8-15][8-16]. We also participated in a quantum computer demonstration experiment to evaluate its practicability for industrial application; the experiment was demonstrated at the Mobile Computing Promotion Consortium; consequently, the effectiveness of Ising machines was verified jointly with Hitachi, Ltd. and Jij Inc. by applying one to an area management optimization problem that involved local 5G operators [8-17] Furthermore, we evaluated the performance of Ising machines by applying it to a parameter optimization problem involving LTE base stations [8-18], and to a generalized vehicle routing problem involving MaaS and logistics [8-19]. To ensure that quantum computers will be able to be utilized in various domains in the future, including the seven technologies, we plan to validate the application of Ising machines for more combinatorial optimization problems, and to establish quantum computing technologies for the effective utilization of gate-based quantum computers.

9. "5. AI"

9.1. The Role of AI Technology in B5G/6G

With the spread of the Internet, both the physical space of the real world and cyberspace have come to play important roles in our daily lives, economic activities, and social systems. In 2030 we will see the advance of CPS through the linking of the seven technologies described above. In this linking, AI will analyze data and information from the real world accumulated on platforms in cyberspace, and deduce ways of providing feedback to the physical space.

9.2. AI Technology Goals

The most commonplace form of AI technologies today is “cyber-based AI,” which has been developed in cyberspace. Cyber-based AI has been driven by global OTT players in Internet services, such as Google, Amazon, Microsoft, Baidu, and Alibaba. It has developed by specializing in tasks such as image and text classification using deep learning, drawing on large volumes of image and text data, etc., held by these companies.

The creation of AI models using deep learning requires vast amounts of data, so the key issue is how to collect such data. For instance, voice recognition requires voice data from a variety of people, and OTT, which has many users, can collect data more easily than other companies. As such, AI is being used for many online services, such as machine translation, image recognition, as well as targeted advertising and price predictions in the digital marketing field. On the other hand, future applications of AI are expected to shift from cyberspace to physical space—one example being the use of voice recognition in smart speakers.

The challenge, in terms of the creation of AI models in physical space, lies in creating the technology to generate AI models from small quantities of data obtained from diverse environments. For example, when using AI for traffic and disaster response, the characteristics of each region and site as well as the available data vary greatly. As such, it is necessary to optimize the use of available data in performing tasks such as predicting traffic congestion and demand, as well as predicting the scale, details, and incidence of disasters.

Moreover, we can assume that society will change in the future based on AI-derived outcomes, and users themselves will change their behavior in response. To this end, AI technology will be required to provide more than uniform information and qualitative knowledge of human psychology as it has done in the past, and persuade people effectively to change their behavior by using quantitative understanding of psychology grounded in data and drawing on qualitative knowledge of psychology. There are, for example, many cases where restaurant recommendations are standardized, showing a simple AI-selected list of restaurants that a user may like. However, by timing the results or presenting them differently (e.g., using visuals) to make users want to visit a restaurant, it will be possible to amplify their desire to go to that restaurant, and cause them to change their behavior.

9.3. Global Situation

The need for “physical space-oriented AI” to generate AI models that solve various tasks in a variety of environments with small amounts of data has been described in “Future Courses of Action Japan Should Take for Basic AI Technology” [9-1], published by the Artificial Intelligence Research Strategy Division of the National Institute of Advanced Industrial Science and Technology (AIST) in May 2018, and in “AI Strategy 2019” [9-2], published by the Japanese government in June 2019. In the corresponding AIST literature, the issues are organized around three axes: AI that can cooperate with humans, AI that can be trusted in the real world, and easily constructed AI, i.e., AI that is not limited to cyberspace but that can be applied to data generated from services that include physical settings, which is one of Japan’s strengths. Additionally, the government’s AI Strategy 2019 states that the field of “real-world industry,” where value is created through interactions with people, nature, and hardware and not solely in cyberspace, contains vast amounts of information that have yet to be systematically acquired, and that it will be necessary to actively focus on this area. At international conferences on AI, where the number of submissions has increased significantly in recent years, there has been an increasing number of workshops and sessions related to real-world AI, such as the “Workshop on Continual Learning” [9-3] and “Transfer, Adaptation, Multi-task Learning” [9-4], a session conducted at IJCAI 2020.

Behavioral change techniques have long been addressed in the field of social psychology in persuasion research [9-5], but such efforts have begun to use and apply ICT in recent years. Fogg proposed CAPTOLOGY (“computer as persuasive technologies”), a concept that uses computers to persuade [9-6]. Oinas-Kukkonen proposed the persuasive system design (PSD) model, systematizing design procedures and factors to be considered when designing systems to elicit user compliance [9-7]; examples of its applications in model interface design have been published [9-8]. Although personalizing persuasion based on these investigations remains a challenge at present, efforts to use AI to elicit behavioral change are beginning to draw attention in the academic community. For instance, a new workshop, “AI for Behavior Change,” was conducted in February of 2021 at AAAI, one of the leading international conferences in

AI [9-9], along with a new topic added to its scope that uses “persuasive technology” (PT), aptly named “AI for Persuasive Technology” [9-10]

KDDI has been using for some time AI that uses location-based Big Data in the physical space. Demographic analysis/forecasting technology, which estimates and predicts population dynamics in any given area in Japan on a quasi-real time basis, is being developed based on behavioral analysis technology that evaluates routes and modes of transportation using location-based Big Data provided by consenting users [9-11]. This makes it possible to estimate and predict not only the population distribution of a given area in real time, but also detailed information such as the number of people travelling or staying in said area, and those travelling by rail or along roads. Providing such information on road conditions and evacuation sites in times of disaster, or traffic congestion and transportation facilities during sizable events, can support a safe and secure society. On the other hand, since circumstances in the city—especially physical spaces—are constantly changing, vast quantities of training data for the most up-to-date situations are required to maintain a high predictive accuracy, and cost is consequently an issue.

9.4. Technologies Required for 2030

KDDI aims to solve social issues by using “real-world AI” that resolves issues specific to the real world, namely, “AI for behavior change” that understands human psychology and can individually tailor their solutions, and “trustworthy AI” that can be used with confidence.

Real-world AI can be classified into four types:

- “Reusable AI,” which uses pre-generated AI models and adapts them to multiple tasks using limited quantities of data;
- “Multimodal AI,” which combines varied modes of data (e.g., spatial and temporal) to generate highly accurate AI models;
- “Collaborative AI,” which leverages both implicit and explicit human knowledge; and
- “Self-improving AI,” which modifies itself to adapt to frequently changing real-world environments.

As Figure 9-1 shows, KDDI launched a new joint research project with top-level overseas universities in October 2020 to promote their and our research [9-12].

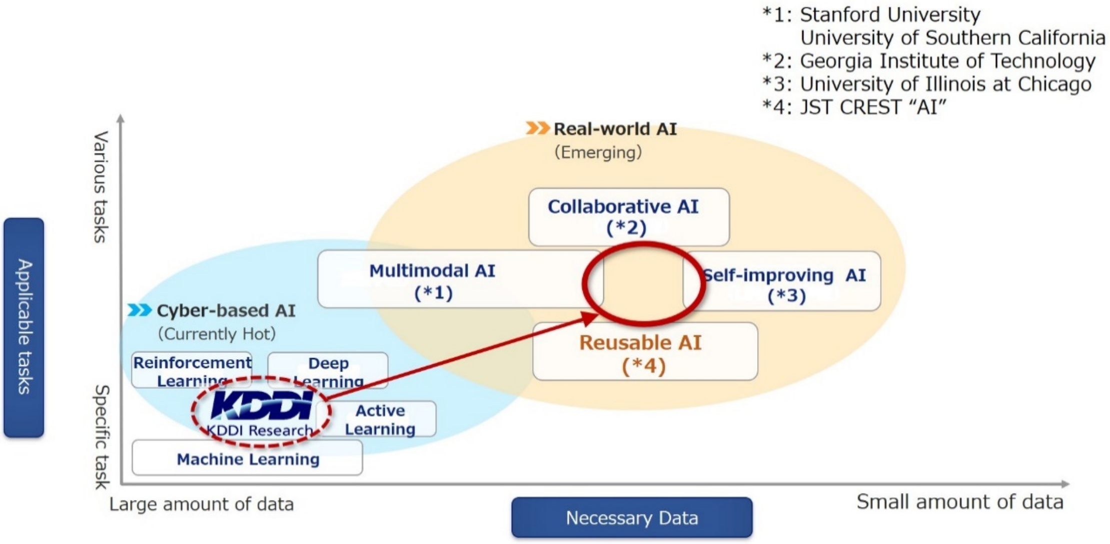

Figure 9-1: Real-world AI and collaborators

Additionally, we have defined two types of AI for behavior change:

- "Human psychology AI," which models characteristics based on psychological research findings and seeks to understand users and their psychological characteristics through biological data and daily actions; and
- "Persuasive AI," which predicts the most effective and appropriate means of persuasion and its results for each user, based on research findings in social and cognitive psychology.

In addition to these, we are undertaking R&D in defining "trustworthy AI," which shows the user the basis on which the AI makes its decisions in an easily understood format.

9.4.1. Real-world AI

9.4.1.1. Reusable AI

Reusable AI is a type of technology that generates AI models which can solve a variety of tasks using small quantities of data.

To use AI in real-world situations like predicting railway demand for Route A, or forecasting disasters for District B, across areas like transportation, disaster response, and health or medical care, it is necessary to generate individual AI models for each environment or area. Moreover, a certain amount of accurate data appropriate to the environment or task to be analyzed is required for learning. Accurate data for training refers to accurately labeled feature data. For example, in the case of predicting railway demand, an accurate label would refer to the number of passengers, while the feature data would be the daily number of passengers video footage from around the station, weather forecasts, population demographics in the station vicinity, and so on.

It is easy to collect large amounts of accurate data in more technologically advanced metropolitan areas and regions. However, low-population areas face problems such as lack of sensors and small number of users, which lead to an insufficient amount of data. As such environments from which feature data can be collected is limited. There are also many issues regarding quality, quantity, and cost of predicting accidents, disasters, and failures—for example, the huge cost of manually assigning accurate labels and the rarity with which relevant events occur.

As described above, "reusable AI" is effective in cases where only small amounts of accurate training data can be secured for analysis, as AI models generated from accurate training data from other environments and tasks are used to generate highly accurate AI models for the environment and task at hand for analysis.

Reusable AI generates models attuned to the target for analysis by further training already trained models. In the railway demand forecasting example above, the model is trained by incorporating data collected from stations in low-population areas into the already trained model created for stations in metropolitan areas. In marketing, where it is difficult to build an AI model for product recommendations using only data collected from the company's userbase, marketing that handles products across multiple companies (known as "cross-domain marketing") can be achieved using data from other companies' userbases and product recommendation AI models. By reusing these AI models instead of collecting vast quantities of data for each use case, the cost and time involved in data collection can be greatly reduced.

In recent years, there has been much research on transfer learning as a key technology for reusable AI. Briefly, transfer learning is a technique for improving the accuracy of AI models in a particular domain by using data from other domains. This can be classified into two types, homogenous transfer learning and heterogeneous transfer learning, depending on whether the data types used are the same across domains.

A common method for homogenous transfer learning is to fine-tune a generic representation model for images or text (ResNet50 for images [9-13], BERT for text t [9-14]) using homogenous data in one's own domain[13]. There are also more general methods that do not restrict the data type, such as using density ratio estimates to account for differences in data distribution across domains when training a model with

---

[13] A method for relearning the weights of an entire model, taking the weights of a learned network as initial values.

training data [9-15], and using adversarial generative networks, which have gained prominence in image generation, to learn how to make latent data representations more difficult to distinguish [9-16].

When considering applications for the aforementioned cross-domain marketing, heterogeneous transfer is essential as the types of user behavior (e.g., browsing websites, visiting physical stores, etc.) and product information (book synopses, food descriptions, etc.) vary. Many heterogenous transfer learning methods were proposed in the 2010s [9-17][9-18], but these assume that user IDs are linked and that raw data is shared. On the other hand, recent years have seen a tightening of laws and regulations due to growing privacy concerns, and data has been highlighted as an asset in business, making it difficult to share raw data as is in many situations. For these reasons, it is difficult to apply these previously proposed methods as is, and the technical challenge is to build a method for heterogenous transfer learning that does not require coordinating user IDs or sharing data.

KDDI is working on heterogeneous transfer learning under the premise that data sharing and user ID exchange is minimized or not performed. This research was accepted in 2018 by JST CREST, "Creation and Integration of Artificial Intelligence Fundamental Technologies for Innovation Creation" [9-19], under the title, "Persona Model Transfer Technology for Heterogeneous Domain User Behavior Prediction" [9-20], and was conducted in collaboration with Osaka University and Nagoya University. Among these, we proposed methods for extending domain adversarial learning in homogenous transfer learning to heterogenous transfer learning [9-21] , and applying Word2Vec [9-22], which learns the latent representation of textual data, to user action sequence data , confirming that they had higher accuracy than existing training methods, as well as methods that did not use transfer learning in actual data. These methods still require some form of user ID exchange, but going forward, we aim to establish heterogeneous transfer learning techniques that can be used without sharing data or exchanging user IDs. The research on heterogeneous transfer learning was accepted as an acceleration phase research project by JST CREST's "Development and Integration of Artificial Intelligence Technologies for Innovation Acceleration" on March 18, 2021 [9-23]. The acceleration phase activities will include the establishment of a consortium to proceed with the R&D and demonstration experiments in autumn of 2021. The purpose of this consortium is to ensure that the research will be effectively utilized to attract interest of potential customers and to perform customer marketing across various industrial fields related to cyber and physical spaces.

9.4.1.2. Multimodal AI

"Multimodal AI" refers to AI technology that makes comprehensive decisions by integrating various forms of data obtained from both cyberspace and physical space, such as video, images, voice, text, location data, and weather. Such a cross-domain integration makes it possible to generate more accurate AI models compare to models that would be using only one type of data.

Single-modal AI makes decisions with a single input, such as detecting a face from an image, recognizing speech and extracting text from it, or forecasting demand using time series data.

Within a product recommendation system, multimodal AI could help recommendations be more interesting. In fact, and based on various inputs such as facial expression, voice tone, temperature at the time of recommendation, time series data, etc., it is possible to make a more comprehensive judgment of the individual in question and present reasons behind recommendations.

In addition, multimodal AI has an advantage when dealing with missing data. Real-world data, such as sensor data, are not always available in an optimal form. Some may have missing data, some (such as temperature) may suddenly become unavailable, and others may have different frequency of acquisition. In such cases, it is difficult for single-modal AI to produce highly accurate models. However, multimodal AI can extract relationships among heterogeneous data types. Such knowledge enables multimodal AI models to appropriately fill missing data and obtain high accuracy, even when multiple data types are incomplete.

In recent years, there have been five technical challenges facing multimodal AI: representation acquisition between modalities (representation), translation between modalities (translation), association between modalities (alignment), prediction with integrated modal information (fusion), and knowledge transfer between modalities (co-learning) [9-24].

Of these technical issues, KDDI is focusing on prediction with integrated modal information (fusion) because of its affinity with issues specific to the real world. Various researches have tackled the issue of fusion-based prediction, such as speech recognition using both speech and images [9-25] and emotion recognition from multimodal data [9-26]. However, most of these studies have targeted time-series data with temporal changes. And only few efforts have been focusing on spatiotemporal multimodal data that include spatially changing information such as flows of people and weather. As mentioned in Section 9.3, KDDI has a strong experience with analysis of location-based information. Building from such strength introduction of spatiotemporal information such as population dynamics to domains that have traditionally been limited to forecasts using only time-series data is an important part of KDDI on multimodal AI. For example, when forecasting electricity consumption, it is possible to detect anomalies by focusing on unusual movements of people during unexpected events such as abnormal weather conditions [9-27]; as well as, detect increased demand due to growth in remote work and staying indoors, depending on where people are living [9-28]. We believe that prediction technology that integrates all kinds of spatiotemporal multimodal data will prove to be necessary in tackling real world problems.

9.4.1.3. Collaborative AI

As mentioned above, constructing AI models that can cope with a variety of tasks and environments generally requires a correspondingly large amount of accurate data, but it is highly difficult to secure in advance accurate, well-organized data that covers all possible events across a variety of tasks and environments. One way of solving this problem is to use explicit and tacit human knowledge, otherwise known as "collaborative AI".

In recent years, the concept of human-in-the-loop (HITL), where AI learns efficiently in cooperation with humans [9-29], has been proposed. To create highly accurate AI models, HITL learning requires these main factors: active learning, where data that is likely to contribute to improving the AI's performance is automatically extracted [9-30]; imitation learning, in which AI learns through observation and imitation of human behavior [9-31], and inverse reinforcement learning, in which AI learns optimal rewards from human behavior. Other related technologies include explainable artificial intelligence (XAI) [9-32], which clarifies the basis for AI decisions in cooperation between humans and AI.

KDDI's R&D focuses on tasks and environments in the real world, such as in smart cities and smart homes.

9.4.1.4. Self-improving AI

"Self-improving AI" responds to frequently occurring real-world changes and additions to its environment and tasks, by itself generating evolving a model.

It is desirable to re-generate the AI model after each environmental change to maintain the accuracy of the initial model—for example, during the construction of new stations and competing routes, or surrounding roads in the case of railway demand forecasting. On the other hand, since there may be little data that can be collected in a new environment, it is difficult to generate a model suitable for the new environment that only has a small amount of data.

We are therefore developing a "self-improving AI" that can generate an AI model that can be applied to new environments and tasks, using models trained on prior environments and tasks whenever changes or additions arise. The key is to enhance the AI model by leveraging knowledge gained from existing environments and tasks that can be used as references, to respond to successive changes and additions.

In recent years, lifelong learning has emerged as a key technology for self-improving AI[14]. It is well-known that in deep leaning, the AI model is optimized for the most recent task when learning it, and previously learned knowledge is often forgotten (catastrophic forgetting) [9-33]. Thus, lifelong learning represents a key challenge in overcoming this problem.

To date, there are three known approaches for overcoming catastrophic forgetting: (1) the replay-based approach, in which part of past data is stored and replayed when learning a new task [9-34]; (2) a regularization-based approach, in which a constraint (regularization) is applied so that important information in the past AI model is not forgotten when learning new tasks [9-35]; and (3) a parameter isolation-based approach, in which task-specific knowledge is secured by preparing task-specific parameters in the AI model [9-36]. In computer vision, benchmark evaluation methods such as processing and evaluating to increase the number of new recognition targets by using general handwritten character recognition data are being established, and methods based on approaches (1) to (3) above are being introduced and evaluated worldwide. Conversely, it has been indicated that the development of general methodologies that can be applied to fields other than computer vision, as well as methods of knowledge representation and use within these processes, are issues that need to be addressed [9-37].

KDDI is tackling this research with an eye toward using self-improving AI in the real world, envisioning a situation where not only new tasks are added, but environmental changes also simultaneously occur. We are attempting to determine which of approaches (1) to (3) is most suitable for this situation; we seek to develop one of them, and investigate methods of representing and using knowledge that will understand environmental changes.

9.4.2. AI for Behavior Change

9.4.2.1. Human Psychology AI

"Human psychology AI" creates AI models for understanding the psychological characteristics of individuals when getting results derived from real world-oriented AI and feeding them back to humans and society. People are born with personalities and values

[14] This is also known as "continual learning."

that differ from those of others; these influence how much people are drawn to something or how much they will avoid it, and in general have a significant impact on the motivations, choices, judgments, and executions in their everyday behavior.

For example, the prevailing theory in contemporary psychology is that a person's personality is composed of five axes (the Big Five) [9-38], and it is known that people with high extroversion (one of the Big Five) tend to seek out positive emotions such as excitement, achievement, and praise, while people with high neuroticism tend to avoid negative emotions such as anxiety, worry, and hardship.

In a study examining the relationship between the Big Five and the appeal of advertisements where there were (A) advertisements promoting an exciting aspect of everyday life brought about by smartphones, and (B) advertisements promoting the high level of security of smartphones, it was found that highly extroverted people were more motivated toward purchasing by (A) rather than (B), while the exact opposite was true for people with highly neurotic tendencies.

As these examples demonstrate, it is crucial to understand the personality traits of each individual to encourage people to change their behavior. To encourage real-world changes in behavior, especially where smoking, exercising, and staggered commuting are concerned, it is necessary to understand the psychological characteristics of each person more deeply and broadly. This is because they require stronger motivation than the actions that are carried out in online spaces such as shopping or consuming content.

Thus far, approaches to understanding human psychological characteristics in the field of psychology have taken the form of questionnaire surveys and interviews by experts, but these methods pose the following problems: (1) the range of psychological characteristics that can be investigated is limited due to restrictions on the number of questions and the length of the interview; (2) the interpretation of questionnaire contents and interview results differ from person to person, resulting in the distortion of survey results, and (3) the number of subjects that can be investigated is limited due to cost.

KDDI is engaged in R&D of AI to understand the psychological characteristics of individuals based on daily behavioral data and biometric data observed by the CPS, while making use of research findings gathered to date in the field of psychology.

Specifically, we are working on researching and developing technology to assess personality (the Big Five) and values (Schwartz's Basic Value)[9-39] from daily web browsing patterns and driving logs [9-40][9-41], modeling the relationship between these psychological characteristics and advertising design preferences [9-42][9-43], and predicting responses to those advertisements [9-44]. We are also investigating AI-mediated human-to-human interaction, which involves the utilization of AI to mediate interactions between humans based on an understanding of their psychographic compatibility. The study was designed to take into account the diversity of social activities that involve various types of human relationships, such as husband-wife, friend, teacher-student, boss-subordinate, and company agent-customer relationships. As an example, we examined an approach that matches call center agents and customers in an outbound telemarketing context; we confirmed that our approach resulted in significantly better conversion lift than existing approaches [9-45].

The scope of our research also includes the application of the theory of mind (ToM) to AI; ToM is the ability to understand the mental state, goals, intentions, etc. of other people. ToM is known to be essential for humans to lead healthy social lives. This means that ToM is also essential if AI is to be incorporated into the social communities of humans and interact with humans in a natural way. With this as motivation, much effort has been dedicated to equipping AI with a ToM [9-46][9-47][9-48]. Our research is distinguishable from other existing studies because it focuses on including a sense of agency (SoA) [9-49], which is the subjective experience of control over and responsibility for one's own actions and their outcomes; it is known to affect self-awareness, the experience of volition, the understanding of causal structures, the sense of social responsibility, etc.[9-50]. We envision that AI will become capable of helping and interacting with humans in more comfortable and effective ways if it can be designed to understand the human SoA.

We will continue to pursue these studies with the goal of realizing AI systems that have a broader and deeper understanding of human psychology and are capable of natural and seamless human-AI interaction.

9.4.2.2. Persuasive AI

Persuasion is a form of communication used to change people's feelings and behavior. To change behavior through persuasion, it is effective to make use of behavioral characteristics, or "cognitive biases," as they are known in the field of psychology, in addition to providing motivation for the target behavior. However, the difficulty and method of persuasion varies depending on the target behavior, the individual, and the environment at the time.

For example, accidents caused by people walking while using their smartphone have become a social problem. To make pedestrians voluntarily stop using their smartphones while walking, instead of forcibly interrupting them when spotted, we show pictures that evoke negative emotions along with information about the possibility of imprisonment if another party is injured in an accident caused by smartphone use while walking. The "emotional approach" is an example of persuasion [9-51].

KDDI is researching and developing “persuasive AI” that can accurately predict effective, reasonable, and agreeable means of persuasion and their effects on an individual, using human psychology-estimated user behavioral data in cyberspace and the real world, derived from human psychology AI and psychological knowledge. For example, as left of Figure 9-2 shows, in an experiment with an expressway operator who encouraged taking detours to mitigate traffic congestion, the intent to detour and the actual detours were verified by displaying content at the top of a smartphone app that encouraged taking detours, with multiple varying psychological effects. As a result, we were able to confirm that the efficacy of psychological effects varied among users. For instance, content using visual information to remind users that roads along the detour were clear was effective for those who did not usually drive and were not used to it; content that appealed to the emotions and had the effect of arousing empathy was effective for those with children [9-52]. In addition, we are investigating and demonstrating methods in several fields, such as tourism, health, and healthcare, with our partners [9-53].

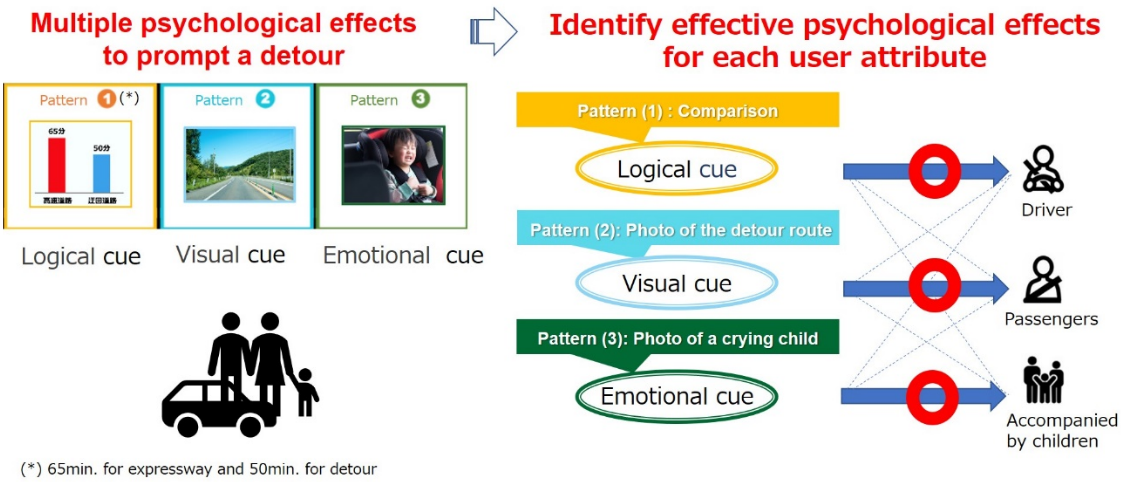

Figure 9-2: Experiments with expressway operators

9.4.3. Trustworthy AI

There are some cases where there is a certain distrust and uneasiness in using results derived from AI systems. This is because AI decisions are black-boxed, and the basis for their decisions is unknown, and there is a risk that biases related to human preferences may potentially be reflected in the real world. Even if a highly reliable AI engine is developed, users will not use this with confidence if the AI technology itself is considered unreliable.

Thus, we have formulated and published the "AI R&D and Utilization Principles for KDDI Group" to allow users to use AI with confidence and contribute to society in a sustainable manner [9-54]. By promoting initiatives based on these principles, we aim to achieve what we refer to as "Trustworthy AI."

In recent years, there has been an increasing amount of research on “explainable AI” (XAI) as a technical solution to the black-boxing of decisions using machine learning and deep learning techniques[9-55]. For example, there is active R&D of AI and with machine learning engineers building models for image recognition, speech recognition, etc. [9-56]. KDDI has also been conducting research and development in this field; we have been awarded the top prize in a competition on explainable AI [9-57].

KDDI will continue to develop and investigate technologies to achieve explainability of AI for users in all positions (AI developers, users, etc.) in real-world services.

Additionally, as AI technologies evolve and become ever more complex, there is the possibility of human rights violations occurring on a scale unimaginable in the past, such as data being collected without individuals’ consent. As laws and regulations have not kept pace with the technological evolution of AI, it has become necessary to develop AI technologies in a way that anticipates regulations while striving for international harmony. Therefore, we will conduct a wide range of research and analysis on AI regulations that are being discussed in parallel around the world (especially from the perspective of ethics and privacy protection), and will ensure that these latest developments are reflected in the AI technologies developed in-house, as well as make recommendations for policies in Japan. KDDI will continue developing AI technologies that are not only convenient and user-friendly, but also safe and secure to use.

9.4.4. Using Combined Multiple AI Technologies

As Figure 9-3 shows, the seven new AI technologies to be researched and developed by KDDI will be used to solve real-world problems, but they will not be used independent of each other; rather, they will have complementary roles, and will be combined with AI technologies created through conventional machine learning and deep learning for different purposes and use-cases.

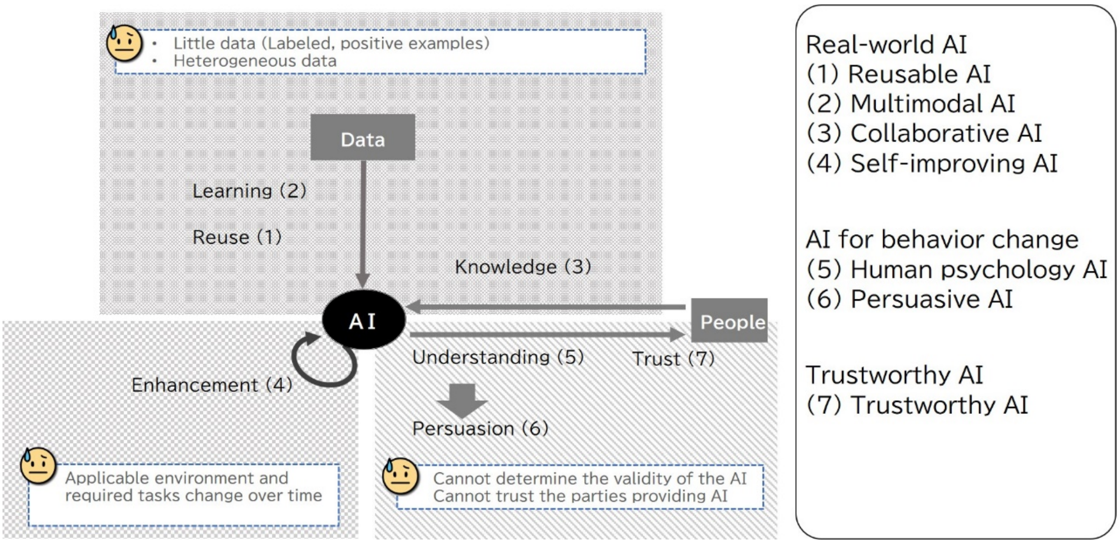

Figure 9-3: Relationship between issues specific to the real world and the seven AI solutions

For example, in the case of creating a lively city by constructing a new station, a model of population from before and after the opening of the new station generated by (2) multimodal AI using various data of a different city with similar characteristics, can be combined with data specific to this city, and (1) reusable AI can be used to generate a predictive model of population change for this city. Should there be insufficient data, (3) collaborative AI will improve the accuracy of the model by supplementing it with real-world human behavior and knowledge. Based on the generated model for predictive population changes after the opening of the new station, the system automatically generates an announcement plan that encourages behavioral change—a plan that balances and harmonizes liveliness and congestion in the city, satisfaction levels for individual residents, and the overall optimization of the city—by using (5) human psychology AI and (6) persuasive AI, which consider the traits of residents in this city. In such cases, local stakeholders such as transportation companies and local governments implementing these measures will feel a greater sense of conviction if the rationale for such AI-based decisions are presented, as in (7) trustworthy AI. When acquiring and using various kinds of data, we will comply with data collection, use, and AI regulations appropriate to each occasion. Although the city and its residents will change over time after the station begins operating, the predictive model for population change will be continuously updated using (4) self-improving AI and used on an ongoing basis.

In the case of starting to cohabitate with one's parents in a new house with a home robot, and based on (3) collaborative AI, the home robot recognizes their preferences while sometimes asking them questions, and (1) reusable AI supports their lifestyle by replacing the integrated support functions in the new house. Furthermore, it has already learned parental behavioral data prior to cohabiting thanks to (2) multimodal AI, and this behavioral data is added to a model for the general behavior of people in their 60s using (1) reusable AI. It adapts to its circumstances and location using (4) self-improving AI, and provides support in a way that satisfies the entire family.

10. "6. XR"

10.1. The Role of XR in B5G/6G

XR is a generic term for technologies that take the results of the fusion of cyberspace and physical space to and make them available for human perception, such as VR, AR, etc. In the seven technologies of KDDI Accelerate 5.0, XR plays the role of communicating the results of AI-derived analysis to humans and encouraging them to change their behavior[15,16]. Content using XR technology needs to be delivered to users at high capacity and low latency compared to conventional video streaming, and this can be achieved through B5G/6G optimized communication and highly efficient, ultra-low-latency 3D space data transmission technology. The combination of B5G/6G and XR technology can create an experience with an unprecedented sense of presence that mixes the five senses in all sorts of life scenes.

10.2. XR Technology Goals

In 2030, IoT devices and sensors installed everywhere will be able to scan information in the real world and reproduce it in cyberspace. Physical space reconstruction and augmentation, which not only reproduces but also superimposes virtual landscapes and objects on the real world, will be realized. With “multimodal interactions,” which combine various perceptual expressions, this is not limited to the display of flat images, but can be combined with a variety of perceptual expressions, such as stereoscopic images through VR/AR glasses, holography, which displays 3D images indistinguishable from the real thing, spatial acoustics that can be felt even at the edges of the field, and force feedback, which gives users the sensation of touching an object.

These advances in XR technology will bring about a tremendous change in communication styles. Specifically, you can recreate places you have visited in the past, and remotely share those memories with your friends and family while in your own room. You can touch the shoulders of someone close to you, and gently lay your hand on theirs. It is possible to express delicate nuances that cannot be conveyed by words alone.

“Highly efficient, ultra-low-latency 3D space data transmission” is important as a mechanism to support such a rich XR experience. Here, information in the real world and XR contents expanded in cyberspace are transmitted back and forth without any time lag as highly efficiently compressed data. The result is a seamless XR experience in CPS.

---

[15] Augmented reality

[16] Mixed reality

10.3. Global Situation

With the rapid spread of remote work and virtual events associated with the spread of COVID-19, remote communication and collaboration using XR technology is becoming more common. For example, virtual conferences and exhibitions that make full use of the viewing experience through VR glasses and self-expression using avatars—such as IEEE VR, a representative international conference on VR—are increasing [10-1]. Some US universities and companies have gone all out and are using similar technologies to introduce virtual campuses and virtual offices [10-2][10-3]. The use of VR/AR glasses is expanding as major IT companies in the US, China, and other countries are steadily improving their performance in terms of higher image quality, wider viewing angle, size, and weight.

As such, although XR technology is steadily gaining traction, as traditionally only certain goods and services have been digitized, the experience of receiving cyberspace feedback has been fragmented. As an example, we would like to introduce KDDI's virtual Shibuya. In this virtual Shibuya, the streets of Shibuya are reproduced in cyberspace as a digital twin, and you can participate as an avatar 24 hours a day from anywhere in the world [10-4]. As another example from Shibuya City, a demonstration experiment that superimposes restaurant information and other items on the actual scenery of Shibuya was conducted using VPS technology that recognizes space from images taken through cameras mounted on smartphones and smart glasses (Figure 10-1) [10-5].

Figure 10-1: Extension of physical space at Shibuya Scramble Crossing "

With regard to vision, conventional cyberspace feedback experiences were mainly limited to forms mediated by 2D displays. As an attempt to pseudo-extend this to 3D, an approach projecting 2D high-quality CG in 3D space using a transparent display or half-mirror is being studied [10-6]. Moreover, R&D of 3Ddisplay technology [10-7] using holography (Figure 10-2), which records and reproduces light waves reflected from the surface of real objects, is underway to realize image expressions that are, in principle, impossible to distinguish from the real object; however, high image quality and wide viewing angles have not yet been achieved due to limitations of display devices.

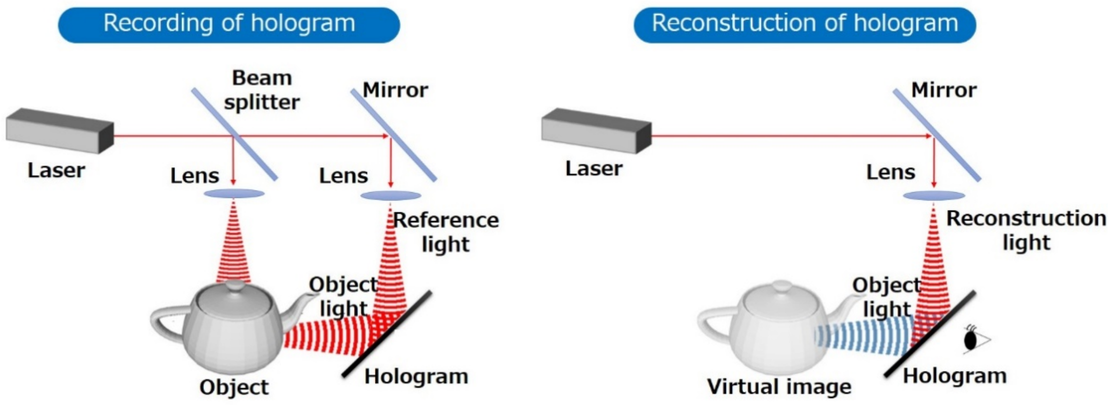

Figure 10-2: Principles of holography

In terms of auditory perception, KDDI’s “OtonoVR” technology enables an interactive viewing experience by synthesizing a sound field zoomed to an arbitrary range in space, allowing the user to freely focus on the part of the 360-degree video that he or she wants to see or hear [10-8]. Figure 10-3 shows an example of a virtual concert using “OtonoVR” technology.

Figure 10-3: Example of a virtual concert using "OtonoVR" technology

Finally, let us discuss the network transmission of XR content. Global data distribution volume (IP traffic) is rapidly increasing, and is expected to reach 278 EB (exabytes: 1 EB = 10^6 TB) per month in 2021 [10-9]. Of this, mobile data traffic is growing at a remarkable rate (from 6 EB per month in 2016 to 41 EB per month in 2021, an increase of about seven times [10-9]), and most of that content in future will be video data, the ratio of which is expected to reach about 80% in 2022 [10-10]. High efficiency video coding (HEVC) is the international standard of video compression technology in practical use as of 2021. While HEVC has already achieved compression to the bandwidth of a few hundredths, further advanced technologies in video coding to reduce data volume while maintaining video quality have been promoted, such the advent of 360-degree video, ultra-high definition (4K/8K) and high dynamic range video, as well as the diversification of viewing devices such as smartphones, tablets, and head-mounted displays. Specifically, by using versatile video coding (VVC) [10-11], which is the latest international standard in 2020, the live broadcasting of 4K/8K high-definition video via mobile network will be possible, and 4K/8K video services for smartphones and tablets are expected to be developed in the future [10-12][10-13].

10.4. Technologies Required for 2030

This section summarizes the technologies supporting XR in the B5G/6G era from the perspectives of physical space reconstruction and augmentation, multimodal interaction, and highly efficient, ultra-low-latency 3D space data transmission.

10.4.1.Physical Space Reconstruction and Augmentation

As the reproduction and augmentation of physical space progresses, every person and object in the real world will be scanned in fidelity and transmitted to cyberspace. After analysis in cyberspace, this cyber information will be superimposed on the entirety of physical space, and we will be able to enjoy services that transcend time and space in every aspect of our lives. B5G/6G will further accelerate the progress of CPS, enabling every place to be connected to cyberspace and enabling us to come and go freely.

In a world that merges physical space and cyberspace, it is possible to recreate in its entirety a place you have visited, in your own room, to be with your friends and family from a distance, or to relive past memories. Or a foreign sporting event can be recreated as a space where you are in a stadium in Japan, rendering possible the unprecedented experience of watching this sporting event as if it were being played right in front of you.

In addition, virtual humans, which represent humans as elaborate 3DCG (photorealistic avatars [10-14]), will be used daily for customer service and guidance in stores, education, nursing care, etc., and will be socially accepted as a common presence in our lives. The image of a virtual human is shown in Figure 10-4 [10-15]. Virtual humans will not only play a role as an interface between people, but will also be widely used as a tool to digitally transform the supply chain; for example, cyberspace will be able to exist as a space to create product samples for product planning and design [10-16]. Also, in cyberspace, one’s own agent exists as a digital twin, and one’s own appearance, clothing, and even gestures and facial expressions can be optimally controlled according to the circumstances; in particular, this will be used in the business world on a daily basis as a form of communication going beyond face-to-face communication.

Figure 10-4: Image of a virtual human

In the reproduction of physical space, information about any object or space needs to be sensed and modeled in cyberspace. In the future, advanced signal processing technology will be extremely important for constructing precise models from a vast amount of information obtained from 3D sensors and high-definition cameras, thus expanding targets to include not only people at close proximity but also in wider spaces at the town or city level.

10.4.2.Multimodal Interaction

With the advancement of multimodal interaction through XR technology, the field of experience will be extended to 3D space, and the viewing experience with 3D images and sound fields, the sensation of touching people and objects, and even the sense of smell and taste will be provided, unrestricted by time or space, resulting in a rich, natural experience comparable to the real thing.

By 2030, holography technology will be able to reproduce light waves in physical space that are exactly the same as those reflected from the surface of a real object. This will enable us to view ideal 3D images through a compact, lightweight transmissive head-mounted display (HMD) without 3D sickness or visual fatigue, which will provide visual and intuitive AI assistance in all aspects of daily life.

In a world where CPS has advanced, physically distant spaces as well as the sound field will be connected in real time, and an immersive experience that transcends live viewing will become possible, as if you were there right now.

Furthermore, by supporting the sense of touch as a mode in addition to the senses of sight and hearing, it is possible to reproduce the sensation of touching other people and objects during remote communication in cyberspace. This enables face-to-face communication such as a tap on the shoulder, a gentle touch on the hand, or a handshake to be realized across time and space. For example, in physical communication such as “toasting” and “pouring” in remote gatherings, various tactile experiences can be realized through the real-time synthesis technology of tactile waveforms. As an example, Figure 10-5 shows an image of a system that reproduces the tactile sensation of “toasting” and “pouring” from a remote location [10-17].

Figure 10-5: An image of a system that enables remote “toasting” and “pouring” with tactile sensation [10-17]

In interpersonal communication, it is more important to pursue cross-modality effects that can be obtained by coordinating multiple senses with each other, in addition to the natural functioning of each sense. In communication, physical and environmental constraints placed on the other person vary from person to person. In other words, working with all the senses is not always optimal. For this reason, it is vital to establish cross-modality technologies that can identify which senses are effective in each situation, such as transmitting sound using light and vibration, or pointing to input using sound and vibration, and superimpose other senses in an extended manner.

10.4.3.High-efficiency, Ultra-low-latency 3D Space Data Transmission

As XR permeates our daily lives, the visual experience will be extended from 2D displays to (physical) space itself, and the subject of the information handled there will also change from 2D video information to 3D space information. Point cloud information representing 3D space is much larger than conventional 2D video information. Therefore, point cloud compression (PCC) technology [10-18], which is a coding method for highly efficient compression and transmission of point cloud data, and its successor technologies, have been established to enable stable handling of 3D space information even on mobile network (Figure 10-7). Figure 10-8 shows the past and future roadmap for 3D space data compression technology. This figure also shows the progress of compression technology for 2D video and 3D space reproduction technology.

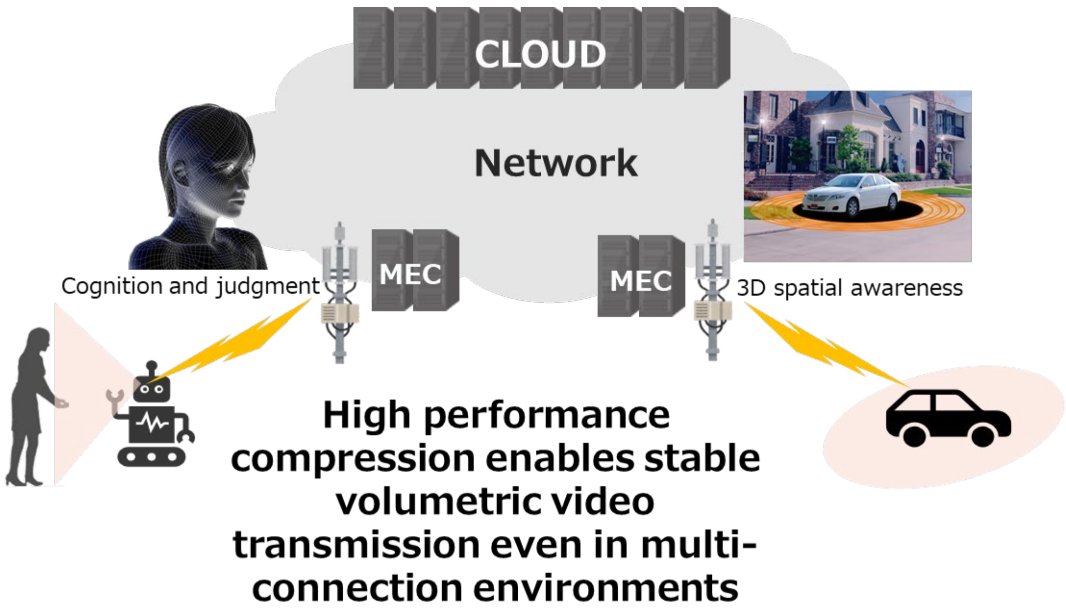

Figure 10-6: Transmission of 3D spatial information

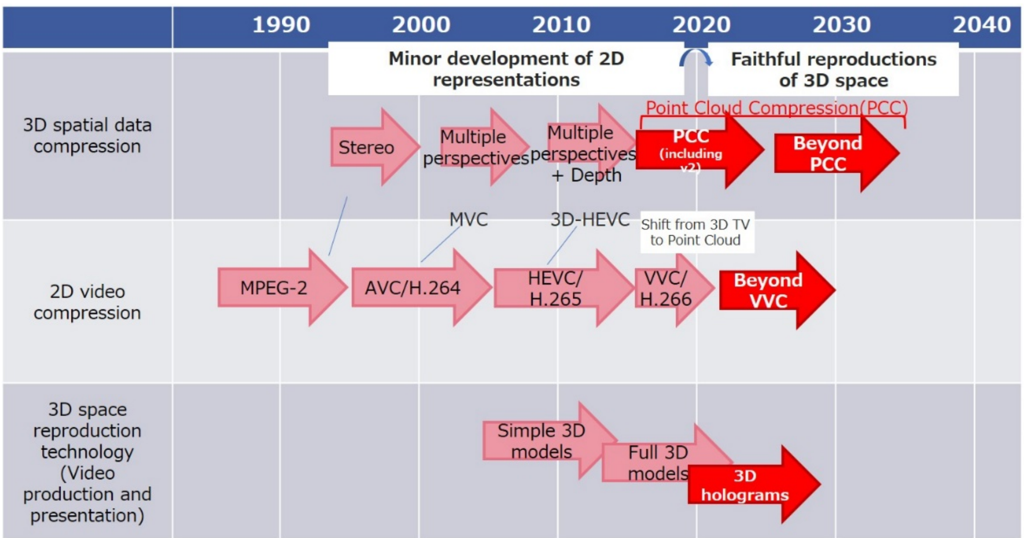

Figure 10-7: Roadmap for 3D spatial data compression technology

In addition, the ability to reproduce and transmit 3D space will increase the need for highly interactive applications, such as remote surgery and robot control. In such applications, ultra-low-latency transmission technology is utilized for instantaneous transmission in 3D space while maintaining the compression performance. For example, when connecting the physical space, where the remote robot exists, to the pilot's space, an end-to-end display delay of 50 milliseconds or less (the world's smallest class in current 4K video transmission) can be achieved, virtually eliminating the gap between visual and physical sensations, enabling accurate and physically intuitive operation. In addition, it alleviates the operator's cybersickness (VR sickness), which is said to be one of the causes of image transmission delay, and enables remote control for extended periods of time [10-19].

Thus, a world with advanced CPS will be realized by both ultra-high-speed, high-capacity, ultra-low-latency mobile networks with B5G/6G and highly efficient, ultra-low-latency volumetric–video transmission technologies.

11. "7. Robotics"

11.1. The Role of Robotics in B5G/6G

In 2030, physical space and cyberspace will be connected by B5G/6G, and the various data obtained from physical space will be transmitted to cyberspace for intelligent analysis. One of the systems that uses such analyzed data to re-act to the physical world is robotics. Here, robotics is not limited to physical robots (equipped with actuators), it also includes virtual robots (or bots) such as virtual agents, and the mechanisms by which these robots act.

The superior network performance of B5G/6G is essential for the development of robotics. For example, ultra-fast, high-capacity communication is important for the platform analyzing sensory data obtained from such sensors as cameras and LiDAR mounted on robots. Ultra-low-latency communication is also required for the transmission of sensory data to cyberspace and the transmission of control data (such as motion planning obtained from analysis) from cyberspace back to robots. Moreover, communications with multiple simultaneous connections will be put to effective use where large numbers of robots of various sizes are installed and operate in human society. Ultra-low power consumption and ultra-safe and reliable communications are also essential for robots to operate safely and reliably for long periods of time.

Thus, the society in which CPS has been advanced by B5G/6G is regarded as a typical scenario for the use of robotics. In the future, robotics will be implemented as part of the city OS, and having entered our lives in a natural way and providing further enrichment.

11.2. Robotics Technology Goals

In 2030, robots that are integrated into human society will be used to perform various tasks, such as patrolling streets and facilities, working at hazardous locations, and delivering goods. It will be necessary to extend the robotics platform to further expand the range of applications for robots. This platform is regarded as a foundation for RaaS, Robotics as a service. The data collected from robotics in physical space are sent to a common platform and analyzed by AI systems built in cyberspace. Instructions from AI systems will act to control the behavior of robots in physical space, and in this situation, a variety of robots will be able to operate with one another via the platform to carry out more complex tasks and share information required to carry out these tasks.

For robots to coexist with people, it is important for robots to be socially and economically accepted in terms of safety and service expense. From the perspective of social acceptability, robots will be able to act autonomously by sensing the environments in physical space by making advanced estimations in cyberspace. This is, for example, expected to contribute to “community support” by understanding a user’s health conditions and personality to casually encourage them to take a walk. By observing robots’ behavior, assessing and analyzing their acceptability to people, and further improving robots’ behaviors, robots will move beyond coexistence, becoming indispensable partners to people.

Through the spread of the RaaS infrastructure described above, the scope of activities performed by robots will expand moving toward 2030. On land and in the air, tests to demonstrate “autonomous driving and smart drones,” responsible for transporting people and goods, are ongoing, but robots will also move into marine fields. In the future, the range of robots’ activities will expand into marine fields through the development of optical communication technologies enabling wireless communications underwater, together with the development of hydrogen fuel cells enabling drones to operate for extended periods of time. This can generate economic effects in a wide range of industries, such as underwater exploration, fishery monitoring, infrastructure inspection, and live undersea video communications using undersea drones.

11.3. Global Situation

The main field in which robots have been operated so far is industry. Industrial robotics is a field in which Japan has shown its strength, and it is said that Japanese-made robots occupy almost a 60% share of the global market. To take advantage of this strength and expand both the applications of robots and global market share, the Japanese government formulated its New Robotics Strategy [11-1] in 2015, and its Plan for the Promotion of Social Transformation through Robotics [11-2] in 2019. This will further promote the implementation of robots in society in step with the advancement of sensing through IoT, AI analysis of sensory data, and the development of computing environments in which AI technologies are implemented. With the participation of various players, the government aims to accelerate the practical application of robots and to make them a more familiar presence in people’s lives. Robotic vacuum cleaners are already in widespread use in people’s homes, and in the business domain; proof-of-concepts of automated deliveries using drones and delivery robots are underway. The fields in which robots play an active role are expected to further expand in the future, and there is a growing need for a robotics platform to efficiently operate and manage a wide variety of robots, as well as to establish the technologies that robots should feature for cooperation with people.

With regard to robotics platforms, some robot manufacturers have constructed their own platforms to create systems to manage their robots [11-3]. On the other hand, efforts to operate a group of robots from various manufacturers and with different functions are also underway [11-4]. The main purpose of these existing platforms is the integrated management of robots, monitoring robots' status, and remote operation in the case of unexpected situations. In response, KDDI has proposed its "life delivery" concept, and is conducting proof-of-concept using the robotics platform. This embodies the "changes in shopping" described in Section 2.2.2, and aims to create a lifestyle where the purchase of goods such as daily necessities becomes an effortless, unconscious action. Specifically, proof-of-concepts are being carried out in the form of "order and delivery" (Figure 11-1), in which a small-scale convenience store is set up in an office, orders are placed using a smartphone application, a remotely operated robot picks products up in response to those orders, and the goods are loaded onto an autonomous delivery robot to deliver them to the orderer. We are constructing a platform that links not only robots, but in considering business development, also incorporates features such as payments.

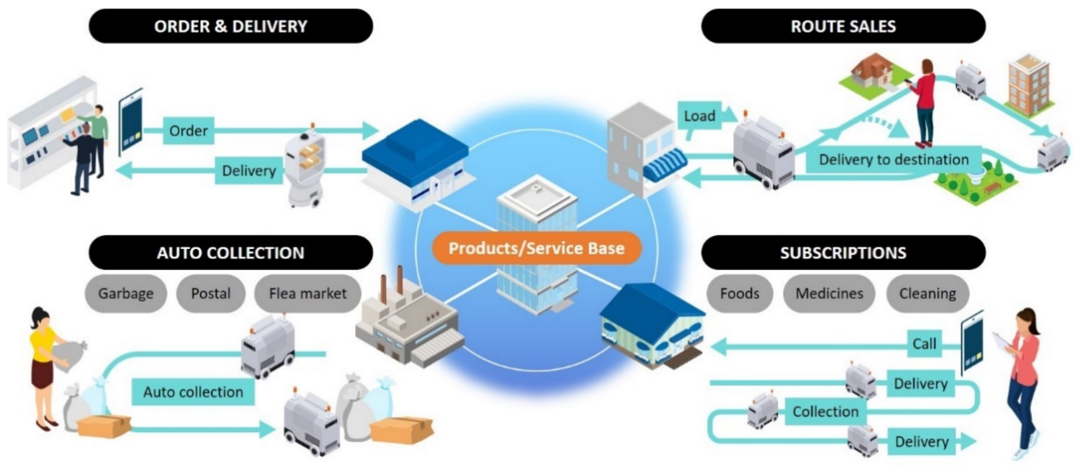

Figure 11-1: The "life delivery" service

With regard to community support, for robots to fit into the human society of the 2030s, they must be able to perform complicated tasks while understanding the situations of the people around them, and be able to cooperate with people. This will require further advances in human-robot interaction (HRI) technologies. In current HRI technology, for example, human poses can be estimated using an on-platform behavior recognition AI [11-5] using images taken by a camera mounted on the robot, and motion planning can be developed according to those estimations. In a task handing objects to a person, the robot creates rule-based definitions, such as whether the person's gaze is toward the robot, whether the direction of the body is appropriate, whether the distance between the person and the robot is appropriate, etc., and then acts to satisfy those conditions. There has been progress in planning optimal motion for robots using reinforcement learning and other techniques in recent years, but incorporating actual human responses into simulations remains a difficult task. In addition to human actions, facial expressions are understood from camera images, and these are integrated into estimated emotions and reflected in the content of the robot’s dialogue with people. Besides camera images, various biometric data such as voice, heartbeat, and body temperature are used to estimate emotional states.

The transportation of goods and persons unconstrained by location and mode, i.e., land, sea, and air, is a function expected as the social system aimed towards 2030. Today, on land and in the air, self-driving proof-of-concepts are underway, and drones are being introduced, though the marine field has yet to be sufficiently explored. Development and proof-of-concept testing of aquatic, hydrogen-powered drones has progressed in recent years (Figure 11-2) [11-6]. Alternatively, a new type of drone, i.e., the aerial-and-underwater-assembled drone, has been developed; this drone includes a UAV that holds an ROV that can fly to and land on the surface of a water body, and then be released to cruise underwater （Figure 11-3）[11-7], but are still behind compared with developments on land and in the air. This is a consequence of the communication issues. Since radio waves are attenuated in water, communication becomes impossible when using radio waves to communicate. For example, in the case of the above-mentioned aerial-and-underwater-assembled drone, a cable is used to connect the ROV and UAV to enable underwater communications. Underwater video captured by the ROV can be transmitted to the UAV via wired communications; the UAV operator is able to watch the underwater video via LTE communications. Thus, the remote control of unmanned undersea vehicles is still performed using forms of wired communication such as optical fiber, or wireless communication using acoustic signals, which have low transmission capacity. In response, efforts are underway to develop underwater communications using blue LED optical wireless communications technology, which has a relatively low attenuation rate in water, to increase transmission capacity [11-8]. With a remote-operating robot, on the other hand, it is extremely important to shorten the end-to-end delay between information acquisition from physical space, such as video, and its reproduction in cyberspace. In July 2020, an end-to-end delay of 50 milliseconds was achieved for the TELEXISTENCE robot, currently the world record for the shortest such delay (Figure 11-3) [11-9]. Prior to this, 100 milliseconds had been the minimum end-to-end delay for 4K video transmission by a drone [11-10].

Hydrogen-powered aquatic drone

UI on Smartphone

Figure 11-2: A hydrogen fuel cell-powered aquatic drone

Airframe of aerial-and-underwater-assembled drone

Separation of ROV

Figure 11-3: Aerial-and-underwater-assembled drone

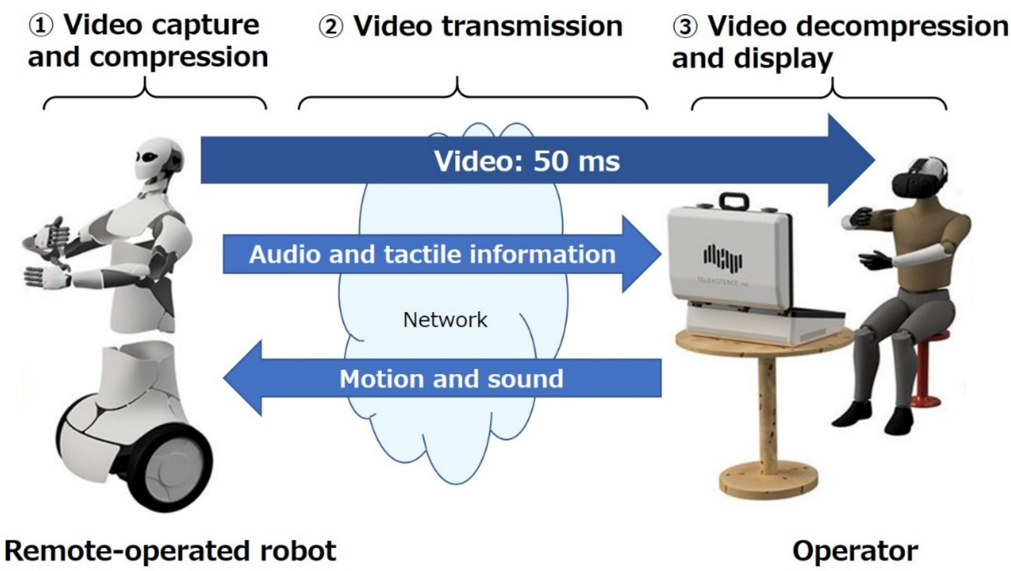

Figure 11-4: Remote control of robots

In addition, several organizations have jointly established a place for co-creation to collaborate on the development of robots and robotic services [11-11][11-12][11-13]. The rate at which use cases and services employing robots are realized (e.g., the improvement of robotic functionalities, implementation of smooth communications between human and robot, and evaluations and experimental environments to facilitate cooperation of robots and communications) is expected to accelerate.

11.4. Technologies Required for 2030

In this section, we compile the technologies supporting robotics in the B5G/6G era from the perspective of RaaS, community support, and autonomous driving and drones.

11.4.1.RaaS (Robotics as a Service)

Figure 11-4 shows an illustration of a robotics platform for B5G/6G. As an example, when providing a robotics service that patrols and cleans a facility, information about the facility collected by the patrolling robot can be managed on a common platform so that the cleaning robot can make use of security information it could not detect on its own. In this case, the cleaning robot does not need to be equipped with sensors and functions for security, and should be equipped only with the minimum functionality necessary for cleaning. In other words, having the cognitive functionality for a robot in cyberspace facilitates flexible operations, such as sharing information about a facility between multiple robots. By constructing such kind of robotics platform, the cognitive and decisive functionalities that govern control over a robot can be upgraded, simplifying the implementation of RaaS. Ultimately, a robot’s hardware needs only to be equipped with the necessary sensors and actuators, and functionalities related to cognition and judgment based on sensory data, and the generation of motion planning (or more precisely, the AI technologies required for these functionalities) can be selected from appropriate options provided on the platform. This will make it possible for even inexpensive hardware to have a high level of intelligence, and such updates can boost its conformity of changes to the robot’s environment and its growth of capabilities.

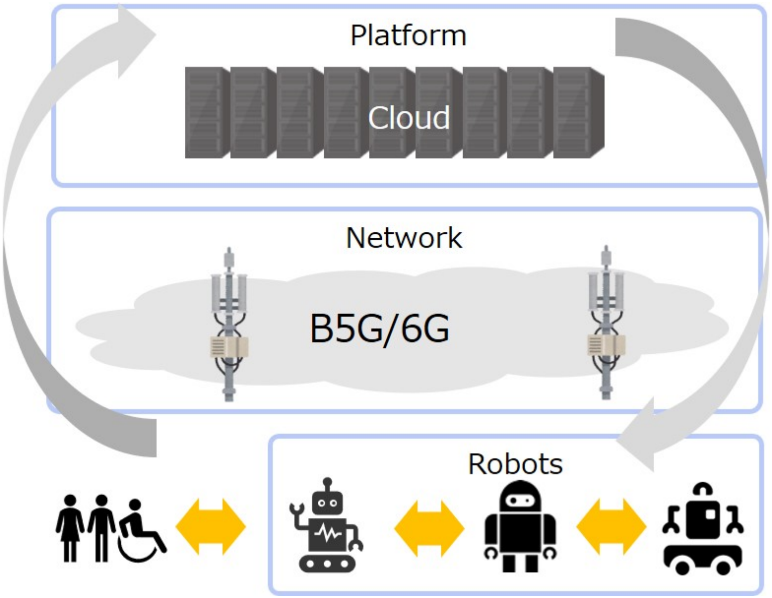

Figure 11-5: Robotics platform

11.4.2.Community Support

By 2030, the world will be one in which robots autonomously solve problems in physical space using analysis performed in cyberspace, and without giving specific instructions to robots from a human. This includes physical tasks such as transportation, maintenance, and housekeeping, as well as solving problems for people. Taking an example case of encouraging a person to exercise in physical space, the robot can understand the situation and atmosphere in physical space using analysis performed in cyberspace, and can cause behavior modifications by changing the environment to encourage that person to exercise (providing information, encouragement. etc.). Specifically, this is a world in which the person does not actively say to the robot, “I would like to go for a walk, can you recommend a route?” but rather, the robot interacts with the person, naturally and thoughtfully drawing on its knowledge of that person’s lifestyle and interests stored in cyberspace.

The evolution of HRI is indispensable for realizing such kind of world, and the elements that seem particularly important are (1) predictive detection, (2) formulating persuasive strategies, and (3) natural and sensible dialogue. Figure 11-5 shows the positioning of these elements in the CPS. (1) Predictive detection is a technology in which a robot observes a person and anticipates behaviors by predicting actions and emotions. This makes it possible for the robot to behave according to person’s own actions, and to prevent unintended actions such as a person falling in advance. The system models human motion, robots, and surrounding environment, then learns and predicts important correlations and causal factors affecting human behavior in complex interactions. (2) Persuasive strategies are required for robots making proposals to people. Persuasive AI (see Section 9.4.2.2) makes it possible to determine the most effective timings, and plan the most effective approach based on each person's personality, psychological state, and environment which are estimated via data obtained from cyberspace. Regarding (3) dialogue technologies, together with understanding the other party's emotional state by understanding facial expressions and gestures, robots and virtual humans will be able to use smooth and sensible expressions using a series of dialogue processes, such as expressing gestures, producing communication that is filled with empathy and trust.

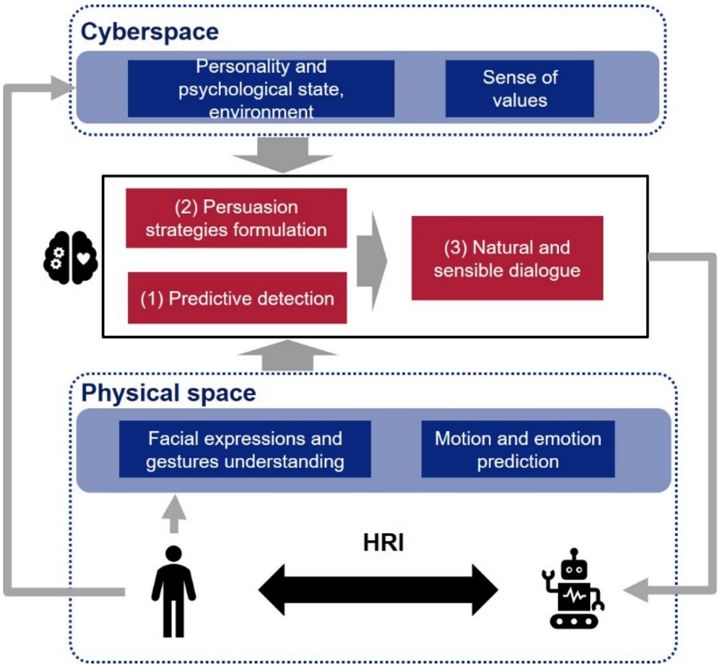

Figure 11-6: Constituent technologies for implementing HRI

Sense of Agency (SoA) and social acceptability are success indicators for the HRI technology described above. SoA refers to a mindset in which a person proactively decides what to do, and the robot plays a supporting role. For example, a one-sided assertion from a robot, even when it is a reasonable action or a suggestion for a person, gives a sense that a person is being controlled by an AI system or a robot, which leads to a decrease in SoA. Social acceptability, on the other hand, is a criterion that shows how well the presence of robots is accepted in a society consisting of their users and others who are not associated directly. Robots will be active in various places in the society of 2030, and will coexist with people in an open environment. At this point, it is important to improve the psychological assessments of robots, in terms of whether there are concerns that a robot's actions will result in harm, and whether robots can be trusted to act on behalf of people. With the observation of robot and user behaviors, and the full use of analysis in cyberspace, SoA and social acceptability can be improved, which leads to establishment of an ultimate HRI.

11.4.3.Autonomous Driving and Smart Drones

In anticipation of the B5G/6G era, KDDI is aiming to extend its wireless broadband network into the sea using optical communication technology so that wireless communication becomes possible even in marine and aquatic environments. This will make it possible to deploy amphibious drones and remotely operate drones at sea. Drones can be operated for remote underwater exploration, fishery monitoring, and infrastructure inspection without the need for a person to travel to a specific area and dive. It will also become possible to deliver goods to people and to facilities under the sea.

Furthermore, if an undersea wireless communication environment can be created through the technology shown in [11-8], the way of enjoying marine leisure activities will change dramatically: in cyberspace we could reproduce and process live video transmitted from beneath the waves, provide realistic XR experiences in physical space, and experience realistic undersea driving experiences using amphibious vehicles. It will also be possible to provide remote support to underwater workers, and undersea environments will become the new life and economic zone.

On the other hand, the scope of aerial and amphibious drone activities will further expand in 2030. For example, these can be used to assess damage in the event of natural disasters, to search for survivors in marine accidents and mountain rescues, and closer to home, to monitor elderly people and school children on their way to and from school, and to deliver goods to marginal settlements and isolated islands. In 2021, drones offer continuous cruising times in the tens of minutes, but this will have expanded to several hours by 2030, greatly improving the range of actions and capabilities. The development and widespread use of hydrogen fuel cells, produced from renewable energy sources, is an extremely important energy technology, which will replace today's lithium-ion batteries. The use of hydrogen fuel cells for all kinds of transport and logistics by land, sea, and air will serve to accelerate achieving a decarbonized society.

12. Future Development

In addition to presenting a roadmap for the future of the seven technologies set out in the previous chapters, this chapter shows KDDI's future activities in standardization and open communities as well as joint research projects with outstanding researchers overseas, particularly in policy for global deployment.

Overall Roadmap

Table 12-1 summarizes the roadmap for efforts for each of the seven technologies discussed in Chapter 5 through 11.

Table 12-1: Roadmap for the seven technologies

		5G		B5G/6G
Seven Technologies		**–2024**	**2025–2029**	**2030–**
Network	User centric network	Developing essential technologies	Standardization, PoC	Commercial deployment
	Optical transmission	Developing essential technologies, standardization	PoC, partial deployment	
	Open community	Input to the open communities Cloudification	Ecosystem formation, PoC	
Security	Communications infrastructure	PPM for city OS	Trustworthy distribution P/F	Security-enabled network
	Encryption	Post-quantum encryption	Advanced feature cryptographic	
	Detection and protection	AI-based cybersecurity	Security to protect AI models	
IoT	Maintenance-free	Automated configuration management	Automated fault detection	Automated fault recovery
	Sensor	Modular API	Energy harvesting	Reduced burden on the environment
Platform		OSes for specific cities	General purpose OSes for cities	
AI	Physical orientation	Reusable/multimodal AI	Collaborative/self-improving AI	Co-evolutionary (with people) AI
	Behavior change	Human psychology/persuasive AI	(Continuous) persuasive AI	

XR	Transmission	PCC	Beyond PCC/VCC	Ultra-low-latency 3D space data transmission
	Expressive	Holography	Unassisted holography	Large-scale holography
Robotics	RaaS	Technologies for cooperation between different robots	Cooperative actions with people	Versatility
	HRI	Recognition of each human value	Value-based feedback	

Activities in Global Standardization and Open Communities

KDDI intends to advance the R&D of the seven technologies described in the preceding chapters according to the roadmap above, hence standardization efforts of the seven technologies are essential toward commercial services and deployments. In addition, activities in the open communities have become important initiatives in recent years. Since these discussions are often conducted on a global scale, we feel that these will be important to global deployment.

As to the future of these standardization activities with an eye to the B5G/6G era, it is important to achieve inter- and intra- coordination and collaboration between the three layers described in KDDI Accelerate 5.0 concept, i.e. network, platform and business layers. In other words, the coordination and collaboration between networks as well as platforms is being crucial.

Standardization of northbound/southbound APIs, which facilitate coordination between layers, will create a foundation to implement XaaS using a platform integrated with networks, and drive a new era of business. At the same time, in addition to the cooperation between networks that have already been discussed by various standardization bodies—that is, the standardization of interconnection—the standardization of eastbound/westbound APIs enabling cooperation between platforms will promote both competition and cooperation between players.

KDDI will achieve organic linkage both between and within layers, accelerating collaboration and mergers between businesses, and leading to the creation of new value.

While some of the above overlaps with the discussion in earlier chapters, let us touch on them again:

- The technologies on the user centric architecture set out in Section 5.4.1 will be studied with the aim of reflecting them in technical standards to be specified from 2025 onwards such as 3GPP.

- Each of the technologies set out in Section 5.4.2, such as MCF transmission and RoF, will be studied to reflect them in ITU-T technical specifications.
- End-to-end network slicing is one of 5G's key enablers, and indispensable technologies for telecom operators to meet the demands of diverse use cases and to provide network services optimized to those use cases in the B5G/6G era. While the application of virtualization technology is a prerequisite for constructing and operating network slices, the use of operation automation platforms and inter-domain collaboration is essential for the mobile operators to operate multiple logical networks concurrently to satisfy complex and fragmented requirements. As described in Section 5.4.4, ONAP is one of the promising upcoming platforms, and implementations based on the specifications provided by various standardization bodies and communities such as 3GPP, IETF (Internet Engineering Task Force), O-RAN ALLIANCE, and TM Forum are underway. Going forward, the leverage of open communities such as ONAP will be important when considering end-to-end service provision that goes beyond operations management platforms to include collaboration with IoT application marketplaces and edge application management platforms.
- Conventional communication networks often consist of proprietary software and hardware, but it is important to be able to construct these more flexibly in the future. The need for edge computing is expected to be particularly pronounced, since its applications are expected to expand, particularly from wide areas to near-local areas. In these efforts, it is necessary to respond to various needs both flexibly and quickly; it is therefore important to enable the edge computing platform to be applied to various applications through discussions with various global partners to form an ecosystem. Thus, to facilitate these efforts, we prioritize to standardization activities in the bodies such as 3GPP, ETSI MEC etc., as well as open communities such as OCP (the Open Compute Project) and TIP. In particular, for TIP, we will utilize the TIP Community Lab, established by KDDI, to facilitate the disaggregated software and hardware solutions (see Section 5.4.5).
- Security measures for next-generation communication systems, and ensuring the security of software and hardware used in infrastructure, as well as new business fields and functions, are vital initiatives to standardize security for communications system in the B5G/6G era [12-1] As part of infrastructure-facing security measures, KDDI is leading standardization activities for Privacy Policy Management technology

(PPM), as discussed in Section 6.4.1, in oneM2M, ITU-T, and ISO/IEC, to contribute to promote security and privacy by design. We are also investigating the standardization of cryptographic technology for the quantum computer era, as described in Section 6.4.3, as part of our effort to ensure superiority in new business fields and functions. In other fields, we plan to deploy the results of our R&D globally by standardization.

- KDDI has been working on the standardization of transmission technologies for XR content, and will continue to do so going forward. In particular, the 2D video encoding technology (VVC, H.266) being studied by the JVET (Joint Video Experts Team, a joint team consisting of ISO/IEC JTC1/SC29 and ITU-T SG16 WP3), described in Section 10.3, and PCC being developed by ISO/IEC JTC1/SC29 WG7, described in Section 10.4.3, will be studied and deployed globally as technical standards supporting the high capacity, low latency, and scalability expected from B5G/6G from the application layer.

Joint Research Projects with Outstanding Researchers Overseas

To implement KDDI Accelerate 5.0, as of October 2020, KDDI has begun joint research with researchers overseas with proven track records in various fields of research [12-2]. KDDI will steadily expand this initiative going forward. In each project, several researchers from the Advanced Technology Laboratory of KDDI Research Inc. and various universities engage and collaborate to achieve state-of-art research results. To this end, KDDI intends to make our advanced technology research activities further global and strengthen the system of R&D by developing the human resources and inviting/recruiting researchers through participation in world-class communities and exchange and collaboration with researchers.

13. Conclusion

This white paper has introduced KDDI's concept for B5G/6G, which is expected to become commercially available around 2030, and for the technologies involving B5G/6G.

In terms of lifestyle changes, we summarized new lifestyles from nine perspectives. We described the various technologies that will be required to realize these new lifestyles. We will continue to study new lifestyles with external partners.

Next, as a concept for B5G/6G, we introduced the Society 5.0 concept, presented by the Japan Cabinet office, and the Beyond 5G Promotion Strategy, by the Ministry of Internal Affairs and Communications, and gave an overview of KDDI Accelerate 5.0, which KDDI announced in August 2020.

We cite "life delivery" as an example of a use case based on the new lifestyles, and discuss how the component technologies in the seven technologies set out in KDDI Accelerate 5.0 can contribute to achieving that use case. We further introduced the roles and objectives of each of the seven respective technologies in B5G/6G, their situation globally, as well as the technologies that will be needed heading into 2030.

As you can see from the "life delivery" example, it will be necessary for these seven technologies to work together to realize Society 5.0. A cooperative operation is referred to as "orchestration" in this white paper, and will be key to realizing Society 5.0. Thus, orchestration will be studied in parallel to the R&D of the seven technologies.

In this white paper, we have summarized KDDI's concept for B5G/6G, lifestyles around the year 2030, and the component technologies they will require. However, we do not believe the contents set out here will satisfy the necessary and sufficient conditions for B5G/6G. We would therefore be grateful for any opinions, suggestions, or comments received from the readers of this white paper. We at KDDI are determined to contribute to the prompt realization of Society 5.0 by eliciting opinions from outside the company, and by actively incorporating the thoughts, ideas, and technologies of our partners. With the help of our partners, we shall continue our studies, R&D, and in turn revise this white paper.

References

Chapter 1

[1-1] Ministry of Economy, Trade and Industry, Japan: "Guidelines for Promotion of Digital Transformations (DX Promotion Guidelines) Ver. 1.0," https://www.meti.go.jp/english/press/2018/1212_003.html, December 12, 2018.

[1-2] "KDDI Accelerate 5.0," KDDI Research, Inc., http://www.kddi-research.jp/kddi_accelerate5_0/ (in Japanese).

Chapter 2

[2-1] "KDDI and KDDI Research Inc. open the research base 'KDDI research atelier' to offer new lifestyles taking 2030 into account on Dec. 17, 2020, - Promoting 'KDDI Accelerate 5.0' with their domestic and foreign partners -", KDDI Corp./KDDI Research Inc., https://www.kddi-research.jp/newsrelease/2020/121701.html, Dec. 17, 2020 (in Japanese).

[2-2] The United Nations: "Sustainable Development Goals," https://www.un.org/sustainabledevelopment/ .

Chapter 3

[3-1] Japan Cabinet: "Society 5.0," https://www8.cao.go.jp/cstp/english/society5_0/index.html .

[3-2] Japan Cabinet: "the 6th Science, Technology and Innovation Basic Plan," https://www8.cao.go.jp/cstp/kihonkeikaku/index6.html (in Japanese).

[3-3] Ministry of Internal Affairs and Communications, Japan: "Beyond 5G Promotion Roadmap -Roadmap to 6G-, "https://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/presentation/pdf/Beyond_5G_Promotion_Strategy-Roadmap_towards_6G-.pdf, Jul. 30, 2020.

[3-4] Ministry of Internal Affairs and Communications, Japan: "Recommendations from the Beyond 5G Promotion Strategy Roundtable," https://www.soumu.go.jp/main_content/000696612.pdf , Jun. 30, 2020 (in Japanese).

[3-5] Ministry of Internal Affairs and Communications, Japan: "Establishment of Beyond 5G Promotion Consortium, and Holding of General Meeting, and Establishment of Beyond 5G New Management Strategy Center," https://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/pressrelease/2020/12/11_02.html, December 11, 2020.

[3-6] "KDDI Accelerate 5.0," KDDI Research, Inc., http://www.kddi-research.jp/kddi_accelerate5_0/ (in Japanese) (redisplaying).

[3-7] For example, "JR East and KDDI sign basic agreement for aiming joint commercialization to develop new decentralized city planning centered on Shinagawa Development Project",KDDI etc., https://news.kddi.com/kddi/corporate/newsrelease/2020/12/15/4865.html, Dec. 15, 2020 (in Japanese).

Chapter 4

[4-1] M. Nakazato, "Efforts to realize 5G in 2020," https://www.soumu.go.jp/main_content/000593247.pdf, Dec. 18, 2018 (in Japanese).

Chapter 5

[5-1] R. Li (Chairman of ITU-T SG15 FG-NET2030), "Towards a New Internet for the Year 2030 and Beyond," Third Annual ITU IMT-2020/5G Workshop and Demo day, Jul 2018.

[5-2] Ministry of Internal Affairs and Communications, Japan: Release of "Beyond 5G Promotion Strategy -Roadmap towards 6G-," https://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/pressrelease/2020/6/30_7.html, Jun. 30, 2020.

[5-3] ITU-T Focus Group on Technologies for Network 2030, https://www.itu.int/en/ITU-T/focusgroups/net2030/Pages/default.aspx

[5-4] ITU-T FG-NET-2030, "Network 2030 A Blueprint of Technology, Applications and Market Drivers Towards the Year 2030 and Beyond", https://www.itu.int/en/ITU-T/focusgroups/net2030/Documents/White_Paper.pdf

[5-5] ITU Focus Group on Autonomous Networks (FG-AN), https://www.tmforum.org/resources/standard/autonomous-networks-empowering-digital-transformation-telecoms-industry/#

[5-6] Japan Cabinet, “Society 5.0”, https://www8.cao.go.jp/cstp/english/society5_0/index.html
[5-7] Ministry of Internal Affairs and Communications, Japan: “Beyond 5G Promotion Roadmap - Roadmap to 6G-, ”https://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/presentation/pdf/Beyond_5G_Promotion_Strategy-Roadmap_towards_6G-.pdf, Jul. 30, 2020 (redisplaying).
[5-8] “Innovative photonic devices for Peta bit/s-class optical fiber transmission,” O plus E, vol.41, No.5, Sep. 2019 (in Japanese).
[5-9] Technical Committee on Extremely Advanced Optical Transmission Technologies (EXAT), https://www.ieice.org/~exat/?en/TopPage
[5-10] "Success of ultra-high capacity optical fiber transmission breaking the world record by a factor of five and reaching a 10 Petabits per Second -Transmission Rates of Ten Quadrillion, Contributing to the Technology that Supports Post-5G Mobile Communications-," KDDI Research, Inc., https://www.kddi-research.jp/english/newsrelease/2017/092201.html, Sep. 22, 2017.
[5-11] "TR-1077-Technical Report of Space Division Multiplexing (SDM) technologies ", Telecommunication Technology Committee (TTC), https://www.ttc.or.jp/document_db/information/view_express_entity/1238 (in Japanese).
[5-12] National Institute of Information and Communication Technology (NICT): “R&D on innovative optical fiber and communication technologies toward standardization (i-FAST),” https://www.nict.go.jp/collabo/commission/k_20301.html (in Japanese).
[5-13] “World’s first demonstration of transoceanic multi-core fiber transmission,” KDDI R&D Laboratories Inc., https://www.kddi-research.jp/newsrelease/2012/092001.html, Sep. 20, 2012 (in Japanese).
[5-14] “Success of largest transmission capacity on transoceanic multi-core fiber transmission experiments -World-record capacity-distance product of 1 Exa (bit/s x km) -,” KDDI R&D Laboratories, Inc., https://www.kddi-research.jp/newsrelease/2013/092501.html, Sep. 25, 2013 (in Japanese).
[5-15] "KDDI R&D Laboratories Achieves Ultra-High-Speed Data Transmission of 2 Pbps over Optical Fiber Approximately Double the World’s Previous Maximum Data Transmission Capacity," KDDI R&D Laboratories, Inc., https://www.kddi-research.jp/english/newsrelease/2015/100101.html, Oct. 1, 2015.
[5-16] “3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; System architecture for the 5G System (5GS); Stage 2 (Release 16),” 3GPP TS23.501, v16.7.0 (2020-12).
[5-17] “3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Procedures for the 5G System (5GS); Stage 2 (Release 16),” 3GPP TS23.502, v16.7.0 (2020-12).
[5-18] “3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Policy and charging control framework for the 5G System (5GS); Stage 2 (Release 16),” 3GPP TS23.503, v16.7.0 (2020-12).
[5-19] A. G. Forte, W. Wang, L. Veltri and G. Ferrari, “A Next-Generation Core Network Architecture for Mobile Networks,” Future Internet, Vol. 11, No. 7, Jul 2019.
[5-20] R. J. Cho and Z. J. Van., “A Scalable, Programmable and Evolvable Mobile Core Control Plane Platform,”. Proc. MobiCom, Oct. 2018.
[5-21] A. Mohammadkhan, KK Ramakrishnan, and V. A. Jain, “CleanG - Improving the Architecture and Protocols for Future Cellular Networks With NFV,” IEEE/ACM Trans. on Networking, Vol.: 28, Issue: 6, Dec. 2020.
[5-22] M. Ahmad, S. U. Jafri, A. Ikram, W. N-A Qasmi, M. A. Nawazish, Z. A. Uzmi, Z. A. Qazi, “A Low Latency and Consistent Cellular Control Plane,” Proc. SIGCOMM 2020, Aug. 2020.
[5-23] H.Q. Ngo, A. Ashikhmin, H. Yang, E.G. Larsson, and T.L. Marzetta, “Cell-free massive MIMO versus small cells,” IEEE Trans. Wireless Commun., vol.16, no.3, pp.1834–1850, March 2017.
[5-24] E. Björnson and L. Sanguinetti, “Making cell-free massive MIMO competitive with MMSE processing and centralized implementation,” IEEE Trans. Wireless Commun., vol.19, no.1, pp.77–90, Jan. 2020.
[5-25] T. Choi et al., “Co-located vs distributed vs semi-distributed MIMO: measurement-based evaluation,” Proc. of Asilomar Conf. Signals Syst. Comput., Nov. 2020.
[5-26] M. Ito et al., “On Spectral and Energy Efficiency of Semi-Distributed Cell-Free massive MIMO,” 2021 IEICE general conference, B-5-19, 2021.
[5-27] “World first successful demonstration of wireless network deployment methodology for Beyond 5G, KDDI Research Inc., https://www.kddi-research.jp/english/newsrelease/2021/100701.html, Oct 7, 2021.
[5-28] T. Murakami et al., “Research Project to Realize Various High-reliability Communications in Advanced 5G Network,” 2020 IEEE Wireless Communications and Networking Conference (WCNC), 2020, pp. 1-8.
[5-29] Naoki AIHARA, Akio IKAMI, Takahide MURAKAMI, Yu TSUKAMOTO, Hiroyuki SHINBO, ‶A

User-Centric RAN Architecture using Cell Free massive-MIMO for 6G System, " 2021 IEICE Society conference BS-3-9, Sep. 2021. (In Japanese).
[5-30] "World's First Successful Development of Dual-band Light-visible Metasurface Reflector in 28 and 39 bands in 5G era" KDDI Research Inc., https://www.kddi-research.jp/newsrelease/2021/012001.html, Jan. 20, 2021 (in Japanese).
[5-31] Q. Wu, S. Zhang, B. Zheng, C. You and R. Zhang, "Intelligent Reflecting Surface Aided Wireless Communications: A Tutorial," IEEE Trans. on Communications, doi: 10.1109/TCOMM.2021.3051897.
[5-32] "Development of the world's first direction-variable liquid crystal meta-surface reflector", KDDI Research Inc. and Japan Display Inc., https://www.kddi-research.jp/english/newsrelease/2021/100702.html, Oct 7, 2021.
[5-33] T. Kawanishi, K. Inaga, A. Kanno, N. Yamamoto, T. Aiba, H. Yasuda, T. Wakabayashi, "Terahertz and Photonics Seamless Short-Distance Links for Future Mobile Networks," Earth and Space Science Open Archive, doi: 10.1002/essoar.10503612.1.
[5-34] KDDI's SDGs: https://www.kddi.com/english/corporate/csr/sdgs/
[5-35] "Realization of multicore fiber with low crosstalk and ultralow attenuation loss - Demonstration of ultralong-distance transmission with current submarine cable size -," KDDI Research, Inc., https://www.kddi-research.jp/english/newsrelease/2020/113001.html, Nov. 30, 2020.
[5-36] Shohei Beppu, et al., "Real-Time Strongly-Coupled 4-Core Fiber Transmission," Proc. Optical Fiber Communication (OFC) 2020, Th3H.2, San Diego, CA, USA, March 2020.
[5-37] "World's first successful 7,200-km coupled multicore fiber transmission experiment by real-time MIMO signal processing method," KDDI Research, https://www.kddi-research.jp/english/newsrelease/2021/062401.html, June 24, 2021.
[5-38] Yuta Wakayama, et al., "Pure-Silica Single-Core to Multi-Core Fiber Coupler with Side-Polishing Approach," Proc. Opto-Electronics and Communications Conference (OECC) 2020, T3-3, Taipei, Taiwan, Oct. 2020.
[5-39] NICT "Beyond 5G R&D Promotion Project: Research and Development of Space-Division Multiplexed Optical Network Node Technologies to Support Beyond 5G Ultra-high Capacity Wireless Communications (002)," https://www.nict.go.jp/info/topics/2021/07/05-1.html
[5-40] "A New Record of 2048-QAM Transmission over Optical Fiber with COTS Devices," KDDI Research, https://www.kddi-research.jp/english/topics/2021/062901.html, June 29, 2021.
[5-41] Ministry of Economy, Trade and Industry (METI) "Post 5G Information and Communication System Infrastructure Enhancement R&D Project, Research Item 3) Cutting-edge Research (b) Transmission line technology "High-capacity optical transmission system technology for metro and long-haul network", https://www.meti.go.jp/press/2020/10/20201027001/20201027001.html
[5-42] CPRI Specification V7.0 (2015-10-09), http://www.cpri.info/downloads/CPRI_v_7_0_2015-10-09.pdf
[5-43] eCPRI Specification V2.0 (2019-05-10), http://www.cpri.info/downloads/eCPRI_v_2.0_2019_05_10c.pdf
[5-44] 3GPP TR 38.801 V14.0.0 (2017-03), https://www.3gpp.org/ftp//Specs/archive/38_series/38.801/38801-e00.zip
[5-45] "Success of optical fiber transmission breaking the world record for mobile wireless signal capacity -Contribution to the rapid deployment of infrastructure for 5G and beyond mobile communication-," KDDI Research Inc., https://www.kddi-research.jp/english/newsrelease/2017/101901.html, Oct. 19, 2017.
[5-46] "World's First Demonstration of Radio over Fiber Technology for Mobile Networks with Large Capacity Transmission and Superior Installability – Effectively covers indoor dead spot and enables transition to Beyond 5G/6G –," KDDI Research Inc., https://www.kddi-research.jp/english/newsrelease/2020/120701.html, Dec. 7, 2020.
[5-47] "New transmission method for nine-fold improvement of signal-to-noise ratio at an optical fiber," KDDI Research, https://www.kddi-research.jp/newsrelease/2021/072601.html, July 26, 2021.
[5-48] NICT "Beyond 5G R&D Promotion Project: Research and Development of Radio and Optical Converged Wireless Communication Systems for Beyond 5G Ultra-high Capacity Wireless Networks (005)," https://www.nict.go.jp/info/topics/2021/07/05-1.html
[5-49] F. Ferrari, M. Zimmerling, L. Thiele, O. Saukh, "Efficient network flooding and time synchronization with Glossy," Proc. 10th ACM/IEEE International Conference on Information Processing in Sensor Networks, Chicago, IL, USA, 2011, pp. 73-84.
[5-50] J. Lewis and M. Fowler, "Microservices," http://martinfowler.com/articles/microservices.html, 2014.
[5-51] "KDDI, NEC, and NICT announced research and development activities for advanced virtualized network infrastructure technology towards the 5G and Beyond-5G era", KDDI, https://news.kddi.com/kddi/corporate/newsrelease/2021/09/07/5379.html, 2021 年 9 月 7 日.
[5-52] John L. Hennessy and David Andrew Patterson, "A new golden age for computer

architecture," Vol. 62, No. 2, Communications of the ACM, Jan. 2019.
[5-53] "KDDI and Tokyo University adopted by NEDO, to research power-saving and AI-driven operational technologies for communications infrastructure in the post-5G era.", KDDI, https://news.kddi.com/kddi/corporate/newsrelease/2020/12/04/4848.html, 2020 年 12 月 4 日.
[5-54] KDDI、"KDDI selects SpaceX's Starlink for cellular backhaul," KDDI Press Release, https://news.kddi.com/kddi/corporate/english/newsrelease/2021/09/13/5400.html, Sep. 2021.
[5-55] NASA, "What is Artemis?", https://www.nasa.gov/specials/artemis/
[5-56] D. J. Israel et al., "LunaNet: a Flexible and Extensible Lunar Exploration Communications and Navigation Infrastructure," 2020 IEEE Aerospace Conference, 2020, pp. 1-14, doi: 10.1109/AERO47225.2020.9172509.
[5-57] NOKIA, "Nokia aims for the Moon with LTE/4G," https://www.nokia.com/about-us/newsroom/articles/nokia-aims-for-the-moon-with-lte4g/, Nov. 2020.
[5-58] Space ICT Promotion Initiative Forum, https://spif.nict.go.jp/
[5-59] Cabinet Office in Japan, "About selection of strategy project in the strategy program of accelerating space development and usage," Committee on National Space policy Sub-Committee on Satellite development and evaluation 8th meeting Document 1, https://www8.cao.go.jp/space/comittee/02-jissyou/jissyou-dai8/siryou1.pdf, Jul. 2021. (In Japanese).
[5-60] T. Nagao and T. Hayashi, "A Study on Urban Structure Map Extraction for Radio Propagation Prediction using XGBoost", 2021 15th European Conference on Antennas and Propagation (EuCAP), 2021.
[5-61] Masayuki Nakano, Hiroaki Honma, Yoji Kishi, Toshiki Tanaka, Toshiro Shimizu, "Efforts of Antennas and Propagation in au×HAKUTO MOON CHALLENGE Project," IEICE technical report, vol. 117, no. 436, AP2017-190, pp. 77-80, Feb. 2018. (In Japanese).

Chapter 6

[6-1] 6G Flagship, "Key Drivers and Research Challenges for 6G Ubiquitous Wireless Intelligence," University of Oulu, http://jultika.oulu.fi/files/isbn9789526223544.pdf Sept. 2019.
[6-2] P.W. Shor, "Algorithms for quantum computation: Discrete log and factoring," Proc. 35th Annual IEEE Symp. on Foundations of Computer Science, pp.124-134, Santa Fe, NM, USA, Nov. 1990.
[6-3] Security Aspects of Network Capabilities Exposure in 5G, NGMN: next generation mobile networks, 2018.
[6-4] Deloitte, Smarter Cyber, How AI can help manage cyber risk, https://www2.deloitte.com/content/dam/Deloitte/ca/Documents/risk/ca-en-smart-cyber-pov-aoda.pdf
[6-5] National Institute of Standards and Technology, "Post-Quantum Cryptography Standardization," https://csrc.nist.gov/projects/post-quantum-cryptography/post-quantum-cryptography-standardization, 2016.
[6-6] ITU-T, X.1363: Technical framework of personally identifiable information handling in Internet of things environment, 2020.
[6-7] WarpDrive Project, https://warpdrive-project.jp/
[6-8] N. Aragon, J. Lavauzelle, and M. Lequesne,"decodingchallenge.org: Syndrome Decoding in the Goppa-McEliece Setting," Inria, https://decodingchallenge.org/goppa, 2019.

Chapter 7

[7-1] Ministry of Internal Affairs and Communication, Japan: "2020 White Paper on Information and Communications in Japan," https://www.soumu.go.jp/johotsusintokei/whitepaper/eng/WP2020/2020-index.html
[7-2] "IoT Case Study," KDDI, https://iot.kddi.com/cases (in Japanese).
[7-3] Report Ocean, "Global Automotive IoT Market 2020-2027 by Offering, Communication Type (In Vehicle, V2V, V2I), Connecting Form (Embedded, Tethered, Integrated), Application, Distribution (OEM, Aftermarket), and Region: Trend Outlook and Growth Opportunity".
[7-4] Liu, R., Wang, J., and Zhang, B., "High Definition Map for Automated Driving: Overview and Analysis," Journal of Navigation, vol.73, no.2, Aug. 2019.
[7-5] Y. Li and J. Ibanez-Guzman, "Lidar for Autonomous Driving: The Principles, Challenges, and Trends for Automotive Lidar and Perception Systems," IEEE Signal Processing Magazine, vol.37, no.4, July 2020.
[7-6] AECC, https://aecc.org/
[7-7] 5GAA, https://5gaa.org/
[7-8] "3GPP, TR21.905 Vocabulary for 3GPP Specifications V15.0.0,", Dec. 2018.

[7-9] Miyasaka, T., Hei, Y., and Kitahara, T., "NetworkAPI: An In-band Signalling Application-aware Traffic Engineering using SRv6 and IP anycast," ACM NAI'20, Aug. 2020.
[7-10] M. Suzuki et al., "Enhanced DNS Support towards Distributed MEC Environment," ETSI ISG MEC Whitepaper, Sep. 2020.
[7-11] Y. Morisawa, M. Suzuki and T. Kitahara, "Resource Efficient Stream Processing Platform with Latency-Aware Scheduling Algorithms," USENIX HotCloud'20, Jul. 2020.
[7-12] Y. Morisawa, M. Suzuki and T. Kitahara, "Flexible Executor Allocation without Latency Increase for Stream Processing in Apache Spark," IEEE Workshop on Real-time & Stream Analytics in Big Data, Dec. 2020.

Chapter 8

[8-1] “Smart Nation Singapore”, https://www.smartnation.gov.sg/
[8-2] “Smart Dubai 2021”, https://2021.smartdubai.ae/
[8-3] Japan Cabinet: National Strategic Special Zones, https://www.chisou.go.jp/tiiki/kokusentoc/english/index.html
[8-4] “Launch of Demonstration Experiment of Service Route and Ridesharing Management System for Self-driving Vehicles - First automatic setting of multiple reservations in Japan for solving the problem of transportation in the Kozoji New Town-”, KDDI,https://www.kddi.com/corporate/csr/regional-initiative/pressrelease/20210618/, Jun 18, 2021.
[8-5] M. W. Johnson, et al.,“Quantum annealing with manufactured spins,” Nature, vol. 473, no. 7346, pp. 194–198, 2011.
[8-6] T. Okuyama, T. Sonobe, K. Kawarabayashi, and M. Yamaoka, “Binary optimization by momentum annealing,” Phys. Rev. E 100, 012111, 2019.
[8-7] Tsukamoto, S., Takatsu, M., Matsubara, S. and Tamura, H.: An accelerator architecture for combinatorial optimization problems, Fujitsu Scientific and Technical J., Vol.53, No.5, pp.8–13, 2017.
[8-8] IBM Quantum, https://quantum-computing.ibm.com/
[8-9] Amazon Braket, https://aws.amazon.com/jp/braket/
[8-10] “Quantum Computer Science for All – Towards novel quantum applications”, https://www.jst.go.jp/crds/pdf/2018/SP/CRDS-FY2018-SP-04.pdf (in Japanese)
[8-11] J. Preskill, “Quantum computing in the NISQ era and beyond,” Quantum J., vol. 2, p. 79, 2018.
[8-12] M. Grassl, B. Langenberg, M. Roetteler, and R. Steinwandt, “Applying Grover’s algorithm to AES: Quantum resource estimates,” Lecture Notes in Computer Science, vol. 9606, pp. 29–43, 2016.
[8-13] “IBM plans a huge leap in superfast quantum computing by 2023”, https://fortune.com/2020/09/15/ibm-quantum-computer-1-million-qubits-by-2030/, Sept. 15, 2020.
[8-14] “World’s First Development of New Dynamic Spectrum Allocation Method to Effectively Utilize Radio Resources and Successful Demonstration of Application of Quantum Computing Technology,” KDDI Research, Inc., https://www.kddi-research.jp/newsrelease/2021/031701.html, Mar. 17, 2021 (in Japanese).
[8-15] K. Saito, A. Ikami, C. Ono, “An Evaluation of Dynamic Spectrum Allocation using Ising Machine,” IPSJ SIG Technical Report, 2021-QS-2, no. 4, pp. 1–8, 2021 (in Japanese).
[8-16] K. Saito, A. Ikami, C. Ono, “Evaluating dynamic spectrum allocation using quantum annealing,” IEICE ComEX, vol. 10, no. 9, pp. 726–732, 2021.
[8-17] “Report on the Results of the Mobile Computing Promotion Consortium’s Project ”Demonstration Experiment for Industrial Application of Quantum Computers”,” KDDI Research, Inc., https://www.kddi-research.jp/topics/2020/060501.html, June 5, 2020 (in Japanese).
[8-18] K. Satio, M. Tanaka, H. Okamoto, “Parameter optimization of LTE Using Annealing Machine,” MCPC technical book “Expanding Quantum Computing, Its Potential for Social Implementation”, pp. 34-37, 2020 (in Japanese).
[8-19] K. Saito, S. Oyama, T. Umeki, M. Kurokawa, C. Ono, “Evaluation of Quantum Annealing for Vehicle Routing Problem,” IPSJ Transactions of Databases, vol. 14, no. 1, pp. 8–17, 2021 (In Japanese).

Chapter 9

[9-1] ”Future direction of AI fundamental technologies in Japan,” Intelligence Research Strategy Department, National Institute of Advanced Industrial Science and Technology (AIST), May 2018 (in Japanese).
[9-2] Integrated Innovation Strategy Promotion Council Decision, “AI Strategy 2019,” https://www.kantei.go.jp/jp/singi/ai_senryaku/pdf/aistratagy2019en.pdf, Jun. 2019.
[9-3] Workshop on Continual Learning at ICML 2020, https://icml.cc/virtual/2020/workshop/5743

[9-4] IJCAI 2021 Session on Transfer, Adaptation, Multi-task Learning, https://static.ijcai.org/ijcai-pricai-2020-schedule/technical_sessions/#machine-learning-transfer-adaptation-multi-task-learning
[9-5] Hovland, C. L., Janis, I. L., and Kelley, H. H., "Communication and persuasion: Psychological studies of opinion change," Yale University Press, 1953.
[9-6] Fogg, B. J., "Persuasive computers: perspectives and research directions," Proc. CHI 1998, ACM Press, 225-232, 1998.
[9-7] Oinas-Kukkonen H. & Harjumaa M., "Persuasive Systems Design: Key Issues, Process Model, and System Features," Commun. Association for Information, Systems, Vol. 24, Article 28, pp. 485-500, March 2009.
[9-8] Paraschivoiu I., Meschtscherjakov A., Gärtner M., Sypniewski J., "Persuading the Driver: A Framework for Persuasive Interface Design in the Automotive Domain," In 14th International Conference on Persuasive Technology (PERSUASIVE 2019), pp. 128-140, Springer, Cham, 2019.
[9-9] AAAI 2021 workshop AI for Behavior Change, https://ai4bc.github.io/ai4bc21/
[9-10] Persuasive 2021, https://persuasive2021.bournemouth.ac.uk/
[9-11] “Forecasting Population Flow for New Visibility: KDDI has Developed Demographic Movement Analysis/Forecasting Technology,” KDDI Research Inc., https://www.kddi-research.jp/newsrelease/2018/042401.html, Apr. 24, 2018.
[9-12] "Launch of Joint Research Projects with Outstanding Researchers Overseas -Toward realizing KDDI Accelerate 5.0, our concept of the future society-," KDDI Research Inc., https://www.kddi-research.jp/english/newsrelease/2020/102601.html, Oct. 26, 2020.
[9-13] K. He, X. Zhang, S. Ren, and J. Sun, Deep residual learning for image recognition, In Proceedings of the IEEE conference on computer vision and pattern recognition, pp.770-778, 2016.
[9-14] J. Devlin, M. W. Chang, K. Lee, and K. Toutanova, Bert: Pre-training of deep bidirectional transformers for language understanding, arXiv preprint arXiv:1810.04805.
[9-15] M. Yamada, T. Suzuki, T. Kanamori, H. Hachiya, and M. Sugiyama, Relative density-ratio estimation for robust distribution comparison. Neural computation, 25(5), pp.1324-1370, 2013.
[9-16] Y. Ganin, E. Ustinova, H. Ajakan, P. Germain, H. Larochelle, F. Laviolette, M. Marchand, and V. Lempitsky, Domain-adversarial training of neural networks, The journal of machine learning research, 17(1), pp. 2096-2030, 2016.
[9-17] O. Day, and T. M. Khoshgoftaar, A survey on heterogeneous transfer learning, Journal of Big Data, 4(1), 2017.
[9-18] M. Kurokawa and K. Yonekawa, "Introduction to Research on Heterogeneous Transfer Learning," Journal of IEICE, Mar. 2019.
[9-19] "[Artificial Intelligence] Development and Integration of Artificial Intelligence Technologies for Innovation Acceleration", JST CREST, https://www.jst.go.jp/kisoken/crest/en/project/1111094/1111094_2018.html
[9-20] K. Yonekawa, H. Niu, M. Kurokawa, A. Kobayashi, D. Amagata, T. Maekawa, and T. Hara, Advertiser-Assisted Behavioral Ad-Targeting via Denoised Distribution Induction, In 2019 IEEE International Conference on Big Data (Workshop on Big Data Transfer Learning), pp.5611-5619, 2019.
[9-21] H. Niu, K. Yonekawa, M. Kurokawa, C. Ono, D. Amagata, T. Maekawa, T. Hara, Exploiting Cross-Domain Sequence Data for Cross-Domain Recommendation, 12th Forum on Data Engineering and Information Management (DEIM 2020), 2020.
[9-22] T. Mikolov, K. Chen, G. Corrado, and J. Dean, Efficient estimation of word representations in vector space, arXiv preprint arXiv:1301.3781.
[9-23] “Accepted as an acceleration phase project by JST CREST, "Artificial Intelligence" area - Safe and easy-to-use "Persona Marketing AI" that connects different industrial fields”, KDDI Research, Inc., https://www.kddi-research.jp/newsrelease/2021/032202.html, Mar. 2021.
[9-24] T. Baltrušaitis, C. Ahuja, and L. Morency, “Multimodal machine learning: A survey and taxonomy,” IEEE Trans. Pattern Anal. Mach. Intell. 41, 2, 423-443, 2019.
[9-25] B. P. Yuhas, M. H. Goldstein, and T. J. Sejnowski, “Integration of Acoustic and Visual Speech Signals Using Neural Networks,” IEEE Communications Magazine, 1989.
[9-26] M. Soleymani, M. Pantic, and T. Pun, “Multimodal emotion recognition in response to videos,” TAC, 2012.
[9-27] G. Habault, Y. Nishimura, K. Yoshihara, and C. Ono, “Detecting errors in short-term electricity demand forecast using people dynamics,” IoTDA, 2019.
[9-28] G. Habault, S. Wada, R. Kimura, and C. Ono, “Elucidating the Extent by Which Population Staying Patterns Help Improve Electricity Load Demand Predictions,” IoTDA, 2020.
[9-29] Xin, Doris, Litian Ma, Jialin Liu, Stephen Macke, Shuchen Song and Aditya G. Parameswaran. “Accelerating Human-in-the-loop Machine Learning: Challenges and Opportunities.” ArXiv abs/1804.05892, 2018.

[9-30] Settles, Burr. "Active learning literature survey." University of Wisconsin, Madison 52.55-66, 2010.
[9-31] Ahmed Hussein, Mohamed Medhat Gaber, Eyad Elyan, Chrisina Jayne. “Imitation Learning: A Survey of Learning Methods.”, ACM Computing Surveys Article No.21. https://doi.org/10.1145/3054912 , Apr. 2017.
[9-32] Adadi, A., & Berrada, M. “Peeking inside the black-box: A survey on Explainable Artificial Intelligence (XAI)”, IEEE Access, 6, 52138-52160. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8466590, 2018.
[9-33] R. M. French, Catastrophic forgetting in connectionist networks, Trends in cognitive sciences, 3(4), pp.128-135, 1999.
[9-34] D. Lopez-Paz, and M. A. Ranzato, “Gradient episodic memory for continual learning”, Proc. 31st International Conf. Neural Information Processing Systems, pp. 6470-6479, 2017.
[9-35] J. Kirkpatrick, et al., Overcoming catastrophic forgetting in neural networks. Proceedings of the national academy of sciences, 114(13), pp.3521-3526, 2017.
[9-36] J. Serra, D. Suris, M. Miron, and A. Karatzoglou, Overcoming catastrophic forgetting with hard attention to the task, In International Conference on Machine Learning, pp. 4548-4557, 2018.
[9-37] Z. Chen and B. Liu, “Lifelong Machine Learning (second edition), Synthesis Lectures on Artificial Intelligence and Machine Learning,” Morgan & Claypool Publishers, 2018.
[9-38] Goldberg LR, “An Alternative Description of Personality”: The Big-Five Factor Structure. Journal of personality and social psychology 59(6):1216, 1990.
[9-39] Schwartz SH, “A proposal for measuring value orientations across nations”, Questionnaire Package of the European Social Survey 259(290):261, 2003.
[9-40] A. Kobayashi, Y. Ishikawa, S. Kuroyanagi and A. Minamikawa, "A Study on Psychological Trait Prediction from Web Access Patterns and Its Utility for Ad Targeting", IEICE Trans. Fundamentals, 104(2), 27-39, 2021.
[9-41] Y. Ishikawa, A. Kobayashi, A. Minamikawa, and C. Ono, “Predicting a Driver’s Personality from Daily Driving Behavior,” Proc International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design (pp. 203-209), June 2019.
[9-42] A. Kobayashi, Y. Ishikawa and A. Minamikawa “A Study on Effect of Big Five Personality Traits on Ad Targeting and Creative Design,” In International Conference on Persuasive Technology (pp. 257-269). Springer, Cham, Apr. 2019.
[9-43] Y. Ishikawa, A. Kobayashi and A. Minamikawa, “Predicting Advertising Appeal from Receiver's Psychological Traits and Ad Design Features”, In Adjunct Publication of the 27th Conference on User Modeling, Adaptation and Personalization (pp. 45-49), Jun. 2019.
[9-44] Y. Ishikawa, A. Kobayashi, and D. Kamisaka, “Modelling and predicting an individual’s perception of advertising appeal”, User Model User-Adapted Interaction, https://doi.org/10.1007/s11257-020-09287-z, 2021.
[9-45] Kobayashi, A., Ishikawa, Y., & Sebastian Legaspi, R. (2021, June). Psychographic Matching between a Call Center Agent and a Customer. In Proceedings of the 29th ACM Conference on User Modeling, Adaptation and Personalization (pp. 229-234).
[9-46] Rabinowitz, N., Perbet, F., Song, F., Zhang, C., Eslami, S. A., & Botvinick, M. (2018, July). Machine theory of mind. In International conference on machine learning (pp. 4218-4227). PMLR.
[9-47] Cuzzolin, F., Morelli, A., Cirstea, B., & Sahakian, B. J. (2020). Knowing me, knowing you: theory of mind in AI. Psychological medicine, 50(7), 1057-1061.
[9-48] Scassellati, B. (2002). Theory of mind for a humanoid robot. Autonomous Robots, 12(1), 13-24.
[9-49] Legaspi, R., Xu, W., Konishi, T., & Wada, S. (2021, April). Positing a Sense of Agency-Aware Persuasive AI: Its Theoretical and Computational Frameworks. In International Conference on Persuasive Technology (pp. 3-18). Springer, Cham.
[9-50] David, N. (2012). New frontiers in the neuroscience of the sense of agency. Frontiers in human neuroscience, 6, 161.
[9-51] Y. Kuriki, W Xu, M. Taya, N. Kobayashi and A. Minamikawa, “An explorative examination of Information Content to prevent Smartphone Zombie,” 2021 IEICE general conference, 2021 (in Japanese).
[9-52] W. Xu, Y. Kuriki, T. Sato, M. Taya and C. Ono, "Does Traffic Information Provided by Smartphones Increase Detour Behavior?" In 15th International Conference on Persuasive Technology (PERSUASIVE 2020), pp.45-57, Springer, Cham, 2020.
[9-53] M. Nagata, T. Konishi, M. Honjo, A. Yoneyama, M. Kurokawa and K. Mishima, “Promotion of walking activities in the workplace utilizing walking events,” Trans. Digital Practice, IPSJ, Vol.10, No.4, pp.803-815, 2019 (in Japanese).
[9-54] “AI R&D and Utilization Principles for KDDI Group, https://www.kddi.com/english/corporate/kddi/public/ai_principles/
[9-55] Amina Adadi and Mohammed Berrada. “Peeking inside the black-box: A survey on Explainable Artificial Intelligence (XAI)”. DOI:10.1109/ACCESS.2018.2870052.
[9-56] P. W. Koh and P. Liang, “Understanding black-box predictions via influence functions,” In

International Conference on Machine Learning, pp.1885-1894, 2017.
[9-57] "3rd Knowledge Graph Reasoning Challenge 2020 Entries", https://challenge.knowledge-graph.jp/results/results2020.html

Chapter 10

[10-1] T. Kameoka, K. Sase, S. Yoshimoto, T. Hachisu, S. Saga, Y. Kuroda, T. Yanai, S. Ishimaru, M. Kawaguchi, K. Kiyokawa, Y. Vibol and A. Shirai, "The Beginning of Online and VR Conferences," Journal of the Virtual Reality Society of Japan, 2020, Vol. 25, No. 2, p. 35-43, 2020 (in Japanese).
[10-2] Matt Zalaznick, "How about using a digital avatar on a virtual campus?," University Business, https://universitybusiness.com/digital-avatar-virtual-college-campus-virbela-edtech/, Aug. 6, 2020.
[10-3] "U.S. eXp's Virtual Office Sales Rise Sevenfold due to Corona Virus Pandemic", NIKKEI, https://www.nikkei.com/article/DGXMZO60130810Z00C20A6I00000/, Jun. 9, 2020 (in Japanese).
[10-4] "Virtual Shibuya, A Distribution Platform Authorized by Shibuya Ward, Opens on May 19", KDDI, https://news.kddi.com/kddi/corporate/newsrelease/2020/05/15/4437.html, May 15, 2020 (in Japanese).
[10-5] ""Shibuya Evolves with 'Entertainment x 5G'; KDDI, Shibuya City Tourism Association, and Shibuya Future Design Launch 'Shibuya Entertainment Tech Promotion Project'", KDDI etc., https://news.kddi.com/kddi/corporate/newsrelease/2019/08/28/3979.html, Aug. 28, 2019 (in Japanese).
[10-6] "NTT Develops Non-Rigid Object Recognition Technology with a Small Number of Database Images -Not Only Rigid 3D Objects but Non-Rigid Objects Such as Soft Packaging or Cloth Products can be Recognized with Low Preparation Cost-," NTT, https://group.ntt/en/newsrelease/2018/11/26/181126b.html, Nov. 26, 2018.
[10-7] T. Yoneyama, E. Murakami, Y. Oguro, H. Kubo, K. Yamaguchi, and Y.Sakamoto, "Holographic head-mounted display with correct accommodation and vergence stimuli, "Opt. Eng. 57(6), 061619, 2018.
[10-8] T. Horiuchi, "Sound Media Technology Reflecting the Viewer's Intention of Watching and Listening," Journal of IEICE, Vo1.104, No.1, pp.22-26, Jan. 2021.
[10-9] Cisco Visual Networking Index (VNI) Forecast for 2016 – 2021.
[10-10] Cisco Mobile VNI Forecast for 2017 to 2022.
[10-11] JVET-S2001, "Versatile Video Coding (Draft 10)".
[10-12] "World's First Successful Demonstration of 4K Live Transmission using Real-time Codec Compatible with the Latest Video Coding Format H.266|VVC", KDDI Research Inc., https://www.kddi-research.jp/newsrelease/2020/122301.html, Dec. 23, 2020 (in Japanese).
[10-13] "World's first 8K video live transmission experiment using real-time H.266|VVC codec", KDDI Research Inc., https://www.kddi-research.jp/english/newsrelease/2021/041901.html, Apr. 19, 2021.
[10-14] "Development of AR Streaming Technology for Photo-Realistic 3D Avatars -Realizes Transmission of Virtual Humans to Smartphones at One-Third the Existing Transmission Rate -", KDDI Research Inc., https://www.kddi-research.jp/newsrelease/2021/021801.html, Feb. 18, 2021 (in Japanese).
[10-15] "Creating New Experiences with 5G and XR, Launching the Creative Team 'au VISION STUDIO'," KDDI, https://news.kddi.com/kddi/corporate/newsrelease/2021/03/10/5006.html, Mar. 10, 2021 (in Japanese).
[10-16] "Launching an Initiative to Support DX in the Apparel Industry Utilizing 5G, and Virtual Humans", KDDI, https://news.kddi.com/kddi/corporate/topic/2021/09/10/5401.html, Sep. 10, 2021 (in Japanese).
[10-17] "We Can Share the Feeling of Cheers Even in an Online Environment. Development of 'Sync Glass' a Communication System That Uses Haptic Technology to Connect with People at a Distance", KDDI Research Inc., https://www.kddi-research.jp/newsrelease/2021/031501.html, Mar. 15, 2021 (in Japanese).
[10-18] MPEG-3DG: "MPEG Point Cloud Compression", http://www.mpeg-pcc.org/
[10-19] "KDDI Research realize the ultra-low latency video transmission of 50ms for a remotely operating robot – remote operation is possible without a gap between visual cognition and operation", KDDI Research Inc., https://www.kddi-research.jp/newsrelease/2020/070901.html, Jul. 9, 2020 (in Japanese).

Chapter 11

[11-1] Headquarters for Japan’s Economic Revitalization, Japan: “Summary of Japan’s Robot Strategy - It’s vision, strategy and action plan-”, https://www.kantei.go.jp/jp/singi/keizaisaisei/pdf/robot_point_150210EN.pdf, Feb. 10, 2015.

[11-2] “Environment change surrounding robots and future direction – Plan for Promoting Social Change Taking Advantage of Robots –", Council for Promoting Social Change Taking Advantage of Robots in Ministry of Economy, Trade and Industry, https://www.meti.go.jp/shingikai/mono_info_service/robot_shakaihenkaku/pdf/20190724_report_01.pdf, Jul. 24, 2019 (in Japanese).

[11-3] “LG Electronics' Promise of AI for an Even Better Life Delivered at CES 2019 Keynote”, LG electronics, https://www.lg.com/ca_en/about-lg/press-and-media/LG-Electronics-Promise-of-AI-for-an-Even-Better-Life-Delivered-at-CES-2019-Keynote, 2019.

[11-4] “TIS provides ‘Service robot integration business’ which realizes human task outsourcing and sharing by robots – resolving social issues such as labor shortage and work productivity by RoboticBase, a platform which comprehensively manages multiple robots”, TIS, https://www.tis.co.jp/news/2018/tis_news/20181016_1.html, Oct. 16, 2018 (in Japanese).

[11-5] J. Xu, et al., "Fast and Accurate Whole-Body Pose Estimation in the Wild and Its Applications," ITE Transactions on Media Technology and Applications, Volume 9, Issue 1, pp. 63-70, 2021.

[11-6] “KDDI Research develops Japan’s first USV which can be remotely controlled by a smartphone connecting to mobile network,” KDDI Research Inc., https://www.kddi-research.jp/newsrelease/2020/111901.html, Nov. 19, 2020 (in Japanese).

[11-7] “World’s first development of ‘aerial-and-underwater-assembled drone’”, KDDI Corporation, KDDI Research, Inc., Prodrone Co., Ltd., https://news.kddi.com/kddi/corporate/newsrelease/2021/06/10/5181.html, June 10, 2021 (in Japanese).

[11-8] “World’s first successful communication experiments with an undersea smartphone by the blue LED optical wireless communication technology,” KDDI Research Inc., https://www.kddi-research.jp/newsrelease/2019/100201.html, Oct. 2, 2019 (in Japanese).

[11-9] “KDDI Research realize the ultra-low latency video transmission of 50ms for a remotely operating robot – remote operation is possible without a gap between visual cognition and operation,” KDDI Research Inc., https://www.kddi-research.jp/newsrelease/2020/070901.html, Jul. 9, 2020 (in Japanese).

[11-10] “Japan’s first delivery of 5G pre-service by high definition video transmission and 4K real-time broadcast in the drone race,” KDDI and KDDI Research Inc., https://news.kddi.com/kddi/corporate/newsrelease/2019/10/15/4077.html, Oct. 15, 2019 (in Japanese) (redisplaying).

[11-11] “Robotics Hub”, Panasonic, https://tech.panasonic.com/jp/robot/about.html

[11-12] "Future Robotics Organization," Waseda University, https://www.waseda.jp/inst/fro/en/

[11-13] "’Robot Kobo (workshop)’ established for co-creating new services using robots – towards robot friendly society by harmonizing communication control and robot control –”, KDDI Research, Inc. https://www.kddi-research.jp/newsrelease/2021/090801.html,Sep. 8, 2021 (in Japanese).

Chapter 12

[12-1] M. Miyake, "Standardization of security in communication field", 6th Standardization Strategy WG, Subcommittee on Technology Strategy, Department of Information and Communications Technology, Information and Communications Council, Ministry of Internal Affairs and Communications, Japan, https://www.soumu.go.jp/main_content/000690766.pdf, Mar. 31, 2020 (in Japanese).

[12-2] "Launch of Joint Research Projects with Outstanding Researchers Overseas -Toward realizing KDDI Accelerate 5.0, our concept of the future society-,” KDDI Research Inc., https://www.kddi-research.jp/english/newsrelease/2020/102601.html, Oct 26, 2020 (redisplaying).

（Note） The above citations are as of the time when this white paper was published.

Revision history

Data	Ver.	Update
2021/03/24	1.0	First version released
2021/06/02	1.0.1	Correction of errors
2021/10/22	2.0	Contents are added or updated, e.g. Section 5.4.6: "Communications in space" and Section 8.4.5: "Quantum Computing" as well as several figures in Chapter 2.
2021/12/14	2.0.1	Correction of errors