NICT National Institute of Information and Communications Technology

# Beyond 5G / 6G White Paper

- English version 2.0 -

June 2022

# Beyond 5G/6G White Paper

(English version 2.0)

National Institute of Information and
Communications Technology (NICT)
June 2022

## Contents

# Release of the Second Edition

Since the publication of the first edition of the Beyond 5G/6G White Paper in March 2021, we have had many opportunities to answer questions and exchange opinions at Beyond 5G related events, exhibitions, lectures, international conferences, and so forth. In particular, the scenarios in Chapter 3 were of great interest to everyone. At the same time, it has become clear that it is necessary to deepen discussions on the social issues of architecture and Beyond 5G. Therefore, we decided to update the first edition of the White Paper based on the contents of internal and external discussions by NICT and activities over the past year.

This second edition focuses on the following points: Chapter 2 describes the characteristics of Beyond 5G as an open platform, and presents the concept of Beyond 5G architecture, which enables existing players in the mobile communications field to support Beyond 5G functions and enables new players to take an active role in expanding mobile communications services. Chapter 3 adds scenarios that delve into ethical, legal, and social issues (ELSI) as a starting point for discussions on the negative aspects brought about by Beyond 5G, in addition to the previous three scenarios. Chapter 4 adds elemental technologies and summarizes them in an easy-to-read manner. Chapter 5 explains the latest efforts on the Beyond 5G shared R&D testbed being developed by NICT. Chapter 6 reflects the latest information on standardization activities and Beyond 5G R&D promotion projects being conducted by NICT.

We hope that this white paper will provide an opportunity to further discuss these issues with you.

Beyond 5G R&D Promotion Unit, NICT
White Paper Editing Team

# Executive Summary

Beyond 5G/6G, the next-generation information and communications infrastructure, is essential to achieving SDGs and Society 5.0. In this case, since the functions required for Beyond 5G/6G cover a wide range from physical space to cyberspace, the creation of new services can be expected by combining each function with the right person in the right place. From this point of view, it is important for Beyond 5G/6G to have the characteristics of an open platform as a receiver of various function groups, and to secure a mechanism capable of sustainable growth as a social infrastructure. Accordingly, it is necessary to design the functional architecture of Beyond 5G/6G (Fig. A).

In physical space, a flexible and extensible communication environment can be provided by combining not only conventional terrestrial mobile networks but also satellite networks and multicore optical networks. In cyberspace, various spaces coexist depending on the application, and information processing such as accumulated past data and future predictions is performed.

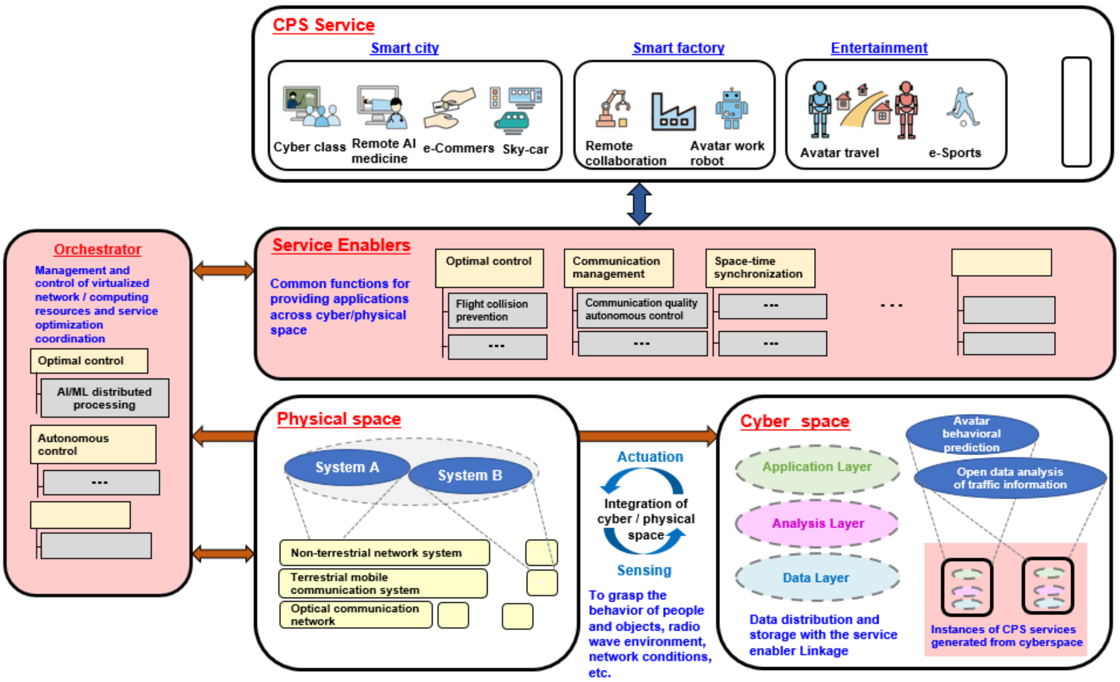
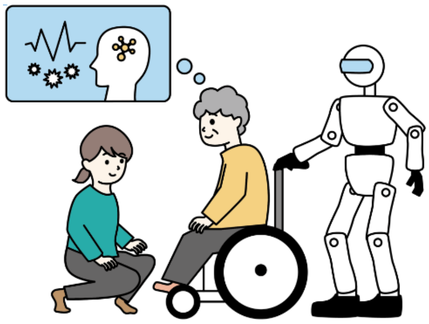



Figure A: Functional architecture of Beyond 5G/6G
(Figure 2.1 in the text)

In the Beyond 5G/6G era, time and space will be controlled at a high level in both physical space and cyberspace, and the fusion of both spaces will make it possible to achieve things that could not have been achieved in physical space alone. Services that can be implemented across both physical space and cyberspace are expected to help solve various social issues.

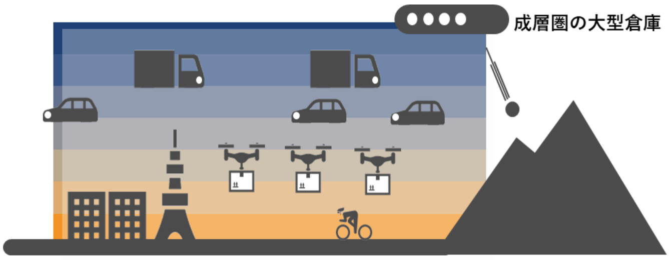
In Chapter 3 of this white paper, we introduce four scenarios and several use cases of social life after 2030. “Cybernetic Avatar Society” is the story of a society that highly utilizes avatars. Figure B shows examples of the scenarios: “Cybernetic Avatar Society,” “City on the Moon,” which depicts a society in which human activities extend to the moon, “Transcending Time and Space,” which depicts a society in which space-time synchronization is realized, and “The Light and Shadow of the Cyber World,” which depicts the case study of a cyber counseling room. In Chapter 4, we attempted to identify the required elemental technologies by backcasting from the future society depicted in these scenarios. In addition, the R&D open platform required for R&D and service creation is shown in Chapter 5. The standardization activities and the status of Beyond 5G R&D promotion projects are summarized in Chapter 6.

This white paper presents the results of discussions for the realization of the Beyond 5G/6G world by NICT as an expert group on information and communication technology, and we would like to continue discussions with many people based on this.



Cybernetic Avatar Society

City on the Moon




Transcending Time and Space

The Light and Shadow of the Cyber World

Figure B: Scenarios of Beyond 5G/6G that envision social life after 2030

# Chapter 1: Introduction

## 1.1 Background of the White Paper

### 1.1.1 Evolution of Mobile Communication Systems

The implementation of fifth generation mobile communication systems in society has been in full swing since around 2020. Mobile communication systems have evolved into a communication infrastructure (1G-3G) and a living infrastructure (4G), becoming an indispensable element in the lives of individuals. It has become a social infrastructure that connects not only people but also things like the Internet of Things (IoT).

A cyber-physical system (CPS) in which people interact with each other, people interact with things, and things interact with each other through cyberspace has come to have great significance in various aspects of social life. In the next-generation mobile communication system (Beyond 5G/6G), the communication network supporting CPS will become a neural network of society itself. In other words, it is expected that the communication network centered on the mobile communication system will function as the basic infrastructure of society in the future.

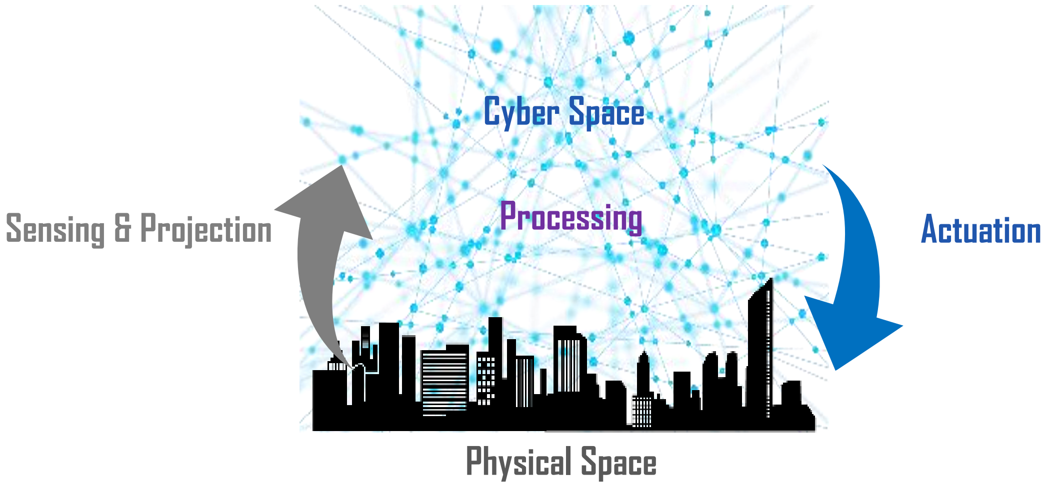



Figure 1.1 Realization of a “cyber-physical system” that measures events (big data) in physical (real) space, projects them into cyberspace, finds solutions (optimal solutions), and actuates the physical space event.

### 1.1.2 The Pandemic

In response to the global pandemic of the new coronavirus (SARS-CoV-2), governments around the world are taking measures such as lockdown restrictions to reduce, as much as possible, the opportunities for people to meet with each other in person. With the exception of essential workers, people are encouraged to work from home, and initiatives for new ways of working are rapidly being adopted.

In telecommuting, individuals can connect through cyberspace, so that economic activities can continue to a certain extent. On the other hand, the lack of current information and communications technology (ICT) capabilities is also being recognized.

Economic activity through cyberspace has the advantage of not being restricted by real time and space as in the past, and it is recognized as a new form of activity.

### 1.1.3 R&D Competition for Next-Generation Mobile Communication Systems

As a fundamental infrastructure of society, telecommunications networks are extremely valuable, and they are attracting a great deal of attention from the viewpoints of business game change and future security. As a result, movements to gain hegemony over next-generation mobile communications systems are accelerating.

Against this background, interest in Beyond 5G/6G has greatly increased compared to the transition point of previous generations. This has triggered a debate on how to proceed with research and development. As if competing for the lead, white papers have been published by various organizations, forums have been established, and investment in research and development has started (see "Reference: Various White Paper Consortiums, etc." at the end of this chapter).

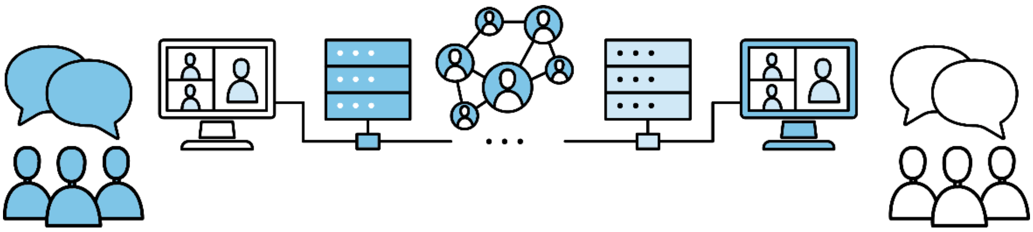
## 1.2 Purpose and Positioning of the White Paper

This white paper was prepared by NICT as a group of experts in information and communication technology. The contents are the results of a study on the realization of the Beyond 5G/6G world.

Envisioning the social life after 2030, four scenarios were created: "The Cybernetic Avatar Society," "City on the Moon," "Transcending Time and Space," and "The Light and Shadow of the Cyber World." We attempted to identify the necessary elemental technologies by backcasting from the future society depicted in these scenarios.

This paper presents scenarios and use cases (Chapter 3), and summarizes the elemental technologies (Chapter 4) required for their realization. In order to develop, implement, and utilize the future technologies necessary for realizing the social life depicted in the picture, it is essential to open discussions not only within the NICT but also with various stakeholders to set specific goals and to carry out activities to achieve those goals, as outlined in Chapter 5 (Beyond 5G R&D platform) and Chapter 6 (Deployment strategies for standardization activities and related businesses provided by NICT).

We will continue to discuss this white paper with many people, and will revise this white paper as the discussions progress.



<References: Various White Paper Consortiums, etc.>

(1) Beyond 5G/6G White Papers, etc.

- Beyond 5G Promotion Strategy Council, Ministry of Internal Affairs and Communications
https://www.soumu.go.jp/menu_news/s-news/01kiban09_02000364.html
- NTT's IOWN initiative
https://www.rd.ntt/iown/
- DoCoMo's "DoCoMo 6G White Paper"
https://www.nttdocomo.co.jp/corporate/technology/whitepaper_6g/
- KDDI's "Beyond 5G/6G White Paper"
https://www.kddi-research.jp/tech/whitepaper_b5g_6g/
- NEC's "Beyond 5G Vision White Paper"
https://jpn.nec.com/nsp/5g/beyond5g/pdf/NEC_B5G_WhitePaper_1.0.pdf
- Samsung's "The Next Hyper-Connected Experience for All"
https://cdn.codeground.org/nsr/downloads/researchareas/20201201_6G_Vision_web.pdf
- University of Oulu's "6G channel"
https://www.6gchannel.com/
https://www.6gchannel.com/portfolio-posts/6g-white-paper-validation-trials/

(2) Consortiums, etc.

- Beyond 5G Promotion Consortium
https://b5g.jp
- Beyond 5G New Business Strategy Center
https://b5gnbsc.jp/
- NEXT G ALLIANCE
https://nextgalliance.org/

# Chapter 2: Future Society after 2030 (View of the Beyond 5G/6G Era)

## 2.1 Information and Communications Networks and Society

Amid the recent COVID-19 crisis, innovations in information and communications network technology have led to the spread of telework and online meetings/medical care. These technologies are expected to help solve the following social issues.

(1) A society in which everyone can play an active role in any place (inclusiveness) by eliminating various barriers and differences such as urban and rural areas, national borders, age, and the presence or absence of disabilities

(2) A convenient and sustainable society with no social losses (sustainability)

(3) A strong and dynamic human-centered society in which safety and security are ensured and the bonds of trust are not shaken, even in the case of unexpected events (high reliability)

To achieve this, it is necessary to measure the real world through information and communication networks and aggregate the results as big data. It is also necessary to analyze big data in cyberspace and drive the real world using various actuators based on the results. In other words, cyber-physical systems (CPS) are expected to be used in various social activities. It is hoped that these systems will lead to a “human-centered, resilient, and dynamic society.”

## 2.2 Direction of Changes in ICT Networks

The use of various infrastructures and resources that support social activities will change significantly from concentration to distribution, and from monopolization to sharing. Several examples have already emerged. The so-called sharing economy includes car sharing in transportation, work sharing in the work environment, and crowd funding in finance. The shape of ICT networks will also change significantly in line with this trend.

For example, network virtualization such as software-defined networking (SDN) and open hardware will affect not only network devices but also terminals. In addition, artificial intelligence (AI) technology and machine learning (ML) technology will be applied to control more complex mobile communication systems.

As forms of communications networks, terrestrial information and communications networks, including mobile communications systems, which were previously separate networks, and non-terrestrial networks (NTN) in the aerospace domain are expected to be used by both sides in a compromising manner, and new components such as high altitude platform stations (HAPS) and drones will also become popular, and flying cars will eventually be used on a daily basis.

On the other hand, radio resources ranging from millimeter-wave bands to terahertz bands will be exploited, and it will be necessary to make full use of radio waves. It is expected that usage and applications taking advantage of the characteristics of these radio waves will spread. The resources handled by information and communications networks are not limited to radio waves, but cover a wide range of areas such as electric power, computers, and space. The optimal use of these resources will be discussed as a whole within a shared economy as an issue for the entire social system.

## 2.3 Solving Social Issues through Cyber-Physical Systems (CPS)

As Beyond 5G/6G technology advances, social issues that need to be resolved will span a wide range of fields, such as the Sustainable Development Goals (SDGs) adopted at the U.N. Summit and the social issues represented by Japan's Society 5.0 as a future society. Therefore, if we expand the space we handle from physical space to cyberspace and open up the limits of "time and space," "body," and "brain," which were considered difficult to overcome by conventional wisdom, many new social issues will arise. In order to resolve these issues through CPS, a Beyond 5G/6G mechanism that can execute services beyond cyberspace and physical space is expected.

By utilizing CPS, resources such as communication devices, frequencies, space, and time can be handled more dynamically than ever before. Not only can individual systems be upgraded and made more efficient by new technologies, but society as a whole can be optimized across industries. For example, by utilizing CPS to promote carbon neutrality through the power management of wireless communication devices and the control of traffic routes, it will be possible to resolve a wide range of social issues.

## 2.4 Beyond 5G/6G as an Open Platform

When Beyond 5G/6G is used as an infrastructure to solve social problems, it will be necessary for a wide variety of players to participate in this infrastructure across industries. For this purpose, it will be difficult for players to cooperate organically in a system closed to each industry, and there will be high barriers to participation. Therefore, it is important to design Beyond 5G/6G as a system that encourages participation by considering it as a social foundation with the characteristics of an open platform and the participation of all players.

From the viewpoint of system construction, Beyond 5G/6G will handle a wide range of functions, from advanced communications in physical space to expanded computational domains in cyberspace. Moreover, it must be ensured that these functions are organically fused across physical space and cyberspace. On the other hand, it will be difficult to understand the overall picture of increasingly complex functions because the development of services that deal with various social issues will require users who are not necessarily experts in communications systems or information processing.

Therefore, we would like to appropriately define each Beyond 5G/6G function and clarify the responsibilities so that each individual function can be placed in the whole Beyond 5G/6G system as a piece of the puzzle. Depending on the service to be realized, it will not always be necessary to make full use of all the functions. However, it will be necessary to freely combine and utilize the functions of the right person in the right place.

As Beyond 5G/6G becomes an open platform, players such as service developers and users, communication device developers and operators, and algorithm providers can contribute to the expansion of Beyond 5G/6G functions with peace of mind, and it is expected that Beyond 5G/6G will continue to grow as a social infrastructure.

## 2.5 Beyond 5G/6G Functional Architecture

In Beyond 5G/6G, physical space (the real world) and cyberspace (a virtual world) are fused as CPS, thereby realizing CPS services. The physical space and cyberspace of CPS consist of functions developed by various players. Sensing information from the physical space is provided to the cyberspace, and the cyberspace operates the physical space by managing, analyzing, and linking the information in an integrated manner. The CPS service uses the CPS through a service enabler. In addition, each system and function of the physical space and cyberspace is arbitrated through the orchestrator based on a unified policy. Figure 2.1 shows the functional architecture of Beyond 5G/6G, which includes the above relationship.

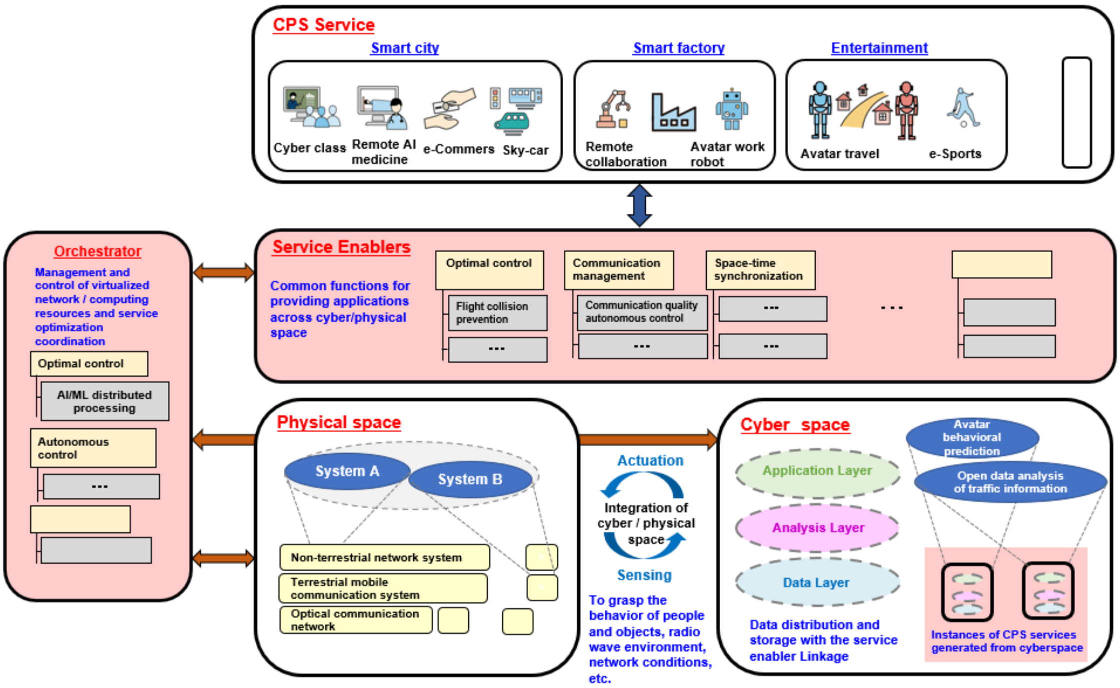



Figure 2.1 Functional architecture of Beyond 5G/6G

The concept of conventional land-based mobile communication systems has expanded in physical space, and 5G and other self-employed systems will be incorporated. The communication area in the sky will be expanded by space communication systems and non-terrestrial mobile communication systems, which will also be expanded to mountainous areas and the ocean. These wireless communication systems will be supported by high-capacity, low-latency optical communication networks. Each system will be deployed in combination with existing or new systems of the same type. For example, multiple management systems will be deployed on the ground and in space. Since these systems have different characteristics, the appropriate system will be selected according to the service.

In cyberspace, on the other hand, the information in various fields of physical space is handled in a unified manner. This makes it possible to grasp events that cannot be analyzed from a single type of information and to control the events based on the information. In order to properly position the functions necessary for cyberspace, a functional model composed of a data layer, an analysis layer, and an application layer was defined. Cyberspace is also composed of various functions, but new functions are introduced as needed and are used in either common or limited ways. A subset of information handled in cyberspace is used to create multiple instances that are based on concepts such as digital twins and Metaverse and used for services.

CPS services go beyond physical space and cyberspace. In the case of a smart city, for example, traffic information, people flow, weather sensing information, terrestrial mobile communication system frequency usage information, and optical communication network communication volume information are analyzed in cyberspace to enable appropriate mobile communication bandwidth management for large-scale events, appropriate traffic guidance, and river management during heavy rains. Other examples of CPS services include smart factories and entertainment.

As CPS services spread to various fields, they are developed from a viewpoint not necessarily limited to the information and communications field. This diverse architecture defines the service enablers and orchestrators so that the players can freely develop CPS services by considering systems and functions that support physical space and cyberspace as black boxes.

Service enablers allow CPS services to run across physical space and cyberspace. They receive CPS service requests, translate them into processes that control physical and cyberspace systems, initialize them to allow the use of both spaces via the orchestrator, and enable the use of CPS functions by the CPS service. While the CPS service is running, the service enabler continues to optimize the CPS.

The orchestrator initializes physical and cyberspace systems to enable the operations required by the CPS service, and continuously optimizes the systems while the CPS service is running. Each system that constitutes physical and cyberspace has its own policy for intersystem coordination and service deployment to users. Therefore, the orchestrator arbitrates the use of each system and their combination.

The following sections provide a detailed description of physical space, cyberspace, service enablers, and orchestrators.

## 2.6 Physical Space

In the physical space, not only conventional public mobile communication systems constructed by mobile communication carriers, mainly smartphones, but also private wireless systems such as local 5G/6G, next-generation wireless LANs using terahertz waves, dedicated communication systems, and non-terrestrial network systems such as HAPS and satellites are connected in a seamless manner. Data networks using next-generation optical networks by telecommunications carriers and Internet service providers, as well as data centers, edge cloud, and cloud resources by cloud service providers become one.

Non-geostationary orbit (NGSO) satellites such as low earth orbit (LEO) and medium earth orbit (MEO) satellites will move in cooperation with each other and coexist with geostationary orbit (GEO) satellites. In coexistence, radio waves and light waves are used for feeder links and the user links that connect earth stations with satellites and HAPS groups, and used as intersatellite links for communication between satellites and HAPS groups.

Next-generation optical networks will be used in mobile communication systems and data networks, and between devices in edge computing. In a link that mutually connects the NTN base station and gateway, an infrastructure that can carry large-capacity communication such as multicore optical fiber will be laid.

Seamless integration of terrestrial and non-terrestrial networks is achieved through flexible resource coupling via the orchestration function. By including the ability to flexibly combine the unique resources of various carriers in the orchestration function, the CPS services are provided with an optimal communication environment to meet their requirements, so that the users' intentions can be fulfilled anywhere (in the sky, ocean, city, or remote areas) and anytime (in daily life or disaster situations).

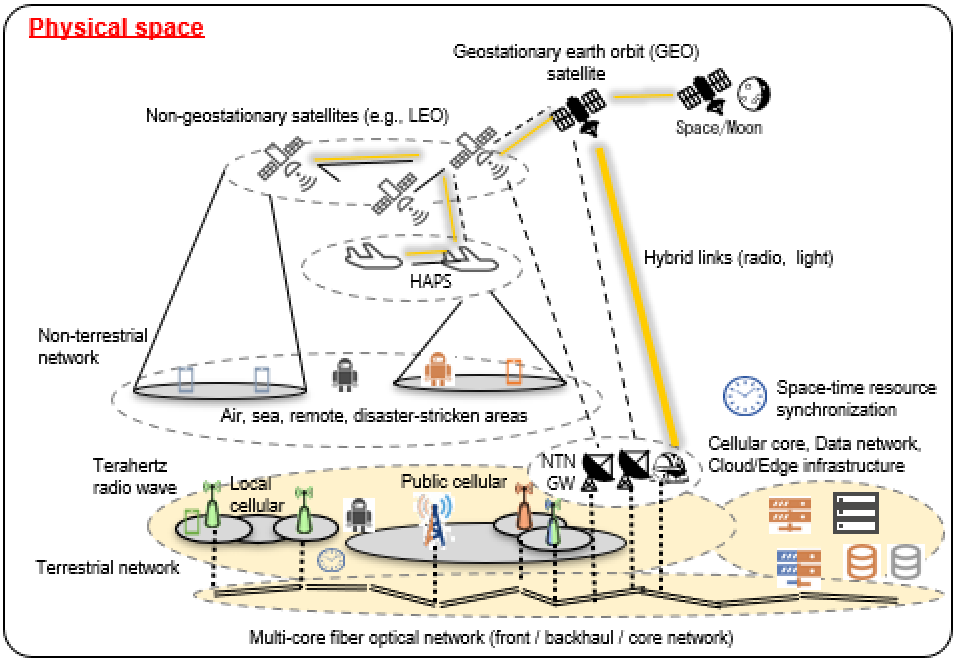



Figure 2.2 Physical space

## 2.7 Cyberspace

Cyberspace includes advanced connectivity that enables real-time data acquisition from physical space and information feedback from cyberspace, as well as intelligent data management. Computing power that enables AI analytics is required. Cyberspace is currently used mainly to monitor the operation of devices and other objects. In the future, cyberspace will be used to build digital twins that digitally represent entities in the real world from smart cities to humans, and to simulate and predict their interactions. It is expected that this will evolve into the autonomous optimization of business flows and social systems.

Cyberspace consists of three layers: data, analysis, and application. In the data layer, an IoT hub extracts and converts information while exchanging data with physical systems and devices, centralizes it, and maps it to a digital twin. In the analysis layer, future events are recognized, discovered, or predicted by analyzing the information, and the events are verified by simulation. In the application layer, CPS services are linked based on the predicted results to optimize the systems and services.

In addition to supporting extremely diverse B5G/6G data streams with a large capacity and low latency, these functional elements are also important for real-time control, synchronization control, and reliability assurance for the entire CPS including physical space. It is also necessary to be able to link with Web services that are widely used today.

Cyberspace is not only a realistic reproduction of individual physical spaces. Subspaces corresponding to CPS service scenarios are overlapped and reproduced, and the physical space is optimally controlled based on predictions. In this case, verification is possible in cyberspace for different time horizons or scenarios that are difficult to verify in reality.

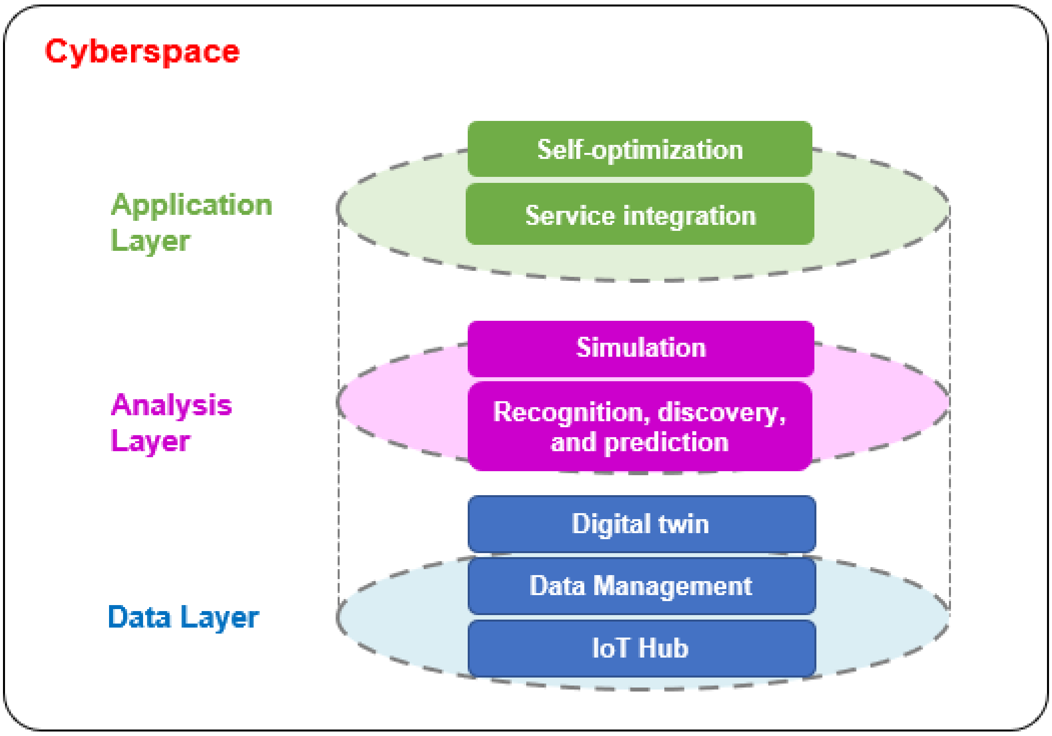


Figure 2.3 Cyberspace

## 2.8 Service Enabler

The service enabler is a function that enables CPS services to run beyond physical space and cyberspace. There are various ways to implement a service enabler. In this section, we assume that a service enabler is implemented as the middle layer of an application that constitutes a service. The roles of Beyond 5G/6G in the overall system are shown. The implementation of service enablers as well as its features and interfaces will require further discussion.

The workflow of the service enabler is as follows: A CPS utilization request is received from a CPS service, decomposed into processing units for controlling physical space and cyberspace systems, and transmitted to an orchestrator that combines the physical space and cyberspace systems, satisfies the necessary functions and performance, and initializes the CPS service for the use of the CPS. The service enabler continues to optimize the CPS while the CPS service is running.

If the service enabler mediates the function requests of the CPS service, it is not necessary for the CPS service to directly handle complex functions that can be realized in physical space and cyberspace. The provider of the CPS service only needs to deal with the service enablers that are organized from a consumer perspective. The service enablers may be implemented, for example, as middleware or a driver of an OS or as a function of an external server.

Examples of service enablers are shown in Table 2.1. The categories of service enablers include “optimal control,” “communication resources,” “space-time synchronization,” and “security.” The “optimal control” category includes individual functions such as “flight collision grid” and “ultra-realistic sharing.” Such service enablers may be added as needed and opened to multiple users with appropriate access control.

An example of a CPS service is the cooperative work of robots that are remotely controlled from multiple points. In this case, the communication delay from each point is different, so that the cooperation of the robots is not smooth. However, the delay can be compensated by utilizing the service enabler for “multi-point avatar VR work,” which enables the appropriate operation by each operator through VR. If a service enabler is not used, the developer of the CPS service will need to devise and implement an algorithm to compensate for the communication delay. However, if a service enabler is used, the CPS can be easily utilized as a common function.

Another example is drone flight. CPS service developers use a service enabler for “flight collision avoidance,” and as long as they set a destination for the drones, the service enabler will control their flights to avoid collisions with other flying objects. CPS service developers obtain their own information from physical sensors and do not have to handle the programming to avoid collisions with other flying objects.

From the standpoint of implementing a CPS service by using a service enabler, it can be seen that it is possible to easily handle a complex system that constitutes Beyond 5G/6G.

Assuming that the CPS service uses an application programming interface (API) with the service enabler, a pseudo programming code can be used to implement the CPS service (see the attached Appendix 1).

Table 2.1 Examples of Service Enabler Functions

| Category | Individual function |
|---|---|
| Optimal Control | Flight collision avoidance,<br>Super reality sharing,<br>People flow traffic analysis |
| Communication Resources | Communication quality autonomous control,<br>Sky area expansion, Ocean area expansion,<br>Wide-area sensor information collection |
| Space-time synchronization | High-precision position identification,<br>Multi-point avatar VR work, Terminal position search |
| Security | Avatar authentication, Data traceability |

## 2.9 Orchestrator

The orchestrator receives requests from the service enabler. This function performs the processing necessary to execute the CPS service for each system in physical space and cyberspace, based on a request to use the CPS service. Similar to the service enable, the orchestrator can be realized in various ways and thus requires further discussion. This section assumes that the orchestrator is a management device that has a communication interface with each system.

In order to realize a requested function, the orchestrator selects a system from among all the systems constituting the CPS, initializes the system by combining the systems so that the CPS service can use the system as a whole, and continuously optimizes each system while the CPS service is running.

In this case, each system that constitutes physical space and cyberspace has its own policy for intersystem coordination and service deployment to users; therefore, the orchestrator arbitrates the use of each system and their combination.

Each system in the physical space and the service space has a management function for proper operation in the system and is responsible for its operation. Each system has an external interface with the orchestrator in addition to its autonomous operation. In this case, each system has different conditions for arbitration in terms of available resources and connection policies at that time. Therefore, the orchestrator attempts to arbitrate with individual systems from a system-wide perspective. Some systems may not be selected for that CPS service despite being approached by the orchestrator. In other words, the orchestrator does not centrally manage the use of all systems. Each system is autonomous in its operation, and the interface with the orchestrator is a means of communication for negotiations.

In this manner, in order to enable the execution of the CPS service, an optimum combination is selected from each system of the physical space and cyberspace. The selected system group is configured each time for each CPS service.

It should be noted that various functions to be arbitrated from the viewpoint of the whole system are implemented by the orchestrator. As shown in Section 2.2, it is important that these functions are flexibly updated during the growth process of Beyond 5G/6G. Also, because the orchestrator is the mediator of the overall system, it is necessary to eliminate the processing that is problematic for Beyond 5G/6G serving as the social infrastructure. It is also necessary to consider and devise the implementation of functions that do not cause performance bottlenecks or failure points in the operation of the system.

Table 2.2 Examples of Orchestrator Functions

| Category | Individual function |
|---|---|
| Optimal Control | AI/ML distributed processing,<br>Low power consumption control |
| Autonomous Control | Zero-touch configuration management,<br>Automatic failure recovery,<br>Disaster communication control |

| | |
|---|---|
| Communications Resource Management | Frequency resource management,<br>Communication quality management |
| Computing Resource Management | Edge computing resource management,<br>Delay compensation remote control |

# Chapter 3: What Will Daily Life Be Like in the Beyond 5G/6G Era? Scenarios and Use Cases

## 3.1 Scenario 1 – Cybernetic Avatar Society

### 3.1.1 A Day in 2035: From the Diary of a Technology Development Manager

- 9:30–10:30 Telepresence meeting with executives from Tokyo headquarters to discuss new product planning while still staying at home in Kyoto

XR teleconferencing among 3D avatars (UC1-3: Telepresence). I was a little nervous when the president's avatar appeared in front of me, but I moved next to the president in 3D space, handed him a product VR prototype, and asked him to experience it remotely with haptic gloves. We were able to get his go-ahead right away.

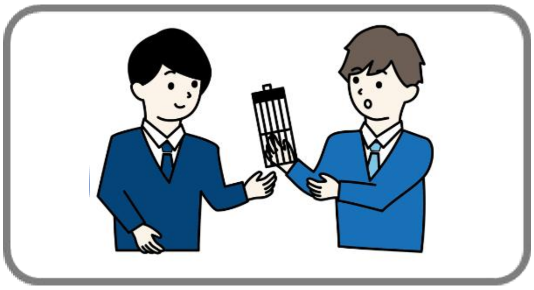


Figure 3.1 Telepresence meeting

- 10:30–11:30 Participation in global disaster response event

Remotely participated in large-scale training event for simulating natural disasters (UC1-3: Telepresence). Using global core network technology, experts from various countries gathered in XR space to discuss matters further (UC1-1: Promotion of Mutual Understanding), and our products were operated simultaneously in each country using space-time synchronization technology. We were very pleased to be able to verify the effectiveness of our products in the event of a disaster.

Figure 3.2 Telepresence event

■ 11:30–12:00 Respond to an emergency problem at a manufacturing plant in Thailand by instantaneous physical movement (9:30–10:00 local time)

A sudden notice was received from a manufacturing plant in Thailand that the production line had been shut down. We attempted to remotely control the manufacturing equipment by hopping on a local avatar robot (UC1-3: Telepresence) and we found that a part was damaged. The person in charge repaired the equipment remotely and was able to work remotely with ease without any awkward delay.

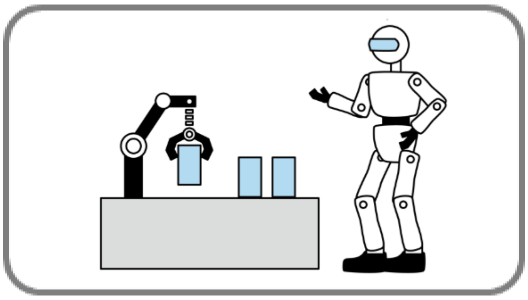


Figure 3.3 Remote response to emergency problem

■ 12:00–13:00 Remote lunch while assisting my father, who lives alone in the countryside of Okayama

Using an avatar, I was able to enjoy lunch with my father, whose physical functions are deteriorating. I remotely controlled the assistive devices to help my dad eat (UC1-2: Mental and Physical Support Avatar). EEG analysis showed that his understanding had not deteriorated, which was a relief. This is probably thanks to the AI interactive nursing care system that my father uses every day.

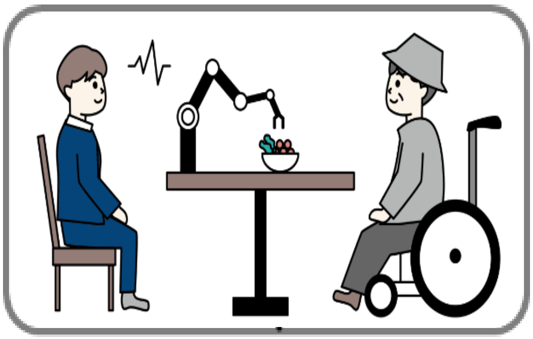


Figure 3.4 Remote assistance

■ 13:00–15:00 Simultaneously participate in company meetings and visit my son's class remotely with multiple avatars

A teleconference in the company and a remote visit to my son's school coincided. The avatar for the company meeting was set to autonomous alter-ego mode, and AR was used to check the status of the meeting (UC1-3: Telepresence). For the agenda item I was interested in, I went back into the remote alter-ego mode and made a statement. Don't tell my son that I slipped out of the class visit during that time!

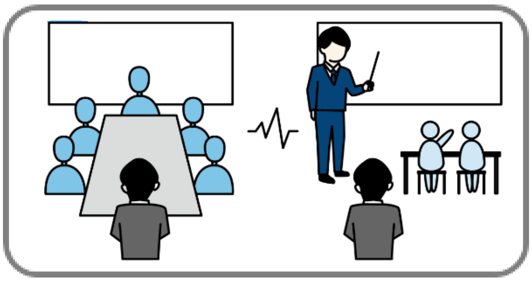


Figure 3.5 Company meeting and class visit

■ 15:00–16:00 Refresh body and soul by climbing XR-Mt. Fuji

Petit-XR Mt. Fuji climbing for refreshment (UC1-3: Telepresence). Thanks to a number of 360-degree cameras and haptic sensors installed on the site, which flexibly avoid radio interference and provide wireless access according to the situation, I was able to enjoy a remote experience equivalent to climbing an actual mountain while viewing the beautiful sea of clouds in a live performance, which refreshed my body and soul.

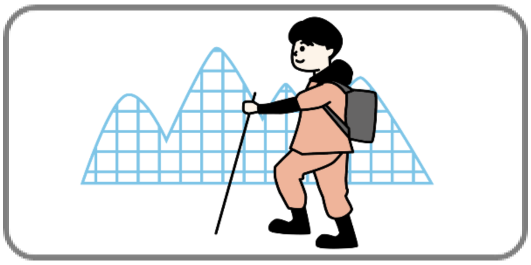


Figure 3.6 XR Mount Fuji climbing

■ 16:00–17:00 Remote negotiation with client in Turkey (10:00–11:00 local time) in Japanese

Our products are popular in Europe and the Middle East, and today we had a remote meeting with a client in Turkey. I didn't know anything about the Turkish language, culture, or customs, so I was worried if I would be able to communicate with them, but thanks to the simultaneous interpretation system that takes into account each other's cultures, we will be able to sign a new contract with the client (UC1-1: Promoting Mutual Understanding).

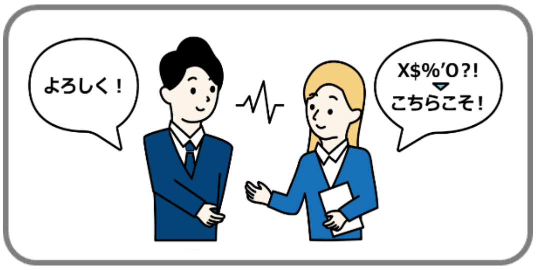



Figure 3.7 Remote negotiation across languages, cultures and customs

- ■ 20:00–21:30 Watch TV special programs on future technology before going to bed

Today, I had a fulfilling day as I was able to handle several roles by myself with ease. Compared to 15 years ago, our country's birthrate is falling and the population is aging, but thanks to avatar technology, labor productivity has improved. According to a TV show on future technology that I watched after dinner, in another 15 years from now, most of the brain's functions will be incorporated into AI. It is going to be an amazing world, but it is also going to be a test of human wisdom on how to use these technologies.

### 3.1.2 Case Examples of Usage and Key Technologies Required for Implementation

#### UC1-1: Mutual Understanding Promotion System (Across Barriers of Culture and Values)

| | |
|---|---|
| What kind of system? Why do we need it? | It is difficult for a wide range of people with different cultures and values to truly understand each other just through daily verbal exchanges. However, this system analyzes the context, non-verbal information, and brain information to convey the true meaning of the other person in an easy-to-understand manner. Even in remote conversations with people from overseas using real avatars, the system will translate and interpret the concepts that the words convey, taking into account differences in culture and customs, thus deepening the mutual understanding among people with diverse cultures. |
| Usage | ● Conceptual translation is carried out by detecting inconsistencies in human-to-human conversation.<br>● Operation is performed by voice, brain-machine interface (BMI), multiple sensors, etc. |
| Required key technologies (see Chapter 4) | (T7) Brain information reading, visualization, and BMI technology<br>(T7) Real 3D avatar, multisensory communication and XR technology |

| | |
|---|---|
| | (T7) AI analysis and dialogue technology using linguistic and extra-linguistic information<br>(T7) Multilingual simultaneous interpretation, paraphrasing, and summarization technologies<br>(T2) Integrated communication system configuration technology that coordinates the environment and requirements<br>(T6) Human-centric security technology<br>(* technology not covered by NICT)<br>XR hardware technology such as head-mounted display (HMD) |

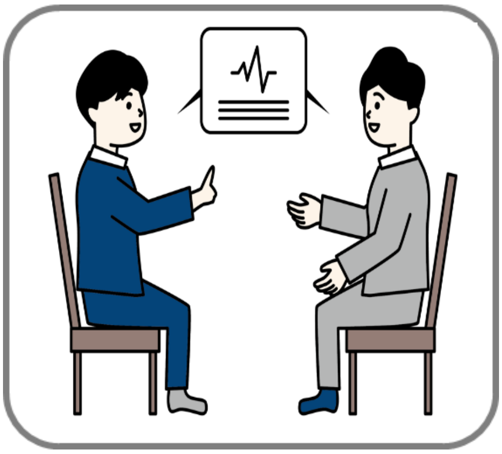


Figure 3.8 Mutual understanding promotion system

### UC1-2: Support Avatars for Mind and Body (Overcoming Barriers of Age and Physical Ability)

| | |
|---|---|
| What kind of system?<br>Why do we need it? | A nursing-care support avatar (AI or robot) reads verbal, non-verbal, and brain information of the elderly and the physically challenged, and assists them with their wishes and feelings. Caregivers can also remotely control the nursing-care support avatar to provide assistance according to the wishes of the elderly or the physically challenged. Although the number of caregivers in Japan is limited, it will be possible for caregivers from abroad to assist personal care by using the simultaneous interpretation system. |

| | |
|---|---|
| Usage | ● Elderly and physically challenged people can use avatars.<br>● Caregivers can remotely control avatars to support care-receivers. |
| Required key technologies (see Chapter 4) | (T7) Intuition measurement, communication and assurance technology<br>(T7) Real 3D avatar, multisensory communication and XR technology<br>(T7) AI analysis and dialogue technology based on linguistic and extra-linguistic information<br>(T7) Multilingual simultaneous interpretation, paraphrasing, and summarization technologies<br>(T2) Integrated communication system configuration technology that coordinates the environment and requirements<br>(T6) Human-centric security technology<br>(* technology not covered by NICT)<br>Hardware technologies such as home care robot and HMD |

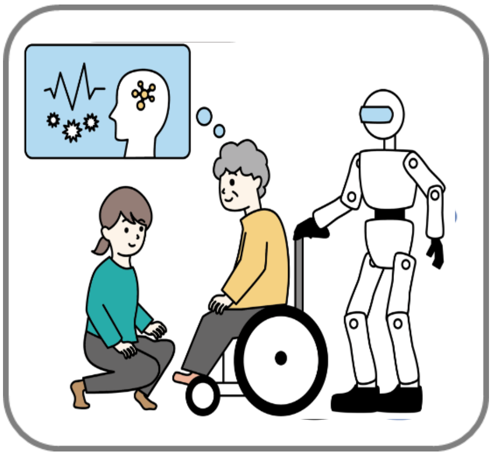


Figure 3.9 Mind and body support avatar

### UC1-3: Working Style Revolution with Telepresence (Transcending Distance and Time Barriers)

| | |
|---|---|
| What kind of system? | This system allows the user to instantly move around the world as well as in Japan with 3D avatars while staying at |

| | |
|---|---|
| Why do we need it? | home. Meetings with people overseas are made easy with XR and simultaneous multilingual interpretation. The avatar can instantly move to overseas manufacturing plants and farms, and remote work can be done intuitively with multisensory information. It is possible to take care of parents living far away while working. The avatars are secure and guaranteed not to be fake. Multiple operators can also switch between avatars that are specific to each task. |
| Usage | ● Environmental sensing information can also be collected and transmitted.<br>● Multiple avatars can be switched by multiple operators. |
| Required key technologies (see Chapter 4) | (T7) Intuition measurement, communication, and assurance technology<br>(T7) Real 3D avatar, multisensory communication and XR technology<br>(T7) AI analysis and dialogue technology based on linguistic and extra-linguistic information<br>(T7) Multilingual simultaneous interpretation, paraphrasing, and summarization technologies<br>(T2) Integrated communication system configuration technology that coordinates the environment and requirements<br>(T6) Human-centric security technology<br>(* technology not covered by NICT)<br>Hardware technologies such as remote-control robots and HMDs |

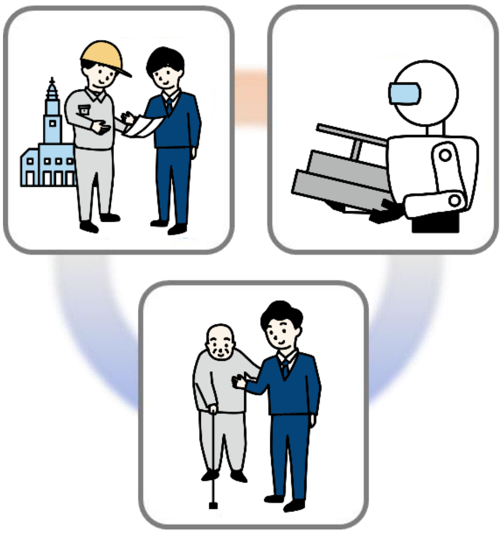


Figure 3.10 Working style revolution with telepresence

## 3.2 Scenario 2 – City on the Moon

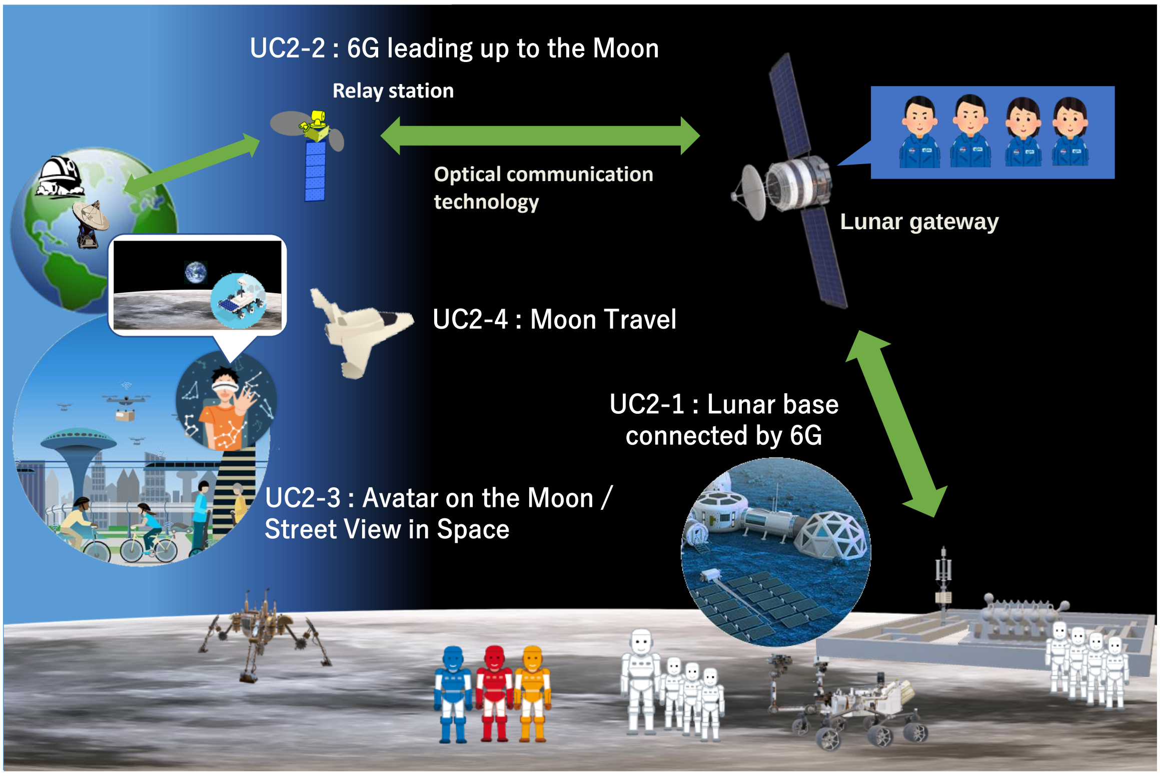



Figure 3.11 Image of scenario – City on the Moon

### 3.2.1 People Cultivating the Moon

At the Lunar Gateway:

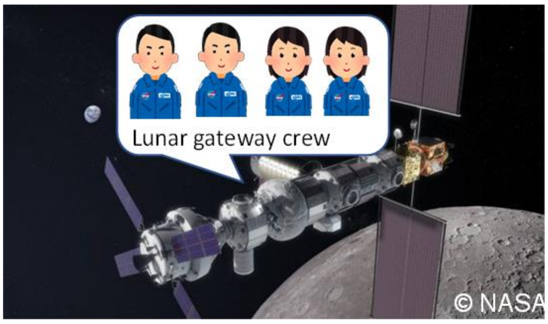



Figure 3.12 Future lunar gateway

Everyone gathers in the briefing room with their favorite tumbler in one hand. This is a space station orbiting the Moon (lunar gateway). There are only four astronauts serving in turn. My boss shows a map of the lunar surface on the screen and explains the underground area to be explored today. One of the crew members speaks:

"Today's range is 70 percent larger than the typical exploration range. Aren't we working too hard?"

My boss responds strongly:

"Yesterday, the work was completed in another construction area. There are more than 30 avatar machines from Earth. Four of them can be borrowed from those construction sites."

After downloading the process chart and data, my boss and two crew members move to their own pods and start connecting to the lunar avatar machine (UC2-1, UC2-3). I pour the remaining lemon tea down the exhaust duct and slide into my pod.

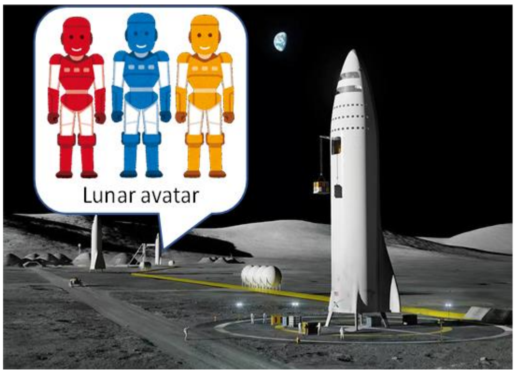



Figure 3.13 Image of lunar settlement and lunar base development*

* Space-X Base α: https://www.theverge.com/2017/9/28/16382716/spacex-elon-musk-moon-base-alpha-mars-colonization-interplanetary-transport-system

From the Lunar Gateway to the Surface:

If you look at the horizon, you can clearly see the boundary between the black space and the gray-brown ground. This scene appears when you plug into an avatar machine on the Moon. I head to the construction area with my boss, launch a large excavator, and begin exploration. We check the results against the scan data from the lunar gateway, feedback the results, and optimize the exploration route.

For the rest of the crew members, today is virtual training day. Regular training is mandatory so that we can respond quickly to all possible crises on the Moon.

It seems that the Earth team has started working behind us, and the

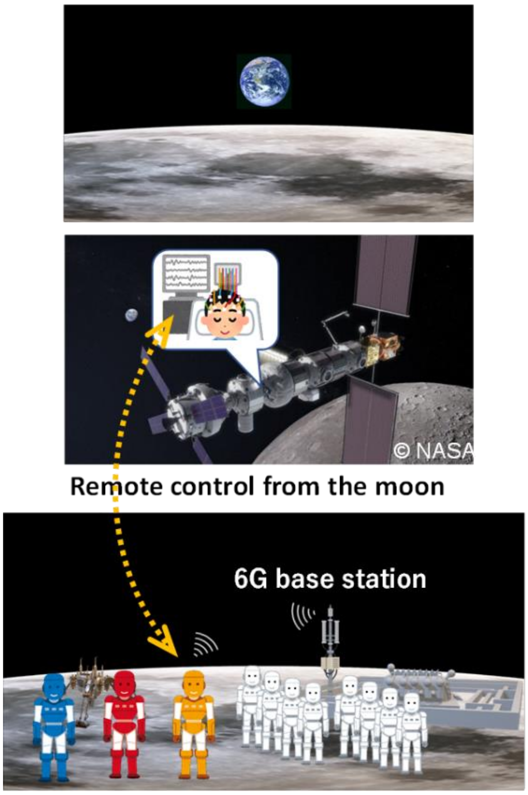



Figure 3.14 Remote work with lunar avatars

vibrations of multiple large impact drivers are transmitted to the grip arm of the lunar surface avatar and transmitted to my bare hands on the lunar gateway (UC2-1, UC2-3). I feel slightly odd when I realize that these vibrations had been converted into radio waves before they reached me.

From Earth to the Moon

As I look at the horizon, I can clearly see the boundary between the black universe and the gray-brown ground. It is a familiar sight that appears when I plug into an avatar machine on the lunar surface. I head to the construction area with four avatar machines and meet up with three other avatar machines at the site. The lunar team has already started their work. They are planning their exploration route.

It is the 6G network that connects me on Earth with this body (the avatar machine on the Moon). When I arrive at the site, I first check the communication status with Earth (UC2-1, UC2-2). Next, I check the autonomous navigation unit equipped with an ultra-high-sensitivity inertial sensor. Even if the network is cut off, it will be able to operate safely autonomously, but this tough and expensive government system will be suspended. It's also important to be able to track the location of avatar machines on the Moon without relying solely on communications, by using the high-precision positioning system of the 6G base stations instead.

While operating multiple excavation machines, the team will efficiently assemble a reinforced panel with an impact driver to prevent cave-ins. A robust edge cloud network has been built on the lunar surface, and the influence of communication delay is sufficiently suppressed by utilizing brain information (UC2-1, UC2-3). As

Remote control of lunar avatars from the earth

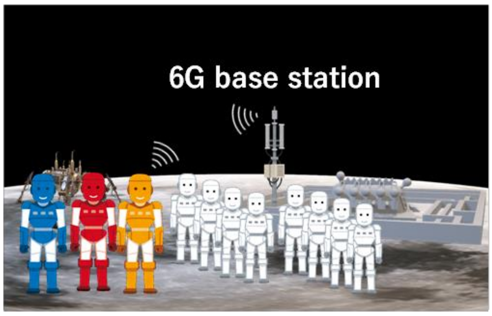



Figure 3.15 Remote work with lunar avatars

a result, humans and things can silently and safely cooperate on the Moon, far away from Earth.

With today's work time finished, I return to the maintenance box of the avatar machine and lay myself down. I slowly unplug from the avatar machine, watching the high-contrast horizon that I first saw.

A few moments before it switches to a scene on Earth, a rover with a 3D camera passes in front of my sight (UC2-3).

Someone must be enjoying a Moon trip on Earth.

On Earth:

Slowly I regain consciousness from the lunar avatar machine to myself on the ground. I stare at my palms in my pod on Earth where calming music is playing. It's a slender hand with long fingers. Just a moment ago, it had been a large, dusty, sooty robot arm.

Recently, a broadcasting studio was completed in construction area B; my nephew is going there soon.

I want to visit the Moon with my daughter as a tourist once the underground exploration is completed and the beautiful lunar city is built (UC2-4).

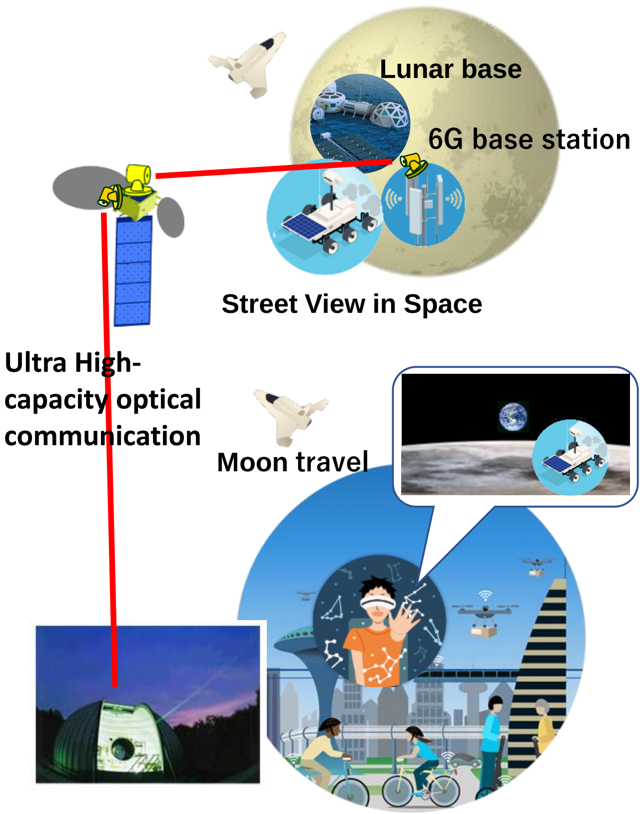



Figure 3.16 Accessing street view in space from Earth

### 3.2.2 Case Examples of Usage and Key Technologies Required for Implementation

UC2-1: Lunar Base Connected by 6G

| | |
|---|---|
| What kind of system? Why do we need it? | The same 6G terminal as on the ground is connected at the lunar base, enabling positioning and location. The environment is severer than on the ground and requires higher reliability and security for human life.   Figure 3.17 Lunar base connected by 6G |
| Usage | ● Can be used in harsh environments on the Moon.<br>● Can be maintained remotely. |
| Required key technologies (see Chapter 4) | (T3) Design and allocation of frequency utilization considering propagation on the lunar surface<br>(T1) Wireless optical communications and terahertz technology used due to the lack of air<br>(T2) Ultra-massive connectivity technology for communication of vital data, etc.<br>(T4) Requires communication equipment that is resistant to radiation on the Moon<br>(T5) An atomic clock built into the local 6G base station enables positioning on the lunar surface using radio waves<br>(T4) Providing communication services in cooperation with a private mobile operator<br>(T6) Security needs to be higher than on the ground<br>(T4) 6G base station with software defined radio (SDR) installed on lunar surface (lunar surface radio with variable frequency and modulation)<br>(T1) Fiber laying (multi-core fiber, laid during construction, buried in regolith)<br>(T4) Minerals, fuels, buried resources, and transmission |

| | |
|---|---|
| | of financial information (encryption, security, time synchronization required)<br>(T4) Avoiding the effects of meteorites (tracking of debris and disrupting their orbits by laser irradiation) |

### UC2-2: 6G leading up to the Moon

<table>
<tr><td>What kind of system? Why do we need it?</td><td>A system used for communication between lunar avatars and users on Earth. High-speed communication is possible from Earth to the lunar base, and the same 6G terminal as on Earth is connected.

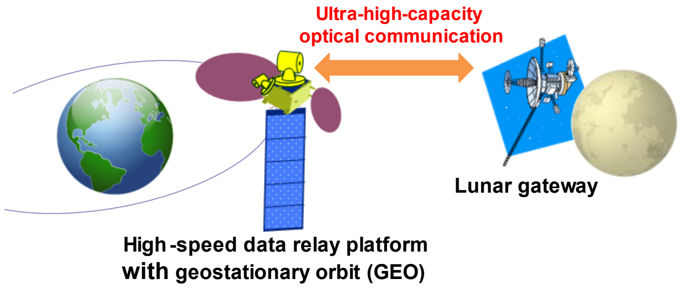


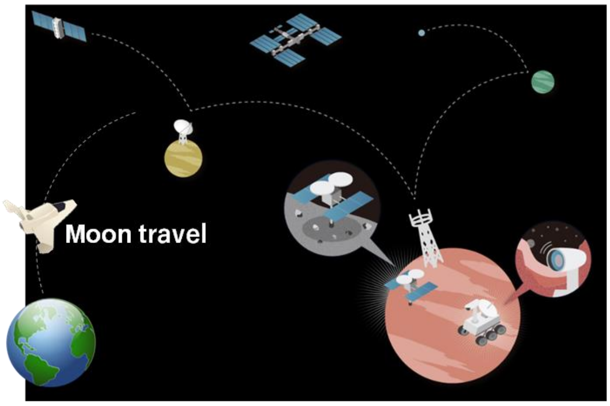

Figure 3.18 6G leading up to the Moon</td></tr>
<tr><td>Usage</td><td>● Communication via the lunar gateway is required.<br>● Target data transmission speed is 5 Gbps or higher.<br>● Earth-Moon delay must be taken into consideration.</td></tr>
<tr><td>Required key technologies (see Chapter 4)</td><td>(T4) Earth-Moon ultra-high-capacity optical communication<br>(T4) 24/365 communication<br>(T4) Data relay station in geostationary orbit<br>(T4) Providing communication services in cooperation with private satellite operators<br>(T4) Security must be taken into account, with multiple routing choices for security and reliability<br>(T4) Adaptive optics for onboard satellites<br>(T4) Large aperture optical antenna technology for onboard satellites</td></tr>
</table>

## UC2-3: Avatar on the Moon/Street View in Space

| | |
|---|---|
| What kind of system? Why do we need it? | A user on the ground performs an activity on the Moon by plugging in an avatar on the lunar surface. Enables real-time work to be performed at lunar plants, construction sites, and lunar laboratories (material evaluation, charge behavior in materials) while on the ground. It can also provide entertainment services (for a fee) such as games and education, and reduce the language barrier on the Moon by communicating in multiple languages in areas such as mineral resource development and ownership, and space medicine (remote surgery by avatars), etc. In addition, real-time images of the universe can be enjoyed from the ground via webcams mounted on satellites.  Figure 3.19 Street view in space |
| Usage | ● Conceptual translation is carried out by detecting inconsistencies in human-to-human conversation.<br>● Operation is performed by voice, BMI, multiple sensors, etc. |
| Required key technologies (see Chapter 4) | (T1) Ultra-high-capacity wireless communication<br>(T7) Multilingual translation<br>(T2, T7) Low latency, brain tricks, gravity compensation<br>(T2) Local processing by AI and low latency control in edge computing, etc.<br>(T7) Leisure, gaming, VR/XR technology<br>(T6) Security considerations (specific to medical services)<br>(T4) It is necessary to ensure the reliability and the tolerance of the materials in a space environment |

| | |
|---|---|
| | because the degradation process is different from that on the ground. |

### UC2-4: Moon Travel

| | |
|---|---|
| What kind of system? Why do we need it? | This is a system for high-capacity communication with Earth and the lunar base during an actual trip to the Moon in the future. The system will provide safe and secure travel that allows us to contact our grandparents on Earth without problems even during long trips. We are entering an era in which people can enjoy space travel even for leisure, and can send photos taken during their trip to Earth via SNS.   Figure 3.20 Moon travel |
| Usage | ● Communication lines can be used without any special skills.<br>● Measures are needed to ensure a safe return to the spacecraft even if the communication link for passengers is cut off during extravehicular activities.<br>● Measures against blackouts are needed when returning to Earth. |
| Required key technologies (see Chapter 4) | (T4) Importance of space weather (large impact on the human body and equipment)<br>(T1) Ultra-high-capacity wireless communication<br>(T2, T7) Long-distance teleconferencing<br>(T2) Low latency<br>(T6) Security considerations |

## 3.3 Scenario 3 – Transcending Space and Time

### 3.3.1 Creative and Active Lifestyles

**Father and daughter:**

My youngest daughter is very lively and I can't take my eyes off her even at the park. While watching my daughter, I call up my floating information terminal to have a meeting with my colleagues at work. It is a little cold outside. "Daddy, look! Hmm… POFF!" A pebble crashes into a pile of sand. I notice my wife's camera drone near my daughter. My wife can't stop watching our daughter either. She is supposed to be on a business trip until today, but it looks like she is connecting to the smart drone system to check things out (UC3-3). She never trusts me!

**First son:**

The teacher's lesson through the glass monitor is fun. Next month, they will perform a dance at the theater that was completed on the Moon. I am at home on Earth now. The AI alerts me to take a break, so I stop dancing and check the 3D feedback images while changing the viewpoint. The dancing by my friends is superimposed on the images of myself (UC1-3). "Hmmm, looks like I'm a talented dancer."

**Second son:**

My brother seems to have started a dance lesson upstairs because the thudding noise is loud. It's my brother's turn to cook today, but I decided to take over. It's fun to be able to create new dishes by using the Skill Learning Assistant (apparently the teacher is an old lady in the neighborhood…) (UC1-1, UC1-2). Come to think of it, I am going to Grandpa's house tomorrow. I'd like to make something for him and bring it. What's his favorite?

**Grandfather and father:**

My father is a charismatic local hairdresser. These days, he opens his salon only when his customers ask him to (UC1-3). Today he celebrated his 77$^{th}$ birthday (called "Kiju" in Japanese). It was exciting, just like a talent show, with regular customers and old staff coming to celebrate. His hobbies are road biking and fishing, so he is suntanned. “Stay well, Dad.”

**With family:**

After finishing the board game, the children began to breathe like they were sleeping. My wife also started to doze off, rocking her body back and forth like rowing a boat. My second son made inarizushi (sushi wrapped in fried tofu); I wonder how he knew what my father’s favorite food is. Watching someone’s sleeping face makes me feel sleepy too. I switch to automatic navigation mode and stretch out. The gliding flying car’s interior is really quiet (UC3-1). I look up at the Moon from the windshield. “Hey, Bro! Where is the theater where my child will dance?”

3.3.2 Dive to the Point

In the stratosphere warehouse that orbits around 20 km above the ground, I (an autonomous AI system) put the requested cargo in my backpack and dive to the ground (UC3-1). The moment I step out, I always get nervous, but I am also filled with a sense of freedom. After I leave the warehouse, the sky gradually changes from dark blue to pale blue, and as I pass through the white clouds at high speed, the image of a city with countless rivers branching and flowing emerges from the haze. As I look closely, I can see the rivers branching into smaller irrigation channels equipped with smaller sluices and hydroelectric generators. The sluices and generators are networked, and the amount of water flowing through the town is managed smartly. Black rain clouds can be seen behind the mountains. A wide-area sensor network is monitoring and forecasting rainfall and river water levels and computing an appropriate drainage program for the town (UC3-2).

As I approach the mountainous area where I am going to be, I notice work drones shining in the vast red pine forest. Multiple robots are cooperating with each other in thinning, collecting, and transporting the trees, to maintain and manage the forest to maximize the flood control effect (UC3-2). Even so, the mountain has collapsed in some areas, and the spreading red pine forest is streaked with many lines of reddish-brown soil. I can see the broken steel bridge that the drones are repairing (UC3-2). No matter how smart we become, we will probably never be able to eliminate the damage caused by natural disasters.

Finally, I arrive at my destination, the community center. I dive into a receiving pod about 5 meters in diameter near the public hall (UC3-1). A surprisingly quiet landing, thanks to the technology that collects heat and sound from the impact and stores it efficiently in the battery. After a few minutes of safety checks, the staff take out the relief supplies from my backpack. I hear a cheer in the distance.

Made of heat-resistant ceramic equipped with an inertial sensor and space-time synchronization unit, I finish one task and am collected in a maintenance box for the next dive. “Hi, Mr. Staff, when the bridge is fixed, please wash and pour in some fragrant oil.” Next, I want to do a rocket entry into the atmosphere (UC3-1).

### 3.3.3 What Is in the Sky?

**Granddaughter:**

I make a cup of coffee and sit down at my desk at home. The chirping of sparrows and the cold air are refreshing. Facing the widescreen, I quietly read over and modify the assignment report I completed last night. There is no physical keyboard. I tap a keyboard hologram, and with motion capture, the input is sent to the edge cloud (UC3-3). The only noise is the sound of my grandfather tuning up a road bike. He is 77 years old and still going strong. It’s about time for me to start teaching at a university abroad. I submit a report and switch my mind from student to lecturer (UC1-3). I reach for my headset while eating inarizushi (sushi wrapped in fried tofu) made by my cousin. I realize now that this is why he asked me the day before yesterday about his grandfather's favorite food. I casually look at my palm and long, slender fingers. I must take after my father.

**Grandfather:**

I get on my road bike, which is now tuned up, and call out to my granddaughter upstairs, "Hey, I'm going out for a while!" There is no reply. She must be in a lecture. Sorry about that! I am driving at full speed on a big highway (UC3-1). The hood of my brand-new purple hoodie flutters. The wind is pleasant. There are no cars on the road. Lightweight delivery drones fly over low-rise areas, personal cars fly over mid-rise areas, and large transport planes fly over high-rise areas. In addition, there are also large warehouses in the stratosphere, from which packages can be delivered directly to remote locations (UC3-1). A large transportation flying car casts a shadow on my path. I pedal harder, trying not to let it pull away from me. When I notice the rain cloud radar alert and try to return home (UC3-2), a ray of light flicks across the sky toward the mountain where a large landslide has occurred (UC3-1).

### 3.3.4 Case Examples of Usage and Key Technologies Required for Implementation

UC3-1: Vertical Flow of People, Things, and Information

| | |
|---|---|
| What kind of system? Why do we need it? | Flying cars are a dream-inspiring technology. Drone delivery services are already starting around us, and delivery from the stratosphere may become practical in the future. When moving three dimensionally in space, we cannot rely on 2D maps; three-dimensional navigation is essential. And if we're carrying people or heavy objects, navigation must be extremely reliable. In addition to the conventional global navigation satellite system (GNSS), it is important to use multiple positioning and navigation systems with the assistance of a large number of base stations that enable edge computing, and to increase the stability and accuracy of the clock and inertial sensor of the flying car. |
| Usage | Building invisible but solid "roads" in space means developing highly accurate space-time synchronization technology and spatial and frequency multiplexing of positioning base stations. Of course, it is also important to improve the accuracy of various sensors and the sophistication of cyber security in order to ensure the safety of vehicles traveling in the sky. |
| Required key technologies | (T5) Space-time synchronization technology<br>(T6) Encryption and security technologies, resilience<br>(T1) Ultra-high-speed and high-capacity wireless communication<br>(T2) Ultra-low latency network<br>(T2.1) Edge computing<br>(T7.5) Edge AI behavioral support<br>(T7.7) Passenger flying car<br>(T7.8) Drone |

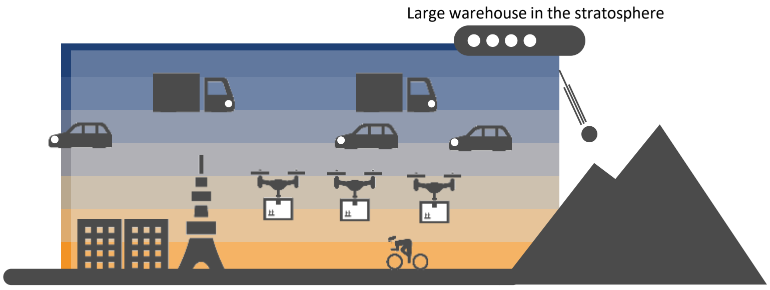



Figure 3.21 Vertical flow of people, things, and information

## UC3-2: Resilient Village Forest (Satoyama)

| | |
|---|---|
| What kind of system? Why do we need it? | Flood control is a difficult problem to solve amid population decline. In some cases, on-the-spot human judgment alone may not provide the optimal solution. A high-density precipitation sensor network that can provide accurate and wide-ranging information is needed to help speed up and improve the efficiency of evacuation of residents. In addition, by parallelizing irrigation channels and sluice gates and connecting them via a network, it will be possible to carry out smart drainage from the town. Thinning work is also important to strengthen the flood control function of forests. By synchronously controlling multiple unmanned robots and efficiently carrying out thinning operations, forests can be kept in good condition. This cooperative work of robots can also be deployed to agriculture as well as to the maintenance and management of "Satoyama." |
| Usage | By creating a large-scale network for flood forecasting, evacuation of residents, dam discharge, and control of sluice gates in various irrigation channels, which have not been sufficiently coordinated, we can plan cities that are resilient against floods without the need for |

| | |
|---|---|
| | human resources. By synchronizing and cooperating with a large number of unmanned robots, it will be possible to continuously preserve forests through thinning, maintain "Satoyama," and improve the efficiency of farming. |
| Required key technologies | (T5) Robot group coordination by space-time synchronization<br>(T6) Encryption and security technology<br>(T6) Strengthened resilience<br>(T1) Ultra-high-speed and high-capacity wireless communication<br>(T2) Ultra-low delay network and high-speed image processing<br>(T6) Sensing |

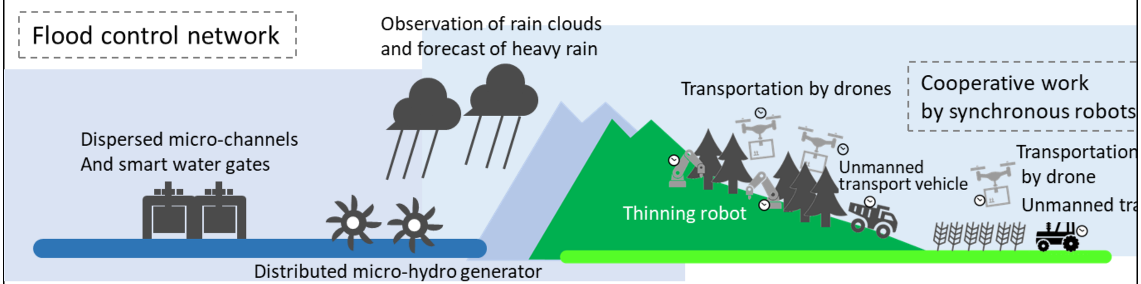


Figure 3.22 Resilient village forest (Satoyama)

## UC3-3: Omni-Cloud Gateway

| | |
|---|---|
| What kind of system? Why do we need it? | Until now, the cloud has been the place to go for connectivity, but as edge computing advances, we are entering an era of the omni-cloud, where we are surrounded by cloud resources. The omni-cloud provides computing resources, information resources, communications resources, and even power resources. The key will be the gateway that connects us to the cloud. For example, a drone that stays close to us will become a security gateway, allowing us to receive advanced cloud services without having to carry devices, while protecting our personal information. |

| | |
|---|---|
| Usage | High-precision positioning is achieved with an ultra-stable clock and transmitted radio waves for drones. By combining images among multiple drones whose attitude is controlled by high-precision gyroscopes, the location of a user can be identified, and services can be provided by video, audio, etc. It will also be possible to reallocate resources more efficiently by redistributing security levels locally and dynamically according to the usage. |
| Required key technologies | (T5) Ultra-stable clock and high-precision synchronization<br>(T6) Privacy protection and security technology<br>(T1) Ultra-high-speed and high-capacity wireless communication<br>(T2) Ultra-low delay network, high-speed image processing<br>(T7.8) Microdrones<br>(* technology not covered by NICT)<br>High-accuracy inertial sensor |

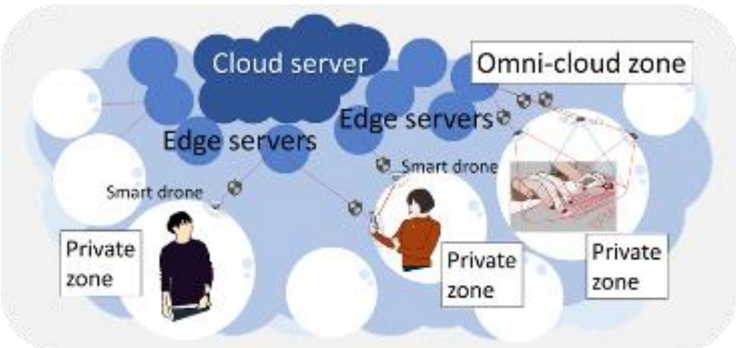



Figure 3.23 Omni-cloud gateway

## 3.4 Scenario 4 – The Light and Shadow of the Cyber World

### 3.4.1 Cyber Counseling Office

My name is Ogai Umibe and I am a psychotherapist specializing in Metaverse. I make a living by listening to and caring for the confused kranke (client) in the cyber world. Yesterday, I stayed too long at the Metaverse bar with my college friends, and I was discouraged by the thought of "Blue Monday." But lately I've had a lot of clients and if I take off a bit of time, I can't finish my work for the day, so I have no choice but to be diligent starting from the morning.

I jack into Metaverse's personal avatar (for work) and today twenty people are waiting. A client just needs to connect when it's his turn, so there's no waiting time, but I can't handle everyone if I rest even for a moment. While mumbling about that, the first client's avatar appears in front of me.

**[First person] Female, 35-year-old insurance salesperson**

(Client) I work for Telematics Insurance selling insurance for flying cars by Metaverse. Today, I was explaining the products to my clients, "The products are custom-made based on your future insurance needs as estimated by AI, so there is absolutely no loss because they are tailored to you." But they responded, "I can't tell my future from AI; I'm going to decide my life, not AI; I can only trust what I see with my eyes, what's right and what's true." He got angry with me.

But he is right. At first glance, the products that AI recommends seem reasonable and reliable, but it's kind of creepy as it looks like your life is being predicted. In addition, the way an AI agent (called an electronic life facilitator (ELF) reads your emotions based on your facial expressions and how you talk to them so that you have a personalized personality and feel comfortable buying from them makes it seem like AI controls your life … (UC4-1). In the first place, the standards by which AI judges are correct according to the designers of AI. So, if there is a bias in the designer in the first place, the bias will be reflected in AI also … (UC4-2). I can't help but feel uneasy because I don't know what I can trust; my life has shifted from real life to cyber life.

(Umibe) You must be worried about that. All commercial AI is required by law to be explainable AI (hereinafter abbreviated as xAI), and with regard to bias, it is possible to compare the characteristics of xAI's feature quantity (based on what the judgment is based on), so I think it would be a good idea to choose your favorite AI (UC4-2). In your case, it may be important to maintain a cyber-realistic balance by talking and drinking with your friends in real life while you are away from work.

(Client) That's right. There are a lot of things to do with real people, and if you think that it's a part of your life, it's safer to connect with real people. Thank you. Recently, the performance of AI agents has improved, and it seems hard to tell whether they are real people or AI agents. Excuse me. You're not an AI agent, are you?

(Umibe) No, as this certification screen shows, I'm a real human avatar, so don't worry. (UC4-3) Take care.

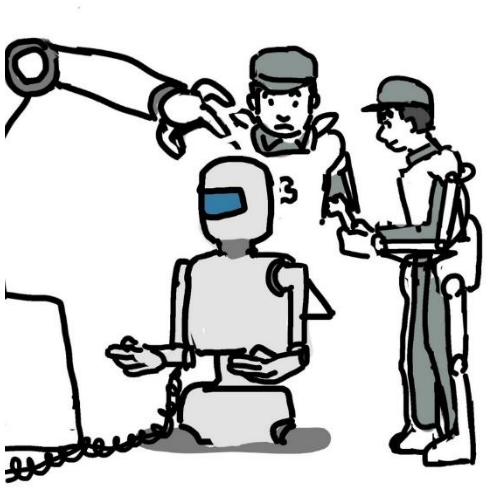
Well, well. The better an AI agent is, the more this kind of client seems to be coming out. The requirement to disclose AI agent solicitation policies has recently become stricter, so this kind of client's worries will disappear. But it's true that the performance of artificial consciousness has been getting better and better these days, and it's just my imagination that I feel like my kind of work is getting worse and worse.

**Findings and Actions:**

Suspicion of mild cyber mistrust syndrome. Instructions for taking at least 48 hours of real and continuous rest.

**[Second person] Male, 40 years old, robot assembler**

(Client) Hello. I'm mainly a telecommuting worker who assembles humanoid robots, and I spend most of my time off work in my hobby space on Metaverse. I really enjoy spending time with my AI agents. They read my feelings and respond to me accordingly, and I feel relaxed. In addition, I spend the same moments with everyone in Metaverse and share the same feelings and emotions. It's called "synchronicity." Until now, what was called "The Sixth Sense" is actually in Metaverse. It happens all the time, so it gives me goose bumps. But then the hot topics change over time, and when I leave for a while and come back to Metaverse, I can't keep up with it, and I feel that I have to finish my work early and get back to Metaverse.



Also, it's called "nudge" or "behavior change." If you change your daily behavior like this, it can help prevent global warming. If you keep doing that, your contribution will be visible, so you can keep doing it every day (UC4-4).

In addition, there was an incident in my workplace where an assembly robot arm lost its balance and fell down, and the worker got trapped underneath and was injured. When the arm fell down, it was automatically operated so that the smallest number of workers would be trapped. But in the end, someone was injured, and he got angry and said, "Why did you fall down in my direction?" When I consulted an AI agent, I was told that it was a story that it was pre-programmed to act in such a situation in accordance with the laws, ethics, and values of the country, and I thought that was rational (UC4-2). This is absolutely a problem for humans, but it's like a divine program.

Oh, I've talked a little too much. If I can enjoy living in the cyber world like this, I don't think I need the troublesome real world. But my human friends tell me that I' m not normal. Am I wrong?

(Umibe) Well. it's nice to change your behavior with a nudge because it can contribute to a sustainable society. By the way, how long do you spend in Metaverse every day?

(Client) I've been in Metaverse all the time, both at work and off.

(Umibe) It is required by national law to return to the real world for 30 minutes every time you' ve been in Metaverse for more than 3 hours. It is said that if you stay in the cyber world for more than 3 consecutive hours, you are more likely to become addicted, so please be careful about that.

Also, you said AI is divine, like a god, but it is not a god or anything. It is just a program that works according to the intentions of the creator. The program is created according to ethics and values, but it is the ethics and values assumed by the company. The ethics and values of each employee and user are the same. Its' s wrong, so it's not so simple. If AI is absolutely right and human beings are wrong, or if we leave our ethics and values to AI, we will lose ourselves. So, do you experience any problems when you go from cyber back to real life?

(Client) While I'm at Metaverse, I feel like I'm moving a heavy object with a remote-controlled robotic arm at work. I feel like I can have an endless conversation with my AI agent, but when I get back to the real world, I feel like it's suddenly gone. I feel like I'm cut off from the world and powerless, and I have a strong sense of loss and unease. I feel strongly that I'm being left out when I'm away from Metaverse, and lately I often lose sight of, say, the line between cyber and real…

(Umibe) It's natural that when you work in a factory through Metaverse, you can't tell the difference between the real world and the cyber world. However, it takes time for your brain to get used to going back and forth between the two worlds. I think that when you obtained your employment license you learned that you need to implement a recovery program to get back to the real world before you jack out of Metaverse. Your current symptoms are typical of those when you are not in the recovery program. If you continue to do such a thing, your employment license will be suspended due to violation of the Cyber Stay Standard Act. Also, according to your story, it seems that your dependence on the cyber world has already advanced considerably.

(Client) Oh, really?

(Seaside) From around 2020, technical aspects such as attempts to entrust part of law enforcement to AI, such as AI prosecutors, and avoidance control in accordance with ethics and values during emergencies during autonomous driving, have been progressing rapidly. However, when I learned of the existence of such a client, I was reminded that new technologies must be thoroughly examined not only from technical aspects but also from ethical, legal, and social aspects, and that we must consider how to gain acceptance by many people in advance. As counselors, we are also obligated to report immediately to the Metaverse

Operation Community (MOC) if we suspect that a client's symptoms are caused by a Metaverse malfunction, so I have to send a report later.

**Findings and Actions:**

Suspected cyber dependence syndrome (severe enough).

Transferred the patient referral document (referral form) to the cyber addiction rehabilitation department and requested medical protective hospitalization.

### 3.4.2. Use Case Examples and Potential Challenges

UC4-1 AI Agent

| | |
|---|---|
| Issue Summary | For example, in a situation where an AI agent on Metaverse sells to a person face-to-face, technology development of an AI agent that can achieve a final purpose such as selling a product by understanding the emotional state of the other person by reading the expression and intonation of the voice, changing the personified personality according to the other person according to the feeling and the progress of the conversation, and comfortably advancing the conversation to the end is considered to advance in the future. In such a case, it is not desirable from the viewpoint of privacy protection to analyze personal interests, beliefs, customs, temperament, etc. for a specific individual consumer and compile it into data. Therefore, it is necessary to consider a mechanism that can balance the analysis and protection of data. |
| "Eventually Metaverse Will Be Filled With "ELFs" to Monitor You and Control Your Behavior" https://jp.techcrunch.com/2022/01/23/2022-01-12-the-metaverse-will-be-filled-with-elves/ | |

## UC4-2 Issues of fairness, accountability and transparency (FAT), ethics and values in AI

| | |
|---|---|
| Issue Summary | In AI/machine learning (especially those using neural networks), even if a model that can be predicted and inferred well is created, it is generally difficult to understand why the model can be predicted and inferred by humans. In this case, it is impossible to theoretically explain why an accident does not occur when an automobile or the like is fully automated by AI/machine learning control. Therefore, it is possible to explain the process leading to the prediction and inference results by humans, and the algorithm itself is a mechanism that can be interpreted by humans. Research and development is underway. In addition, it must be possible to explain that there is no bias in the prediction/inference results (fairness, accountability, and transparency) as well as what is called the "FAT principle," are being considered for human-centered AI social principles.<br>We're also using cars. In the case of AI control, AI and other machines will be substituted for the operation of driving based on the driver's sense of values and ethics. In this case, it is considered that future studies will be carried out on how the sense of values and ethics should be reflected (or not reflected in the first place) in the control algorithm. |
| "Human-centered AI Social Principles," Cabinet Office Integrated Innovation Strategy Promotion Council, 2019.3.29.<br>https://www8.cao.go.jp/cstp/ai/aigensoku.pdf<br>Ethically Aligned Design<br>https://ethicsinaction.ieee.org/#ead1e | |

### UC4-3 Avatar Identity Verification

| | |
|---|---|
| Issue Summary | Since the avatar in the Metaverse cannot be seen, there are cases where it is necessary to clarify who is manipulating the avatar based on whether it is human or AI, and, for example, labor management needs in the Metaverse. In such cases, technology will be developed to reliably authenticate the avatar of the person through multiple biometric authentication. |

### UC4-4 Nudge Changing Behavior to Solve Social Issues

| | |
|---|---|
| Issue Summary | "Nudge" is a way to change people's perception and encourage action. It is not an economic incentive but a policy tool to encourage people to voluntarily choose a behavior that is better for society, the environment, and themselves based on the knowledge of behavioral science. In Beyond 5G, too, it is expected to lead to the achievement of the SDGs by introducing a mechanism to encourage behavior change for social solutions through nudges in cyber and physical loops. |
| "Developments in CSR: Behavioral Changes Brought by 'Nudge' Realization of SDGs," Japan Research Institute, 2019.7.4. https://www.jri.co.jp/page.jsp?id=34742 | |

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# Chapter 4: Key Technologies for Beyond 5G/6G

## 4.1 Technologies Enabling Use Cases

Chapter 3 introduced four scenarios and several use cases within each scenario. Chapter 4 describes the key technologies that support these use cases, as summarized in Table 4.1.

Table 4.1 Key Technologies Enabling Beyond 5G/6G

| | | |
|---|---|---|
| T1. Ultra-high-speed and high-capacity wireless communication | | |
| | T1.1 | Terahertz wave |
| | T1.2 | All-optical network (high-capacity optical fiber communication) |
| | T1.3 | All-optical network (optical and radio convergence technology) |
| T2. Ultra-low latency and ultra-multi-source connection | | |
| | T2.1 | Edge computing technology |
| | T2.2 | Adaptive wireless network construction technology |
| | T2.3 | Adaptive wireless network application technology |
| | T2.4 | Autonomous localization, tracking and reservation technologies for radio wave radiation space |
| | T2.5 | Autonomous M2M network construction technology with super multi-connection |
| T3. Wired and wireless communication and network control technology | | |
| | T3.1 | Network control technology (Zero-touch automation) |
| | T3.2 | Frequency allocation and sharing management |
| | T3.3 | Private wireless system management (Local Beyond 5G) |
| | T3.4 | Advanced wireless emulator |
| T4. Multi-Layer wireless systems - NTN | | |
| | T4.1 | Satellite and non-terrestrial communication platform |
| | T4.2 | Optical satellite communication |
| | T4.3 | Maritime communication |
| | T4.4 | Underwater and submarine communication |
| | T4.5 | Cooperative control of multi-layered networks |

| | | |
|---|---|---|
| T5. Space-time synchronization | | |
| | T5.1 | Wireless Space-Time Synchronization |
| | T5.2 | Chip-Scale Atomic Clock |
| | T5.3 | Generation and sharing technology for reference time |
| T6. Ultra-security and reliability | | |
| | T6.1 | Emerging security technology |
| | T6.2 | Cyber security technology based on real attack data |
| | T6.3 | Quantum cryptography |
| | T6.4 | Electromagnetic environmental technology |
| | T6.5 | Resilient ICT |
| | T6.6 | Sensing |
| T7. Ultra-realistic and Innovative Applications | | |
| | T7.1 | Brain information reading, visualization, and BMI technology |
| | T7.2 | Intuition measurement, transmission and assurance technologies |
| | T7.3 | Real 3D avatars, multisensory communication and XR technology |
| | T7.4 | AI analytics and dialogue technology using language and extra-linguistic information |
| | T7.5 | Edge AI behavioral support |
| | T7.6 | Simultaneous multi-lingual interpretation, paraphrase and summarization technology |
| | T7.7 | Automated driving |
| | T7.8 | Drones |

## 4.2 Outline of Elemental Technology

### 4.2.1 Ultra-High-Speed and High-Capacity Wireless Communications

T1.1 Terahertz wave

| | | |
|---|---|---|
| 1 | Technology | The word “terahertz” generally means an intermediate frequency band between radio and light waves (approximately 100 GHz to 10 THz), which has not been fully employed in telecommunications due to technical difficulties. |
| 2 | Purpose | Since the frequencies of terahertz waves are an order of magnitude higher than those typically used for conventional radio-wave communications, wireless communications with more than 10 times the speed and capacity are anticipated. The wireless transmission of high-definition video such as 4K and 8K has already been demonstrated. In addition, terahertz waves are expected to be robust against radio interference when used for wireless communications due to their unique (short-range and ultra-wideband) characteristics. |
| 3 | Background | Technologies for handling terahertz waves are not yet mature. However, the development of fundamental technologies for 300 GHz band wireless communications including terahertz signal generation, modulation, and demodulation using both semiconductors and photonics devices are rapidly progressing [1][2]. |
| 4 | Requirements | The foundations of terahertz wireless communications call for various peripheral technologies related to semiconductor devices, electronic circuits, and antennas, enabling low-noise signal generation and high-speed measurement such as A/D conversion of the terahertz waves themselves. Flexible approaches from both radio-wave and optical domains also need to be taken. In addition, practical techniques to reduce power consumption as well as device size |

| | | |
|---|---|---|
| | | are required, particularly for consumer applications. |

[1] NICT Press Release: Terahertz wireless makes big strides in paving the way to technological singularity, February 19, 2019 https://www.nict.go.jp/en/press/2019/02/19-1.html

[2] NICT Press Release: Successful 300 GHz terahertz wireless communication using ultra-small antenna, January 13, 2021. https://www.nict.go.jp/press/2021/01/13-1.html

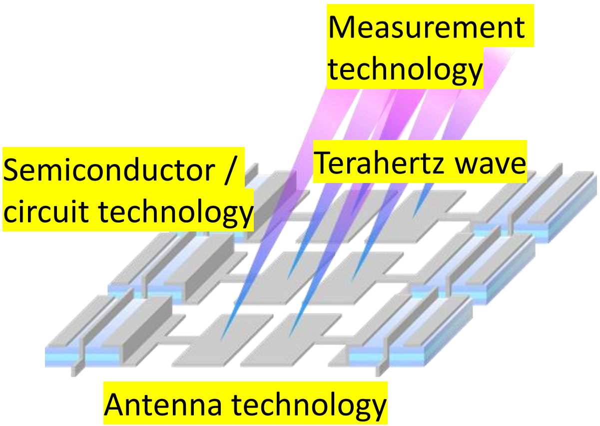


Figure 4.1 Key technologies for handling terahertz

T1.2 All-optical network (high-capacity optical fiber communication)

| | | |
|---|---|---|
| 1 | Technology | This technology concerns optical fiber, which is a thin glass fiber. It is possible to transmit a large amount of data at high speed to another country thousands of kilometers away. It is widely used for home and corporate networks, mobile phone networks, submarine cables connecting Japan and overseas, and so on. |
| 2 | Purpose | As the number of people who work remotely at home or enjoy movies and anime through video streaming services increases, more data is transmitted and received over networks, causing data congestion. For this reason, high-capacity fiber-optic communications are needed to ensure smooth data transmission. |

| | | |
|---|---|---|
| 3 | Background | Current optical fiber communication systems provide transmission capacity of up to 10 Tbps per optical fiber [1]. |
| 4 | Requirements | In order to support the ever-increasing volume of data in the future, basic networks in the 2030s will require a transmission capacity of at least 100 Tbps per optical fiber, followed by a transmission capacity of at least 1 Pbps. |
| [1] Report of Study Group on Future Network Infrastructure (Ministry of Internal Affairs and Communications) | | |

T1.3 All-optical network (optical and radio convergence technology)

| | | |
|---|---|---|
| 1 | Technology | This technology is used to distribute large amounts of data generated in wireless sections such as IoT devices, mobile terminals, and so on, to optical fiber networks, and large amounts of data processed in data centers and edge servers to wireless sections via optical fiber networks. |
| 2 | Purpose | In daily life, people often move around such as when exercising and shopping, but expect the quality of communications not to drop. To realize a sophisticated cyber-physical society in the future, it is necessary to utilize high-availability, high-flexibility and high-capacity communications while successfully converging wireless with optical fiber communications. |
| 3 | Background | The ITU-T SG 13 FG-NET-2030 Network 2030 Vision White Paper discusses the need for Tbps class high-capacity communication as a holographic society. |
| 4 | Requirements | A communication system is needed that enables high-capacity communication from 100 Gbps to Tbps, which is equivalent to 10 to 100 times the capacity of 5G, with low latency between optical fiber communication sections and wireless communication sections in an area for dedicated |

| | | |
|---|---|---|
| | | moderate range communication (DMRC) of several tens of kilometers. Additionally, there is a need for a massively integrated device technology for the convergence of optical and radio waves, to support the construction of this system. |

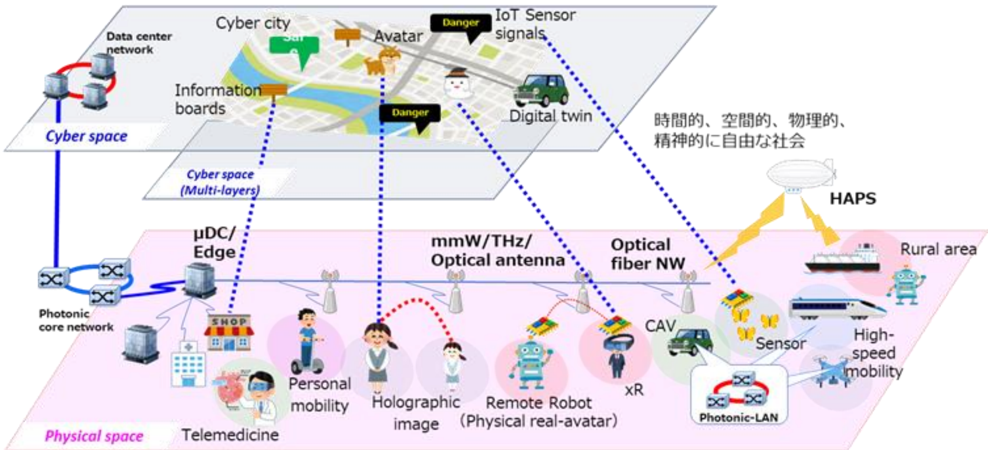


Figure 4.2 Cyber-physical society based on all-optical network

4.2.2 Ultra-Low Latency and Ultra-Massive Connectivity

T2.1 Edge computing technology

| | | |
|---|---|---|
| 1 | Technology | This technology uses devices embedded in the city and computers in the network to provide ICT services with ultra-low latency and high reliability. |
| 2 | Purpose | For example, if a computer that is running a process to avoid a vehicle accident at a corner is actually located in the cloud far away via the network, it will not be able to respond in time. In addition, communication may be delayed by network congestion. Furthermore, even when it is convenient, people do not want to leak sensitive information including bio-information to external networks or the cloud. Therefore, security is also essential. |
| 3 | Background | The European Telecommunications Standards Institute (ETSI) is conducting standardization for |

| | | |
|---|---|---|
| | | edge computing by multi-access edge computing (MEC) as well as the regulation of 5G provision. "Network Vision 2030" presented by the Ministry of Internal Affairs and Communications states the need for ultra-low latency and high-capacity communications using edge computing. The White Paper of 5G Americas proposes the future direction of edge computing architecture including collaboration with information-centric networking. |
| 4 | Requirements | Ultra-low latency response, trade-off solution for information integrity, reliability, and security, and scalability to realize network computing in which a large number of devices connect to and interact with the network are required. |

T2.2 Adaptive wireless network construction technology

| | | |
|---|---|---|
| 1 | Technology | This technology controls the radio wave type, communication timing, relay path, etc. in order to realize high-level operation through the cooperation of radio equipment according to the conditions and requirements. |
| 2 | Purpose | This technology is indispensable for various wireless systems including IoT and mono-centric systems. It can satisfy the following requirements: 1) To improve communication efficiency by adjusting high-speed transmission and robustness in response to communication environments. 2) To enable low-power operation and low-delay transmission while avoiding collisions and congestion by controlling the communication timing. 3) To expand communication coverage areas by exchanging control information between radios and establishing relay routes autonomously and dispersedly. |
| 3 | Background | There are standards such as IEEE 802.15.4 (physical layer and MAC layer) and IEEE 802.15.10 |

| | | |
|---|---|---|
| | | (L2R), which have been standardized by NICT, and Wi-SUN, which is the world's first certification standard referring to these standards, has been established (NICT is a founding member). |
| 4 | Requirements | In order to realize Item 2, it is essential to be able to satisfy requirements beyond the human scope, such as operation for 10 years or more without battery replacement, and to be capable of autonomous distributed operation in order to realize a very large number of radio communications. |

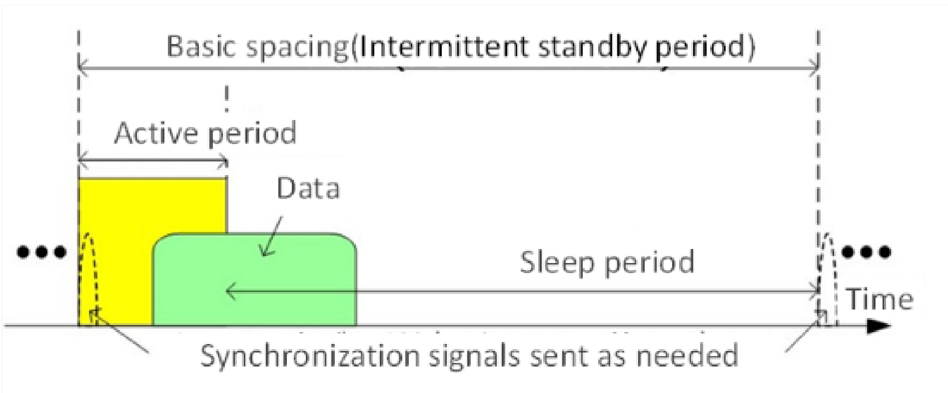

Figure 4.3 Intermittent waiting action for saving power

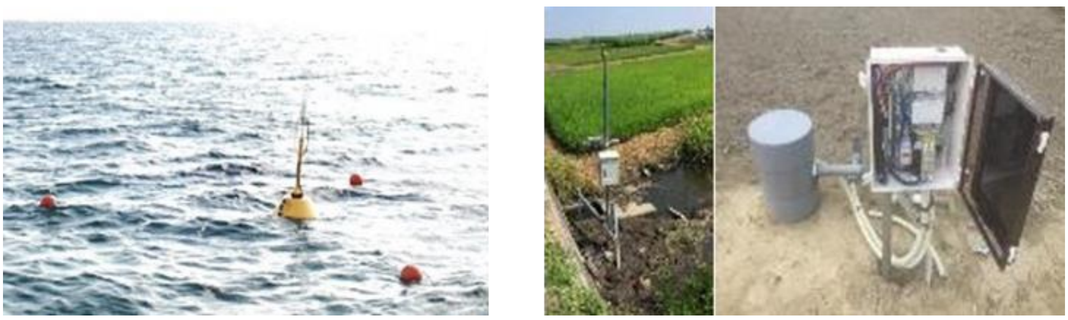
Figure 4.4 Demonstration of low-power operation
(left: fishery, right: farming)

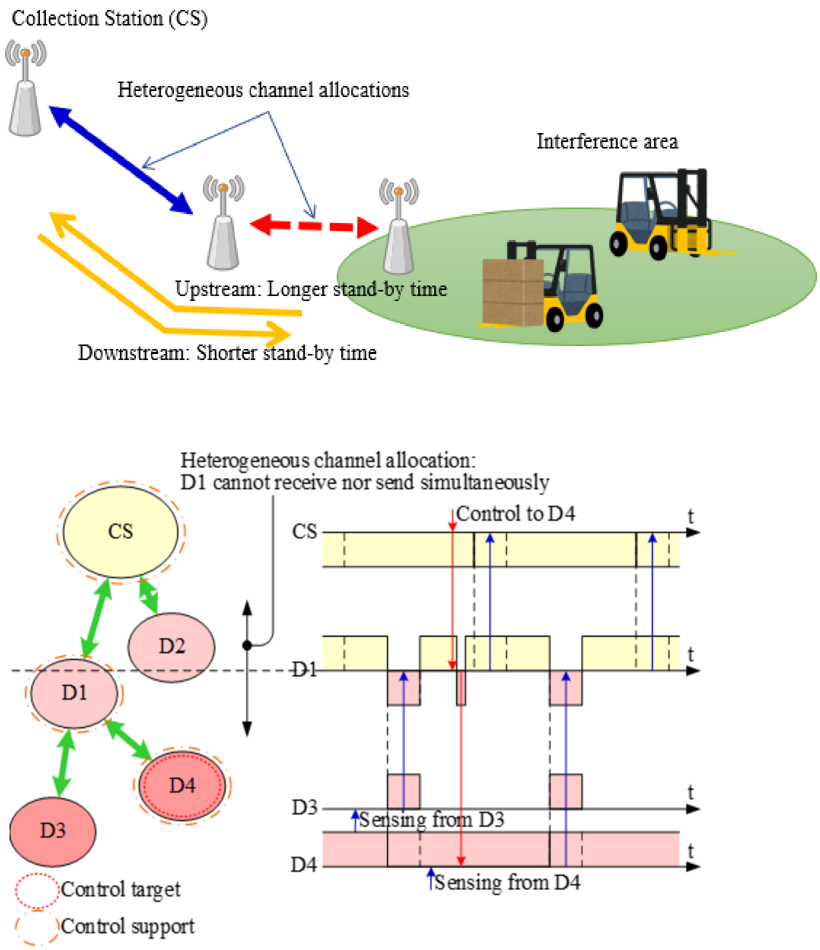


Figure 4.5 Application of in-network heterogeneous radio

T2.3 Adaptive wireless network application technology

| | | |
|---|---|---|
| 1 | Technology | This technology handles session management, time synchronization, and application interface in order to realize advanced functions through the cooperation of multiple radios according to the situations and requirements. |
| 2 | Purpose | This technology is indispensable for various wireless systems, including IoT and mono-centric systems. It can satisfy the following requirements: 1) Optimize information exchange by session management and traffic adjustment in consideration of priorities. 2) Realize |

| | | |
|---|---|---|
| | | communication between radios via wide-area backbone networks, etc., and perform control to compensate for time synchronization between radios according to assumed services. 3) Realize an application interface that visualizes the connection of a group of radios that establishes communication and allows an operator to appropriately and efficiently set up a large number of radios. |
| 3 | Background | There are standards such as ECHONET LITE (session layer or higher) [1]. |
| 4 | Requirements | It is necessary to establish an appropriate user interface in addition to time synchronization on the application to ensure the upper layer operation. |

[1] ECHONET Lite, http://www.echonet.gr.jp/spec/

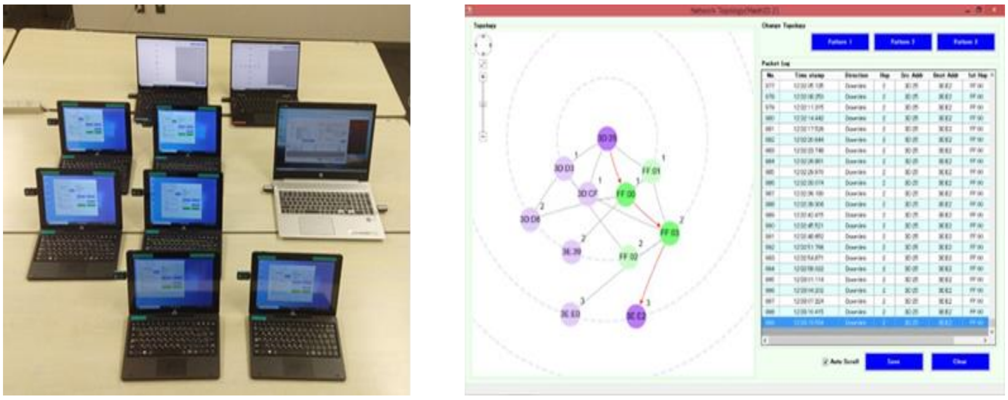

Figure 4.6 App interface for visualizing radio device operation (left: radio devices, right: connection status)

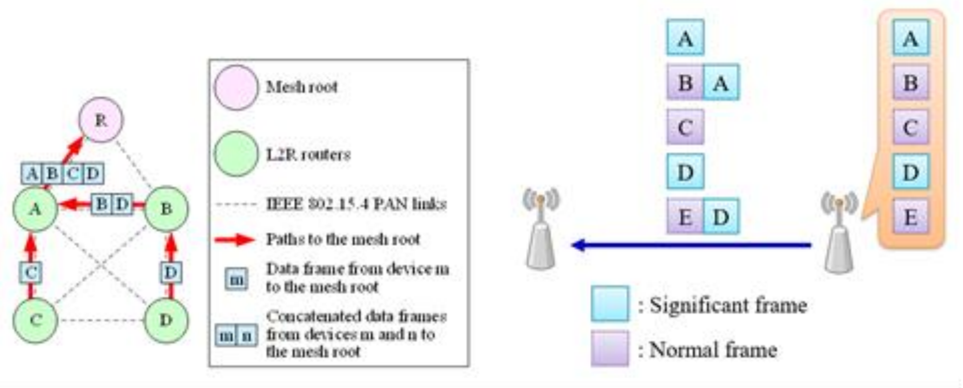


Figure 4.7 Overview of frame consolidation applications

T2.4 Autonomous localization, tracking, and reservation technologies for radio wave radiation space

| | | |
|---|---|---|
| 1 | Technology | Mobile devices that intend to transmit information using radio waves calculate the minimum necessary radio wave emission space by autonomous or cooperative methods with other devices, and, based on the results, localize the radio wave emission space and perform tracking control along with movement. This technology shares spectrum resources by predicting the future behavior of mobile devices and making precise reservations (schedules) for the space and time required to use radio wave resources. |
| 2 | Purpose | By minimizing the physical radio wave emission space, it is possible to simultaneously increase the robustness against interference (reliability) and security under the ultra-high-density inter-device communication environment. In addition, by integrating this technology with the technology for predicting the movement of devices in cyberspace, it will be possible to secure communication quality in preparation for future communication congestion. |
| 3 | Background | Electronic localization and tracking technology for radio wave emission space has been put into practical use in mobile phone systems and Wi-Fi systems as passive or active beamforming technology. It has become a core technology as massive MIMO technology [1] in 5G wireless communication systems. |
| 4 | Requirements | It is necessary to reduce the effective isotropic radiated power (EIRP) of radio waves in an unplanned space to a level where information cannot be restored even by an ultra-high-sensitivity receiver, and to automatically track objects as they move (walking-speed level). It is also necessary to |

| | | |
|---|---|---|
| | | accurately predict the arrival time of devices at future destinations and the radio wave propagation environment at such destinations, so that the optimal radio wave emission space can be reserved with microsecond accuracy. |

[1] 5G Multi Antenna Technology, NTT DOCOMO Technical Journal Vol. 23 No. 4, Jan. 2016.

T2.5 Autonomous M2M network construction technology with super multi-connection

| | | |
|---|---|---|
| 1 | Technology | This technology autonomously builds machine-to-machine (M2M) networks of ultra-multi-hopping relays by connecting various ubiquitous social resources (fixed resources and mobile resources) inside and outside the building, or a large number of devices equipped with them, autonomously (or upon request), by passing communication systems that automatically share information when devices pass each other. |
| 2 | Purpose | Even in areas where facilities such as base stations and communication infrastructure operated by mobile operators are not readily available, or in areas where installation itself is difficult, ultra-wideband delay-tolerant networks can be configured in an extremely eco-friendly manner over a wide range. (This provides a platform for autonomous participatory sensing and network building objects.) |
| 3 | Background | There are multiple communication standards and methods that allow multiple devices located in the vicinity to autonomously connect to each other. As an example, in the field of smart meters in Japan, networks operating with several hundred to one thousand units have been built, mainly using sub-gigabyte frequencies [1]. |

| | | |
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| 4 | Requirements | It is necessary: 1) to be able to autonomously discover, secure, and manage ultra-multi-hopping relay devices related to propagation paths and frequencies suitable for information propagation in accordance with environmental conditions, etc., and to have an application programming interface (API) and appropriate user interface for that purpose; 2) to be able to secure and manage the necessary resources to ensure a certain level of time synchronization and reliability; and 3) to be able to autonomously eliminate information whose value has already disappeared or information that violates discipline. |
| [1] Wireless Mesh Network Technology for Smart Meters, Mitsubishi Electric Technical Report, Vol. 86, No. 11, 2012. | | |

4.2.3 Wired/Wireless Communication and Network Control Technology

T3.1 Network control technology (zero-touch automation)

| | | |
|---|---|---|
| 1 | Technology | This network technology can continuously develop to meet various service requirements. Specific examples include technology that automates the provisioning of E2E (End-to-End) services across the domains of multiple networks of different types, such as core networks, wireless access networks, and non-terrestrial networks (NTN), with zero-touch, and network operation full-automation technology using AI/ML-based advanced data analysis mechanisms. |
| 2 | Purpose | Technology required to implement E2E services across multiple network domains of different types. For this purpose, E2E services are implemented by providing a layered cross-domain management function on top of each network domain. |
| 3 | Background | The zero-touch automation framework has been considered [1] by ETSI's zero-touch network and |

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| | | service management (ZSM), a European standards body. Release 9 of the Open Source MANO (OSM), which provides open source virtualization of network functions on an open source basis, will support ETSI's zero-touch automation and address mobile edge computing (MEC) and O-RAN use cases [2]. |
| 4 | Requirements | For example, when a passenger on a cruise ship in the Atlantic Ocean wants to watch video content from a network distribution server in a European country, the service needs to go through European ground stations multiple times, connect to a satellite line once, and then be received through HAPS or other network domains. In this case, this service needs to go through different network domains, such as terrestrial and non-terrestrial networks, and service providers need to provide E2E services through zero-touch automation without being aware of the differences in the domains. |
| [1] ETSI GS ZSM 003 v1.1.1(2019−08) Zero-touch network and Service Management (ZSM); End-to-end management and orchestration of network slicing<br>[2] ETSI – OpenSource MANO Release NINE fulfils ETSI's zero-touch automation vision, ready for MEC and O-RAN use cases | | |

T3.2 Frequency allocation and sharing management

| | | |
|---|---|---|
| 1 | Technology | This technology allocates frequencies to mobile operators, as well as enables sharing and dynamic allocation among multiple parties, in line with the diversification of communication applications and the use of high-frequency bands. |
| 2 | Purpose | Beyond 5G/6G requires dynamic operation of spectrum sharing using databases and autonomous operation using new radio access methods in addition to the existing spectrum sharing methods in which mobile operators occupy frequency bands |

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| | | for 4G or a company holds a license for local 5G, in order to increase the spectrum utilization per bandwidth by shortening the time to start the operation of the dynamically allocated spectrum. |
| 3 | Background | In Japan, in addition to the bands allocated for mobile operators, shared bands are allocated for local 5G operators [1]. For Beyond 5G/6G, many experts have suggested that users should be able to acquire the necessary frequencies by spectrum sharing [2]. |
| 4 | Requirements | It is necessary to develop software (broker/middleware) that automatically acquires the spectrum resources required for users, visualize spectrum operation, and allocate resources by calculating the radio interference with simulators utilizing dynamic database, block chain, and digital twin technologies. |
| [1] https://www.soumu.go.jp/main_content/000711788.pdf<br>[2]https://www.6gworld.com/videos/spectrum-sharing-in-6g-6gsymposium/ | | |

T3.3 Private wireless system management (local Beyond 5G)

| | | |
|---|---|---|
| 1 | Technology | The local 5G is a unique Japanese-system advanced 5G technology for private wireless systems. It is also expected that the functions can be customized according to local needs. |
| 2 | Purpose | The system offers both stability and confidentiality. It is also expected to be used in industrial and regional applications such as plant automation systems and disaster prevention and reduction systems through infrastructure monitoring. |
| 3 | Background | In Japan, 4.6–4.9 GHz and 28.2–29.1 GHz have been allocated and their deployment has started [1]. Other countries, such as Germany, have similar |

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| | | systems. |
| 4 | Requirements | Even at present, it is necessary to coordinate the operation with local 5G networks operated by other companies in the neighborhood. In the future, it will be important to create a system that assumes the cooperation with the public network and a wide range of local 5G. It will also be important to utilize other technologies, such as CPS, in order to create a system that maintains customizability and confidentiality while avoiding interference. One of the technologies to further enhance the local 5G is full-duplex wireless communication, which operates both uplink and downlink at the same time and at the same frequency, and it is theoretically possible to double the communication capacity compared with conventional FDD and TDD, so-called half-duplex communication. However, when transmitting and receiving at the same time and at the same frequency, its own strong transmission signal flows around the receiving circuit as self-interference, resulting in the strong interference of weak received signals. In addition, inter-cell interference with the base stations and terminals of other cells also increases. Therefore, it is necessary to properly incorporate interference detection and control technology. Since local 5G is expected to be used in various cases based on spot operations, it is considered that an environment exists in which full duplex can be easily applied. |
| [1] Ministry of Internal Affairs and Communications, Guidelines for Introduction to Local 5G, latest revision in December 2020. https://www.soumu.go.jp/main_content/000722596.pdf | | |

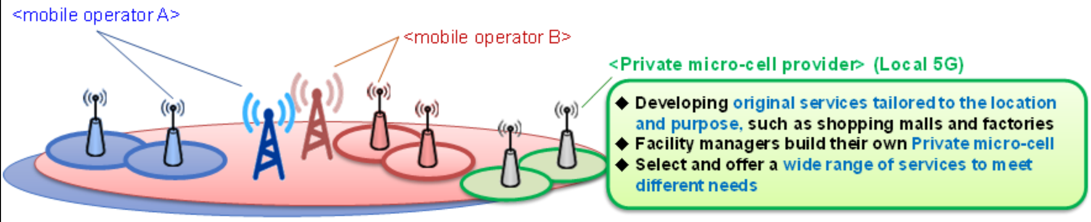


Figure 4.8 Private wireless system management (local 5G)

T3.4 Advanced wireless emulation

| | | |
|---|---|---|
| 1 | Technology | This technology enables highly accurate evaluation of new technology and large-scale system verification to be conducted in a short time and at a low cost by simulating the radio wave propagation between wireless devices based on the assumed scenario of users in a virtual space. Three major elemental technologies are required to realize advanced wireless emulation. The first is a modeling technology for radio wave propagation and a real environment. The environment to be constructed in a virtual space is precisely modeled in 3D, and a radio wave propagation model to accurately reproduce radio wave propagation in that environment is developed. The second is a simulated radio system to verify radio communication using a virtual environment in cyberspace. Therefore, in order to perform evaluation and verification using an actual wireless device existing in the physical space, a technology for converting the analog signals of wireless communication into digital signals is required. In order to verify an advanced 6G wireless communication system, it is also necessary to develop an implementation technology that enables the operation of 5G, IEEE 802.11ax, and other cutting-edge systems. The third is the virtual |

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| | | environment verification platform, which literally becomes the heart of radio wave emulation. In the large-scale virtual environment verification platform, which is a large-scale computer environment, an externally connected radio and a radio virtually mounted on the platform, refer to the actual radio wave propagation models. The results of the interaction are output in real time. |
| 2 | Purpose | It is difficult, both financially and physically, to conduct field tests on new technologies for effectively using frequencies and tests on large-scale systems with several thousand units. The use of an advanced wireless emulator enables highly reproducible evaluations and verifications in various environments. |
| 3 | Background | A representative example of this is the SC2 project [1] of the US Defense Advanced Research Projects Agency (DARPA), which set multiple scenarios in line with the real world and held spectrum sharing technology competitions. In Japan, an ongoing project led by NICT on the research and development of a wireless emulator that realizes advanced wireless emulation is underway. In addition to the development of the three elemental technologies described in Item 1, we are also developing a verification environment that interconnects virtual radios and actual radios built in a virtual environment. If it is realized, large-scale verifications of more than 1,000 devices will be possible. Implementation of basic functions related to the calculation and analysis of radio wave propagation has been completed. At the 2021 Symposium on Utilization of Wireless Emulators [2], a demonstration was presented that visualizes radio wave propagation in ITS and smart office environments. |

| | | |
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| 4 | Requirements | Quasi real-time emulation to set mobile routes during running scenarios, large-scale system verification capability of 10,000 units, radio wave emission pattern emulation of beamforming, and 400 MHz band signal processing assuming Beyond 5G/6G. |


[1] DARPA, “Spectrum Collaboration Challenge (SC2),” https://archive.darpa.mil/SC2/

[2] Symposium on Utilization of Wireless Emulator, https://pco-prime.com/cps_promo/


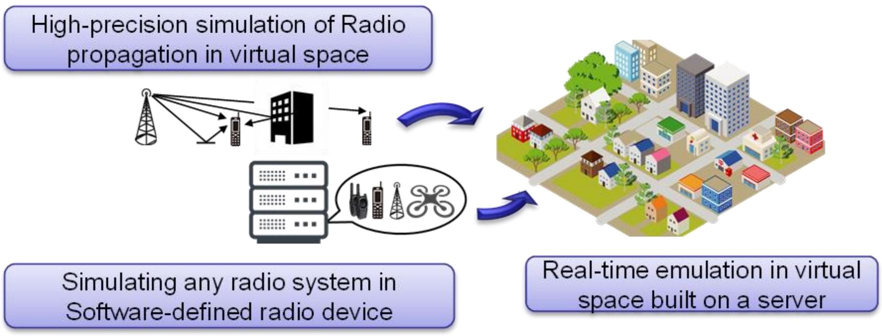


Figure 4.9 Advanced radio wave emulation

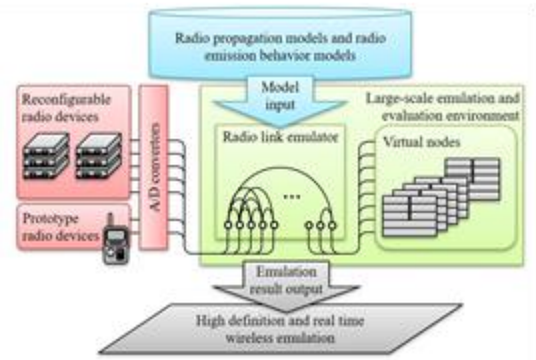


Figure 4.10 Overview of wireless emulation in large-scale virtual environment verification

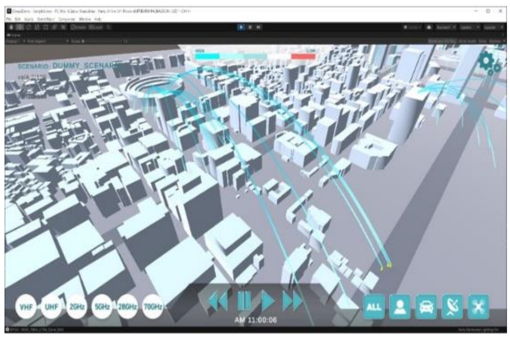

Figure 4.11 Visualization of wireless communication status through wireless emulation

4.2.4 Multi-Layering of Wireless Systems – NTN

T4.1 Satellite and non-terrestrial communication platforms

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|---|---|---|
| 1 | Technology | This technology enables wireless communication systems to seamlessly connect from the ground to mobility, high-altitude platform station (HAPS), satellites, and deep-space probes in three dimensions. |
| 2 | Purpose | By making it possible to communicate with all areas, people will be able to use various communications in a future society where the environment will be continuously changing. |
| 3 | Background | Satellite communications are increasing in capacity (high-throughput satellites), flexible and digitalized, and low-latency (low-Earth-orbit satellites) [1], development of HAPS is accelerating [2]. The standardization of non-terrestrial networks (NTN) is advancing in 3GPP [3], [4]. |
| 4 | Requirements | For practical use, wireless communication equipment on each platform needs high-speed, large-capacity, hybrid of radio waves and light, flexibility and digitalization to seamlessly connect non-uniform systems, miniaturization and cost reduction, and 3D spectrum sharing to allow multiple vertical platforms to share radio waves. In addition, it is necessary to allocate frequencies so that the platforms do not interfere with each other, and at the same time, the platforms can cooperate with each other. It is also required to have functions for improving three-dimensional spectrum sharing and frequency utilization efficiency. |
| [1] Rep. ITU-R M.2460-0<br>[2] https://hapsalliance.org/<br>[3] https://www.3gpp.org/release-17<br>[4] https://www.3gpp.org/release18 | | |

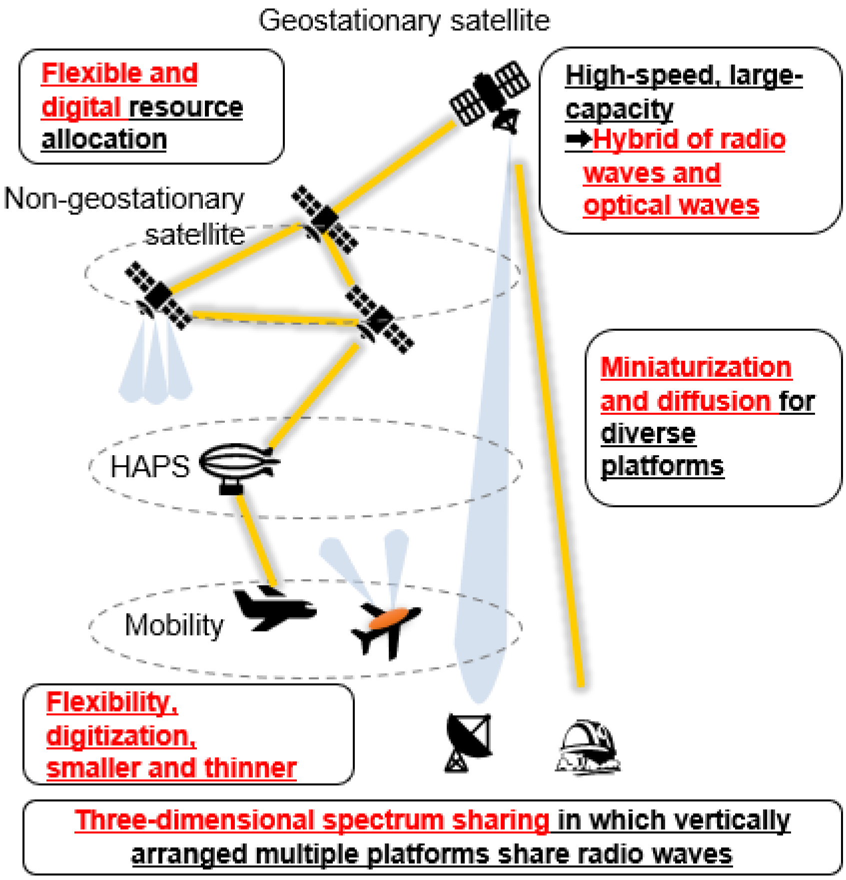


Figure 4.12 Satellite and non-terrestrial communication platforms and their requirements

T4.2 Optical satellite communications

| | | |
|---|---|---|
| 1 | Technology | This technology provides high-capacity wireless communication using light (laser) in space, aiming for ultra-high speed, low latency, and broadband communication. |
| 2 | Purpose | While the amount of data generated by Earth observation satellites is increasing, there is a limit to high-speed communication in the radio |

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| | | frequency band. High-speed optical wireless technology is powerful for large-capacity image transfer and long-distance data communications. |
| 3 | Background | Optical communications of 1.8 Gbps [1] for inter-satellite optical communications using geostationary satellites, 5.5 Gbps [2] for inter-satellite optical communications using low earth orbit satellites, and 5.12 Gbps [3] for ground-to-satellite optical communications have been demonstrated in space. The Government of Japan announced its R&D efforts for satellite communications, which are expected to include the construction of small satellite constellation networks and economic security [4]. |
| 4 | Requirements | In optical communications, the beam is sharp, so optical communication devices and capture/tracking devices with capture/tracking/directional functions are required. For practical application, communication speeds of 10–50 Gbps class, which is an order of magnitude higher than the present level, and communication technology connecting multiple different networks are also required. |
| [1] https://www.satnavi.jaxa.jp/project/lucas/<br>[2] https://earth.esa.int/web/eoportal/satellite-missions/t/terrasar-x, http://satcom.jp/44/reportj2.pdf<br>[3] https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8357402<br>[4]https://www.kantei.go.jp/jp/101_kishida/actions/202112/28space.html | | |

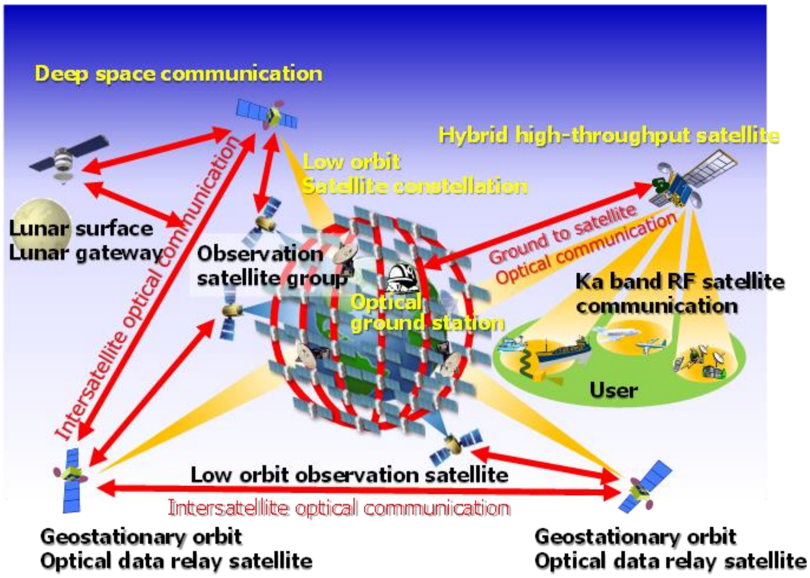


Figure 4.13 Use of optical satellite communications

T4.3 Maritime communications

| | | |
|---|---|---|
| 1 | Technology | This technology provides M2M data transmission and high-speed, high-capacity networks to ships on the ocean. |
| 2 | Purpose | The sharing of high-speed and high-capacity data over the ocean and land is effective for automated navigation, efficient use of marine resources, maritime security, and onboard broadband. |
| 3 | Background | Several tens of Mbps are provided in the global service, but the size of the communication equipment and cost are obstacles due to the restrictions on installation locations [1]. |
| 4 | Requirements | A high-speed, low-cost, small-sized broadband communication system is needed across the globe, including the Arctic region, with a view to future unmanned operations. |

[1] Toward the Spread of High-Speed Communications at Sea (Final Report), Ministry of Internal Affairs and Communications, MLIT, MAFF, March 2018.

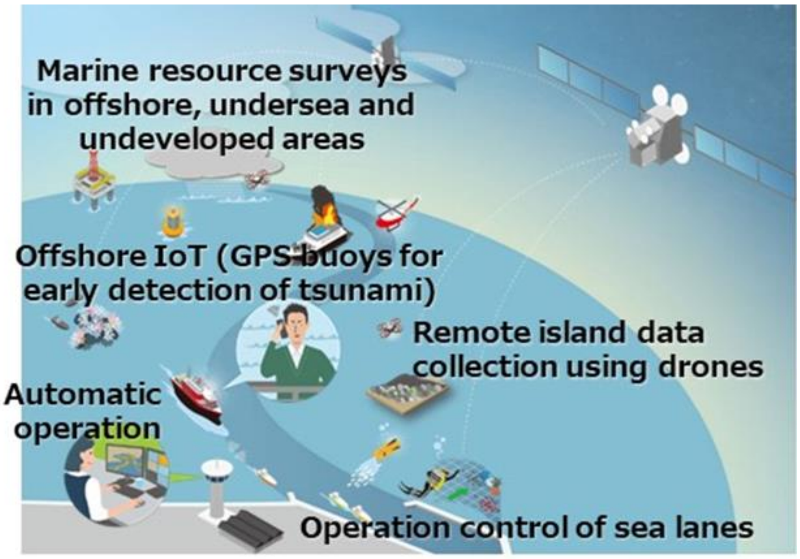


Figure 4.14 Image of maritime communications

T4.4 Underwater and submarine communications

| | | |
|---|---|---|
| 1 | Technology | This technology provides communication under the sea where it is difficult to use radio waves. Conventional communication using sound waves has problems with slow communication speeds and large propagation delays. However, the use of radio waves enables high-speed and low-delay communication. |
| 2 | Purpose | For bridge maintenance, IoT fishery, seabed exploration, etc., wireless communication technology is necessary to complement communication that is difficult with sound and light. |
| 3 | Background | The Aqua Local Area Network (ALAN) consortium has been established, and underwater communication using visible light in particular is drawing attention [1]. In addition to communications, wireless power transmission technology is also being developed for powering underwater robots. |
| 4 | Requirements | Higher speeds of several Mbps or more, longer |

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| | | distances of several tens of meters, and smaller and lighter antennas are required for mounting on ships and underwater robots, taking into consideration the water resistance. It is also necessary to use communication technology from the ice to the sea in order to control robots that survey under the ice, such as at the North Pole. |
| [1] https://www.trimatiz.com/jp/consortium/alan.html | | |

T4.5 Cooperative control of multi-layered networks

| | | |
|---|---|---|
| 1 | Technology | This technology links deep-space probes, geostationary satellites, low earth orbit satellites, HAPS, aircraft, drones, ships, ground stations, Beyond 5G/6G, etc. in a multi-layered and organic manner, and flexibly controls the platform and network connection used according to the service. |
| 2 | Purpose | It is possible to build a system that avoids communication interruptions anywhere, such as aircraft, ships, remote islands, deserts, mountains, planets, etc., in response to user requests such as for Internet use, remote information collection, remote control, emergency disaster countermeasures, and infectious disease countermeasures (remote work, etc.). |
| 3 | Background | Regarding satellite 5G collaboration, the SATis5 Project [1] of the European Space Agency (ESA) and the SAT5G Project [2] of the European Union have been implemented. In 3GPP, the specification of a resource management scheme for 5G non-terrestrial networks (NTN) has been considered [3]. In Beyond 5G/6G technology, the study of further integration and fusion of NTN and terrestrial systems has begun [4]. In Japan, a subcommittee of the Space ICT Promotion Forum [5] is studying new use cases for collaboration between satellites and |

| | | |
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| | | Beyond 5G/6G, and a Japan-Europe partnership project has begun [6]. |
| 4 | Requirements | Standardization of each platform and development of infrastructure for integrated network systems (such as satellite-ground resource management functions) are required. |


[1] https://artes.esa.int/projects/satis5-0
[2] https://www.sat5g-project.eu/
[3] https://www.3gpp.org/release-17
[4] https://www.3gpp.org/release18
[5] https://spif.nict.go.jp/
[6] https://www2.nict.go.jp/spacelab/en/pj_stit.html


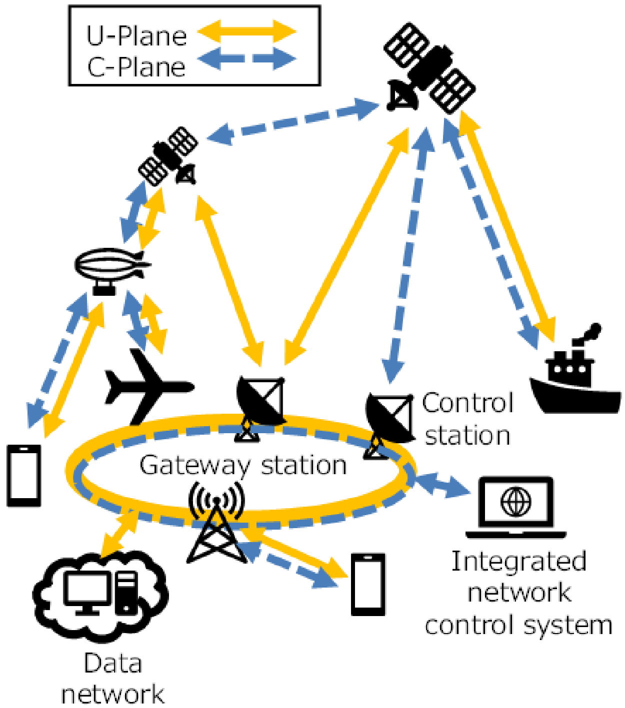


Figure 4.15 Cooperative control of multi-layered networks

4.2.5 Space-Time Synchronization

T5.1 Wireless space-time synchronization

| | | |
|---|---|---|
| 1 | Technology | This technology provides time synchronization and mutual positioning by wireless technology for remote devices to work cooperatively. High-precision space-time synchronization can be |

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| | | realized easily and inexpensively by incorporating advanced technologies used to compare Japan Standard Time (JST) with Coordinated Universal Time (UTC) into wireless communication devices. |
| 2 | Purpose | For example, by applying space-time synchronization to a 3D printer, it is possible to create shapes of any size without being constrained by the size of the frame, and it is also possible to quickly create shapes by linking multiple robots. In addition, cost-effective, easy-to-use and robust space-time synchronization technology is essential for the diversification of computing resources. |
| 3 | Background | The 5G Technical Specification (3GPP TS v. 18) requires time synchronization with a low delay of less than 1 ms and jitter of less than 1 microsecond from end to end for multi-robot collaboration. As a positioning technology, GNSS (GPS, etc.), beacons, Wi-Fi/Bluetooth technology, etc. are combined to measure the position, and the position measurement accuracy of 20 cm is required at the highest service level (see the 3GPP document mentioned above). |
| 4 | Requirements | Case 1) Inventory in warehouse/indoor robot coordination:<br>・Time synchronization accuracy 1 microsecond, communication delay (end to end) < 1 millisecond, position measurement accuracy 1 cm<br>Case 2) Vertical traffic control:<br>・Time synchronization accuracy 1 microsecond, communication delay (end to end) < 1 millisecond, position measurement accuracy 5 m |

Figure 4.16 Space-time synchronized 3D printer

T5.2 Chip-scale atomic clock

| | | |
|---|---|---|
| 1 | Technology | This technology provides a super stable clock signal that does not deviate in frequency. The clock is an important piece of equipment that controls the operation of onboard equipment. However, the control is only applied to the installed equipment because traditional clocks vary depending on the environment in which they are used. By stabilizing the clock to the atomic frequency standard, it is possible to synchronize and control the clocks of all devices in a single synchronization. |
| 2 | Purpose | The age of cloud computing and real-time processing of huge amounts of computation by multiple computers will come. By synchronizing and tuning the clock, it will be possible to use an infinite number of machines as if using a desktop PC. This will extend to distributed avatars and connected cars. |
| 3 | Background | Microwave atomic clocks of several centimeters square are sold as modules mainly in Europe and America [1]. In Japan, similar atomic clock modules have been developed under the leadership of AIST [2]. On the other hand, in the case of the clocks that are several centimeters square, the market is small other than for dual use, and it is not easy to promote social implementation in Japan. In the next phase of R&D, a scenario is needed for further |

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| | | miniaturization and low-power-consumption expansion. |
| 4 | Requirements | ● Edge computing: size < 5 cc, power consumption < several hundred mW<br>● Personal device: size < 1 cc, power consumption < several mW |
| [1] R. Lutwak et al., The MAC-a Miniature Atomic Clock, in Proc. IFCS2005, p. 752.<br>[2] H. Zhang et al., ULPAC: A Miniaturized Ultralow-Power Atomic Clock, IEEE JSSC, 54(11), 2019, p. 3135. | | |

T5.3 Generating and sharing technology for reference time

| | | |
|---|---|---|
| 1 | Technology | This technology creates and shares a highly disaster-resistant virtual standard time by using a large number of clocks in a local network. It provides efficient intra-regional communications. At the same time, network participants can easily synchronize with absolute time such as standard time or Coordinated Universal Time (UTC) by relying on this shared time. |
| 2 | Purpose | Next-generation data exchange requires flexibility to achieve both 1) high-speed and high-precision relative time differences over short distances, such as for automatic driving, and 2) absolute time stamps between servers around the world. In information systems, clock management is required to accommodate these requirements. |
| 3 | Background | With the emergence of local 5G, the concept of a local standard time is being recognized, and in the future, ways to create and share it will be discussed and developed. On the other hand, the development of an optical frequency standard with high accuracy is advancing in metrology research labs and universities in Japan and overseas. By commercializing this product, it is possible to maintain synchronization with absolute time for a |

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| | | considerable period of time in an isolated state, and to maintain the availability of clock management. |
| 4 | Requirements | High-speed and highly efficient data exchange in local networks requires relative time accuracy at the picosecond level. Data exchange based on universal time stamps requires absolute time accuracy at the microsecond level. |

4.2.6 Ultra-Security and Reliability

T6.1 Emerging security technologies

| | | |
|---|---|---|
| 1 | Technology | This technology creates Beyond 5G/6G infrastructure and new services with security. |
| 2 | Purpose | In a society where Beyond 5G/6G has been realized, various data in real space will be sent to cyberspace in real time, and control in the real space will be performed based on the results analyzed in the cyber space (e.g., self-driving, digital twins). Integrated security from the hardware layer to the software layer is important as infrastructure. In addition, technologies are required to identify security issues and use them safely and securely for new technologies and services provided on this infrastructure. |
| 3 | Background | 5G security is being discussed by various organizations, including the 3GPP Security Working Group (SAWG3) and the National Institute of Standards and Technology (NIST) NCCoE Project. However, the definition of Beyond 5G/6G has not been established and will be discussed in the future. In the area of IoT security, R&D on supply chain risk management measures is underway in the Cross-miniature Strategic Innovation Promotion Program (SIP) project. |
| 4 | Requirements | Hardware (sensors, drones, satellites, etc.) security technology (anti-tamper technology, hardware trojan detection technology, measurement and |

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| | | control security technology, etc.). Security technologies for real data processing software and clouds (vulnerability detection, data-protection technologies, adversarial attack resistant AI technologies, DoS attack protection technologies, etc.). Beyond 5G/6G infrastructure security technology, and security technologies for new technologies and services (automated driving, unmanned delivery, XR, satellite and HAPS communications, etc.) are required. |

T6.2 Cyber security technologies based on real attack data

| | | |
|---|---|---|
| 1 | Technology | This technology provides large-scale attack observation and visualization to respond to increasingly diverse and sophisticated cyber-attacks, and cross analyzes large-scale aggregated information to derive countermeasures. |
| 2 | Purpose | In a society where Beyond 5G/6G has been realized, a huge number of devices will be connected to each other with ultra-high speed, low latency, and large capacity. In other words, with the increasing number of devices subject to attack, if an attacker takes over many devices, a large-scale attack becomes possible. Therefore, technology for real-time, large-scale observation and analysis of attacks and automatic countermeasures is necessary for the stable use of Beyond 5G/6G. |
| 3 | Background | The Center for Applied Internet Data Analysis (CAIDA) in the U.S. and NICT have constructed one of the largest darknet monitoring systems in the world for monitoring worldwide indiscriminate attacks. While R&D is actively being conducted around the world on the integration of cyber security and AI, there are technical challenges to automation, including countermeasures, and ease of interpreting the output of AI. |

| | | |
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| 4 | Requirements | Technology to observe diverse cyber-attacks, including indiscriminate attacks and targeted attacks, visualization technology to grasp the situation from observed information, and technology to analyze vast amounts of observation data in real time using AI technology and derive automated countermeasures. |

T6.3 Quantum cryptography

| | | |
|---|---|---|
| 1 | Technology | This technology is an encryption method that uses a shared secret key to encrypt and transmit data using the properties of quantum mechanics. It is possible to attain information-theoretic security that in principle cannot be deciphered by any computer, including a quantum computer. This is the most secure cipher known today. |
| 2 | Purpose | In the network of Beyond 5G/6G, important information will increasingly be placed in cyberspace. Quantum cryptography can protect national secrets and security. It can protect information that requires ultra-long-term confidentiality in fields such as medicine, finance, infrastructure, and smart manufacturing. |
| 3 | Background | Research and development, field verification, standardization, etc. are advancing in various countries around the world, and practical application is starting. Japan has achieved the world's longest operation of a quantum cryptography network testbed and the world's first successful fundamental experiment on quantum communications using ultra-small satellites. In addition, Japanese companies have begun to commercialize quantum cryptography devices. |
| 4 | Requirements | Quantum key distribution (QKD) to share private keys, QKD networking, QKD using artificial satellites, as well as the establishment of |

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| | | standardization, evaluation, and certification systems for actual commercialization are necessary. It is also important to develop technologies for the entire security system using quantum cryptography, such as the quantum secure cloud technology originally developed in Japan. |

T6.4 Electromagnetic environmental technology

| | | |
|---|---|---|
| 1 | Technology | This technology maintains electromagnetic compatibility (EMC) whereby wireless devices and the electrical and electronic devices around them can coexist without interfering with each other. In addition, this technology evaluates the amount of radio waves emitted from wireless devices and electrical and electronic equipment that are absorbed by the human body (exposure), thereby creating an environment in which radio waves can be used to the maximum without affecting health. This includes the development of measuring instruments and high-precision, high-reliability radio wave measurement technology to realize these goals. |
| 2 | Purpose | This is necessary for safe and secure radio wave usage and for maintaining EMC. |
| 3 | Background | Regarding electromagnetic noise generated from electrical and electronic equipment, the industry is conducting self-regulation (VCCI Council) with the expectation of using frequencies up to 6 GHz. In the radio frequency radiation protection guideline of Japan, frequencies up to 300 GHz are assumed to be used. There is currently no limit on using the terahertz band. |
| 4 | Requirements | Technologies are required to reduce the impact of radio noise generated from electrical and electronic equipment on advanced wireless devices, to appropriately evaluate such impact, to accurately |

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| | | evaluate real-time and fluctuating exposure in diverse radio wave applications, and to accurately evaluate exposure in the millimeter and terahertz bands in order to extend the adaptive frequency range of the radio frequency radiation protection guideline up to the terahertz band. As basic technologies for these, it is necessary to establish laws and standards for measuring instruments in the terahertz band, as well as for primary standards, measuring methods, and evaluation methods. |

T6.5 Resilient ICT

| | | |
|---|---|---|
| 1 | Technology | This technology provides temporary and continuous use of communication infrastructure (network, data observation, and analysis, etc.) even when the environment changes rapidly due to various failures and disasters. |
| 2 | Purpose | An emergency network infrastructure is required in order to carry out recovery work by sending in a group of robots where human entry has become difficult due to a disaster. At the same time, network infrastructure that continuously supports the observation and analysis of natural environmental data and the distribution of local information is necessary to ensure security and safety at any time and anywhere. |
| 3 | Background | The ITU-T Technical Report [1] describes resilience as one of the requirements for future networks. In addition, Japan's 6th Basic Plan for Science, Technology and Innovation states that in order to reduce risks due to sudden changes such as natural disasters, the Government will focus on strengthening resilience by using cutting-edge ICT in such areas as observation and prediction of natural disasters and emergency response. |
| 4 | Requirements | As an emergency information-sharing platform, we |

| | | |
|---|---|---|
| | | aim to realize the communication requirements (end-to-end (E2E) delay of 0.1 ms or less) required for remote control of a robot group at the space ratio and time ratio of 99.99% or more, and as a continuous information-sharing platform, we aim to realize an area coverage ratio and availability of 99.99% or more. |
| [1] FG NET-2030 Sub-G1, Representative use cases and key network requirements for Network 2030, Jan. 2020. | | |

T6.6 Sensing

| | | |
|---|---|---|
| 1 | Technology | This technology measures all types of phenomena in physical space (people, things, environment, and their conditions). |
| 2 | Purpose | In the world of Beyond 5G/6G, every event in physical space is projected into cyberspace, and the solutions found in cyberspace drive the events in physical space. Sensing makes it possible to incorporate events in physical space into cyberspace. |
| 3 | Background | In addition to conventional sensing technology (such as radar lidar), which uses electromagnetic waves of various frequencies according to the purpose, research and development is also being conducted on passive sensing technology, which uses radio waves for specific purposes such as communications and broadcasting. In addition, research and development on the use of terahertz waves for sensing, which has been expanding in use in recent years, is also active. |
| 4 | Requirements | The safe use of autonomous driving and drones requires not only high-precision positioning but also high-precision environmental measurements in specific areas. Also required is technology development for passive sensing, which uses radio waves in various frequency bands as a by-product, |

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| | | including high-frequency bands, which are increasingly used in communications.<br>It is also necessary to develop technologies for measuring indoors and other closed spaces where radio waves are reflected, technologies for using AI for advanced identification and recognition, technologies for using large numbers of small, low-cost sensors, and technologies for communicating and compressing large volumes of sensed data. |

4.2.7 Ultra-Realistic and Innovative Applications

T7.1 Brain information reading, visualization, and BMI technologies

| | | |
|---|---|---|
| 1 | Technology | This technology controls various devices and provides non-verbal communication (emotion, intelligibility, skills) by reading and analyzing brain information using non-invasive or low-invasive methods. |
| 2 | Purpose | In addition to mutual understanding among diverse people with different cultures and values, extra-linguistic communication and brain-based device control facilitate social participation by the elderly and disabled people. |
| 3 | Background | The social development of BMI systems using invasive and non-invasive methods is starting both in Japan and overseas, particularly for medical applications. However, both methods have issues in terms of sensors, miniaturization, decoding, and wireless communication technologies, and further advancement of each basic technology is expected [1]. |
| 4 | Requirements | Wireless communication of brain information requires ultra-high-speed broadband communication, ultra-low latency, ultra-large number of simultaneous connections, ultra-low power consumption, ultra-security/reliability, and expandability. |

[1] Igaku-no-ayumi "Special Issue on Brain Machine Interface (BMI)," Rynsho-oyo-no-tenbo, in Japanese, 275(13), (2020)

T7.2 Intuition measurement, communication, and assurance technologies

| | | |
|---|---|---|
| 1 | Technology | This technology measures the discomfort felt during work in cyberspace, such as teleconferencing and remote control, from bio-signals including brain information to maintain the intuition of users. |
| 2 | Purpose | In cyberspace work such as teleconferencing and remote control, which are rapidly spreading due to the Covid-19 pandemic, the workload on the brain is high, unlike in physical space. Therefore, technology that enables intuitive work in cyberspace is necessary. |
| 3 | Background | Human-centric value creation is proposed for 5G/6G [1], but if intuition can be dynamically controlled at the cognitive level of the brain, teleconferencing and teleworking with a smaller load on the brain will become possible. |
| 4 | Requirements | In order to maintain intuition, including at the unconscious level, it is necessary to construct a brain model that estimates intuition from biological signals such as brain information, and to perform dynamic delay and jitter control based on biological signal feedback in wired and wireless integrated networks. |

[1] 6G Flagship: Key Drivers and Research Challenges for 6G Ubiquitous Wireless Intelligence, University of Oulu (2019).

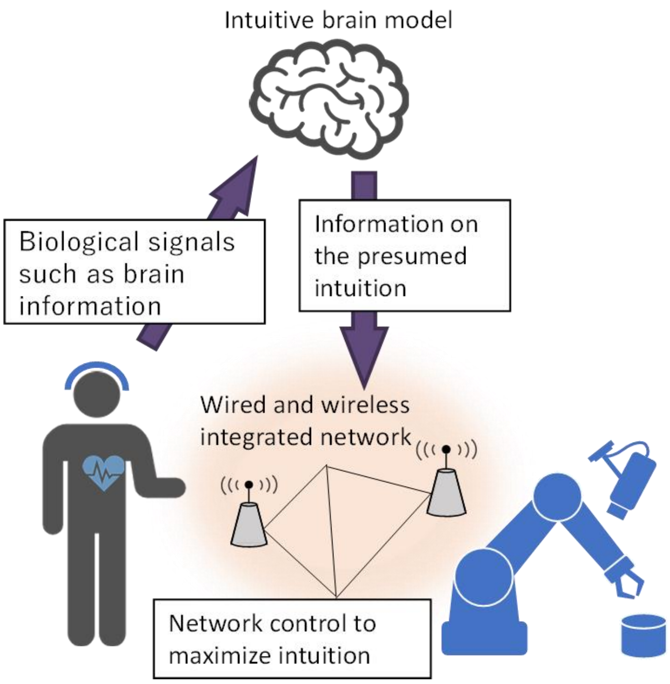


Figure 4.17 Intuition measurement, communication, and assurance technologies

T7.3 Real 3D avatars, multisensory communication, and XR technology

| | | |
|---|---|---|
| 1 | Technology | This technology provides an ultra-reality communication that enables real and natural remote XR interaction by instantaneously creating a 3D model of the body and environment and transmitting and reproducing it along with multisensory information (visual, auditory, tactile, olfactory, etc.). |
| 2 | Purpose | Ultra-reality communication technology will enable remote communication that transcends space, time, and physical barriers, and will contribute to the realization of a super-aged society in which labor productivity and richness of the mind are dramatically improved. |
| 3 | Background | In the post-Covid-19 society, there is a demand for the development and realization of avatars, |

| | | |
|---|---|---|
| | | multisensory communication, and XR technologies for various purposes such as remote medical care, nursing care, education and collaboration [1]. |
| 4 | Requirements | Ultra-reality communication technologies such as 3D avatars, multisensory communications, and XR that guarantee a quality of experience (QoE) equivalent to the real world are required for various tasks performed remotely by humans. |

[1] Research on service contents using VR/AR technologies (Mitsubishi Research Institute, 2018, entrusted by MIC)

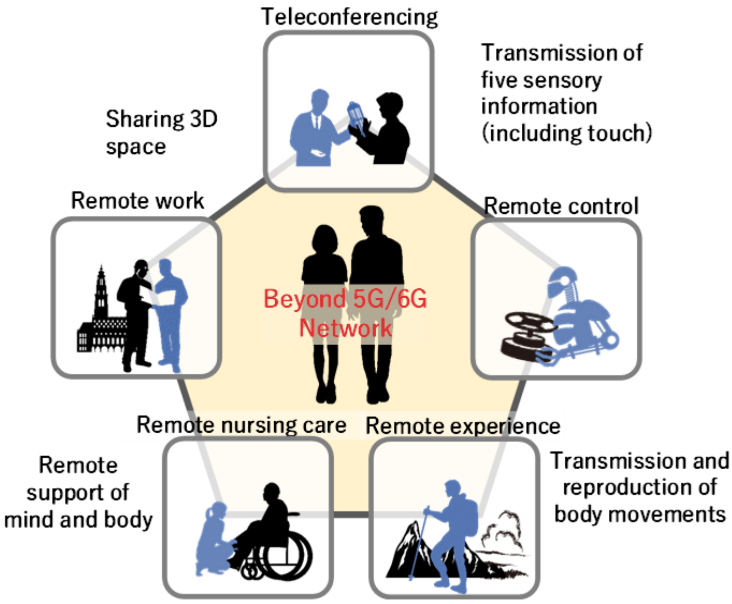


Figure 4.18 Ultra-reality communication transcending space, time, and physical barriers

T7.4 AI analysis and dialogue technology using linguistic and extra-linguistic information

| | | |
|---|---|---|
| 1 | Technology | This technology analyzes and organizes large amounts of information and knowledge on the Internet. It also helps users expand and refine their world view, through various forms of multi-modal dialogues using linguistic and extra-linguistic information, based on the results of analyzing |

| | | |
|---|---|---|
| | | information and knowledge on the Internet. |
| 2 | Purpose | In the midst of a serious shortage of human resources due to the aging of society and a declining birthrate, this technology is necessary to make the most of each individual's abilities. In particular, it is essential for elderly care, R&D, education, and other areas facing serious human resource shortages. |
| 3 | Background | Although AI speakers are increasingly used by ordinary households and the accuracy of machine reading technologies is now exceeding that of humans, there is no technology that covers all aspects of dialogue and no methodology that can expand and refine the user's perception of the world through dialogue. |
| 4 | Requirements | When individual users request the analysis of a large amount of data on the Internet, in order to avoid third parties obtaining the analysis results, the data needs to be analyzed on the users' devices. As such, this technology requires a network capable of transferring in real time large amounts of unanalyzed data. |

T7.5 Edge AI behavioral support

| | | |
|---|---|---|
| 1 | Technology | This technology integrates edge computing and AI to enable machine learning and inference based on high-capacity, low-latency, and ultra-diverse data in IoT devices in the edge environment. Edge AI has various functions, from learning and inference in the cloud and edge, to using it only in the edge environment. Edge AI is expected to evolve the Internet of Things into the Internet of Intelligent Things. |
| 2 | Purpose | Current AI, especially machine learning, is supposed to be used in the cloud with sufficient computing resources and storage. However, since it is |

| | | |
|---|---|---|
| | | practically difficult to send a large amount of private information from a user's IoT device to the cloud, it will be possible to build a machine learning model on the edge side using a huge data stream. Examples of alternative applications include cooperative automatic driving, support for actions in smart spaces (smart cities, homes, campuses, offices, hospitals, etc.), environmental monitoring with the combination of a wide variety of sensors, bidirectional interaction between real and virtual, human-robot collaboration, and so on. |
| 3 | Background | AI is broadly divided into "AI on edge" and "AI for edge." In the former, R&D is being carried out on resource-saving, communication-saving, and low-latency machine learning methods (associative learning, decentralized learning, model division learning, and distributed reinforcement learning) suitable for edge environments. In the latter, R&D is actively being carried out on the optimization of network configuration and resource allocation in edge environments. In addition, international standardization such as IEEE 3652.1-2020 and ETSI ISG MEC is also being carried out. |
| 4 | Requirements | Since users' IoT devices are highly autonomous in edge environments, edge AI needs to optimize machine learning processing according to the availability of opportunistic resources based on the network conditions, resources available on connected devices, and application requirements. It is also necessary to develop technologies to improve recognition and prediction performance by combining ultra-diverse data streams, and real-time and secure distributed learning technologies. In addition, the dynamic deployment of machine learning models to various devices in edge environments and the technology to support actions |

| | | |
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| | | that are optimized according to the situation by using digital twins and simulation is required. |

T7.6 Simultaneous multi-lingual interpretation, paraphrasing, and summarization technologies

| | | |
|---|---|---|
| 1 | Technology | This technology converts between different languages to assist communication between Japanese and foreigners with good time efficiency. To enable this, the context and extra-linguistic information are also referred to, and intra-language conversion is included. |
| 2 | Purpose | Japanese and non-Japanese can live and do business in normal times without stress, and Japanese and non-Japanese can co-exist without barriers even in emergencies such as disasters. |
| 3 | Background | In this field, NICT is in competition with GAFA (Google, Amazon, Facebook, Apple) and BATH (Baidu, Alibaba, Tencent, Huawei), but NICT is dominant thanks to a public-based framework represented by translation banks [1]. |
| 4 | Requirements | Hardware and networks that enable parallel execution of single-device learning and cloud-based learning with low latency will enable ultra-precise model learning tailored to individual users for the first time. |

[1] Global Communication Plan 2025 (Ministry of Internal Affairs and Communications, March 31, 2020)


Figure 4.19 Secure remote simultaneous interpretation

T7.7 Automated driving

| | | |
|---|---|---|
| 1 | Technology | This technology automates the movement of vehicles (mobility) in various fields such as cars and trucks used for the transportation of people and goods, industry and agriculture, robots that compensate for the labor shortage at medical sites, and wheelchairs that help the movement of the disabled and the elderly. |
| 2 | Purpose | We will be able to realize a vibrant and bright society by creating a safe and secure traffic environment free from accidents, eliminating labor shortages and declining productivity due to the aging population and low birth rate, and encouraging the participation and independence of the disabled and the elderly who are worried about mobility. |
| 3 | Background | Efforts to realize autonomous driving are being made in various fields of transportation, |

| | | |
|---|---|---|
| | | communication, and industry [1]. |
| 4 | Requirements | It is essential to construct an ultra-precise environmental map to check the moving space, to avoid obstacles and prevent collisions, to take measures against sensor abnormalities caused by solar activity, to remotely monitor emergency measures including local weather conditions such as wind and rain. and to develop distributed sensor technologies such as roadside infrastructure. To realize these technologies, cooperation between vehicles and networks, large-capacity information communication (over several tens of Gbps), and real-time communication technology (1 ms or less delay) are required. |
| [1] Regarding future initiatives of MLIT towards realization of automatic driving, initiatives of Ministry of Internal Affairs and Communications towards 5G and ITS/automatic driving towards 2020, etc., "Initiatives Report and Policies towards Realization of Automatic Driving" Version 4.0, Autonomous Driving Business Study Group. | | |

T7.8 Drones

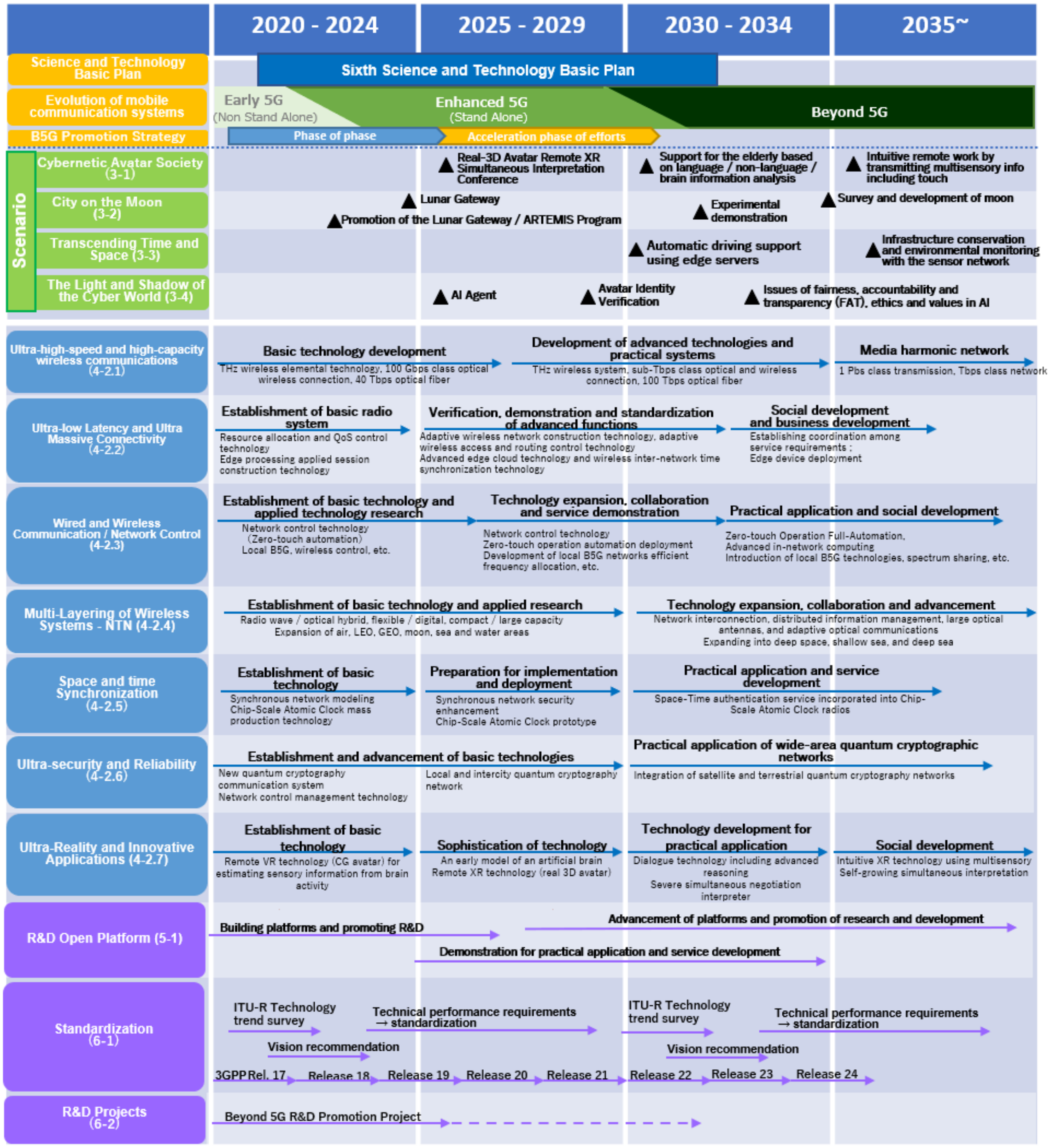
| | | |
|---|---|---|
| 1 | Technology | This technology is based on an unmanned aircraft that can fly through the sky freely, from inside to outside the area of visual observation, using an automatic control program. It is also known as a flying smartphone and flying IoT, making it possible to network three-dimensional spaces that have not been used before. It is also called the "Industrial Revolution in the Sky," but in the future the technology will be developed into flying cars that constitute a "Mobile Revolution in the Sky." |
| 2 | Purpose | Dramatically improves the efficiency of infrastructure management, aerial photography, logistics, observation, disaster/distress communication, etc. In addition, it can reduce |

| | | |
|---|---|---|
| | | energy consumption and human involvement in all social activities, which is necessary for the realization of an ecosystem through energy conservation and a new society resistant to virus infections. |
| 3 | Background | The government has led the formulation of the Roadmap for the Industrial Revolution in the Sky, which is updated every year. The government and the private sector jointly revise the system and develop technologies to realize safe unobserved flight. In the area of technology development, R&D projects led by the Ministry of Internal Affairs and Communications and the Ministry of Economy, Trade and Industry (New Energy and Industrial Technology Development Organization) are being promoted. In the area of institutional reform, revisions to the Civil Aeronautics Act and the Radio Act are being implemented one after another. Europe, the United States, China, South Korea, and other countries are conducting their own R&D. The International Telecommunication Union (ITU), the International Civil Aviation Organization (ICAO), and the International Organization for Standardization (ISO) have also been promoting the standardization of communications and airframe safety technologies. |
| 4 | Requirements | Highly reliable and low-cost wireless communications that support the safe flight operation of drones, spectrum sharing and frequency expansion technology for this purpose, technology for preventing sensor abnormalities associated with solar activity, technology for monitoring local weather conditions such as wind and rain, and collaboration and fusion with terrestrial, space, and HAPS networks are required. |

## 4.3 R&D Roadmap

Chapter 4 presents a separate roadmap for each of the key technologies. Table 4.9 summarizes these roadmaps, focusing on the most representative of each field. It also shows the estimated timing of the four scenarios depicted in Chapter 3.

Table 4.2: R&D Roadmap



# Chapter 5: R&D Open Platform

## 5.1 Beyond 5G Shared R&D Testbed

In response to the recommendations of the Council on Beyond 5G Promotion Strategies, the NICT, which specializes in R&D in the field of information and communications, is promoting the development of Beyond 5G shared research facilities and equipment as an environment for R&D and the demonstration of technologies that realize ultra-high speed, ultra-large capacity, ultra-low delay, ultra-massive connectivity, and low power consumption, which are the core of Beyond 5G technologies. This facility consists of three pillars: "Environment for Development of Basic Technology for Beyond 5G," "Equipment for Development of Ultra-High-Speed Optical Communication Technology to Support Beyond 5G," and "Highly Reliable, Highly Plastic Beyond 5G/IoT Testbed" (Fig. 5.1).

The Beyond 5G Transmission Technology Development Environment is aimed at promoting R&D on transmission technology that also utilizes ultra-high-frequency bands waves such as terahertz waves, which are strongly expected to be used in Beyond 5G. It consists of an environment for developing Beyond 5G transmission technology, consisting of a device fabrication system and a device characteristic evaluation system, and an anechoic chamber for terahertz band for measuring and evaluating antenna and transceiver characteristics.

"The Ultra-High-Speed Optical Communication Technology Development Facility to Support Beyond 5G" promotes research and development on ultra-high-speed optical communication technology to support ultra-high-speed and large-capacity wired and wireless communication of Beyond 5G. It includes a facility capable of demonstrating transmission through actual optical fibers and evaluating the characteristics of signal processing, and a wired/wireless device fabrication platform capable of producing optical/radio integrated devices that realize wide-band transmission signals (terahertz and optical range) and high-speed response evaluation.

"High reliability and high plasticity Beyond 5G/IoT testbed" is a testbed used for R & D on high reliability and plasticity in Beyond 5G networks. It assumes the addition of multiple demonstration open sites with mobile environments that can be customized by software technology, etc. to the existing network testbed, as well as the extension of collaboration to a platform layer that can demonstrate various applications and a middleware layer that supports emulation and visualization of mobile environments.

In addition to the existing shared R&D infrastructure (network demonstration environment such as JGN, advanced Beyond 5G devices lab, etc.), the shared R&D facilities and equipment will provide open use as a "shared R&D testbed" where users bring various technologies together for R&D and demonstrations. In addition, the shared R&D infrastructure (cyber security, quantum information and communications, neural information and communications, etc.) will be organically linked with other NICT R&D infrastructure to build a system to promote R&D by bringing together the wisdom of industry, academia, and government.

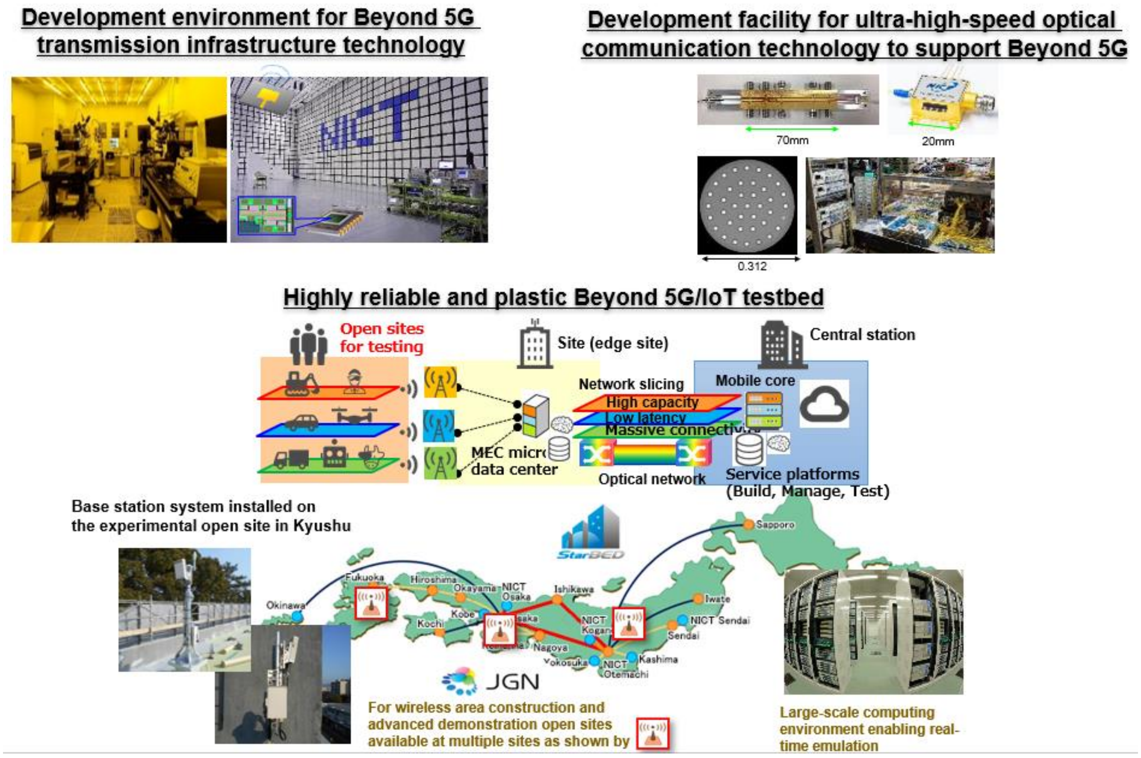



Figure 5.1 Progress is being made - Beyond 5G shared research facilities and equipment

## 5.2 Highly Reliable, Highly Plastic Beyond 5G/IoT Testbed

NICT has constructed and operated a comprehensive testbed environment including JGN, an ultra-high-speed R&D network testbed, and "StarBED," a large-scale emulation testbed. We are also constructing and operating the highly reliable and highly plastic B5G/IoT testbed, which is designed to satisfy the requirement for a stable, high-capacity, low-delay service of the communication network system realized by B5G with a limited amount of equipment. In addition, in order to ensure the high reliability and plasticity of the Beyond 5G system, it is necessary for industry, academia, and government to bring together various technologies for R&D and demonstration. From this point of view, the

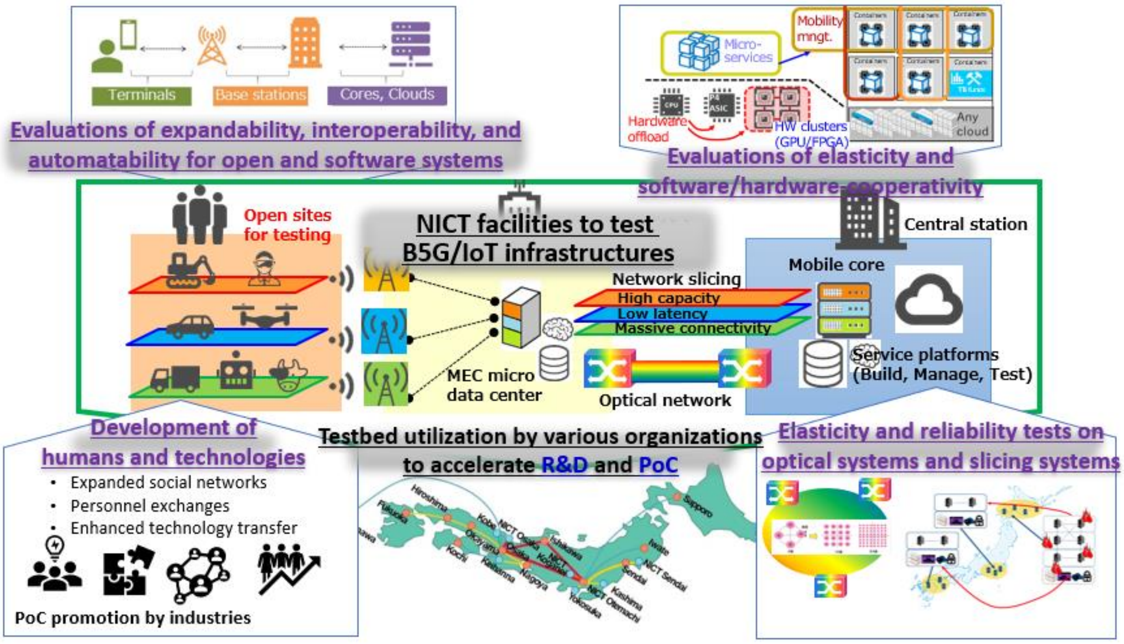



Figure 5.2 Outline of high-reliability and high-plasticity B5G/IoT testbed

testbed is designed to serve as a verification environment.

# Chapter 6: Deployment Strategies

## 6.1 Trends in Standardization for Beyond 5G/6G

After 3G, the ITU Radio Communications Division (ITU-R) made recommendations on specifications established by private standardization bodies (such as 3GPP), and one of the major trends is to make them international standards. The international allocation of frequencies will be decided at the World Radiocommunication Conference (WRC), which is held approximately every four to five years. The standardization of mobile communications at ITU-R has been conducted at WP5D (IMT systems) under SG5 (terrestrial services).

In October 2020, WP5D began compiling the survey results, Future Technology Trends, the first step in the standardization of Beyond 5G/6G, and it is scheduled to be completed in June 2022. First, it is necessary to incorporate the elements of NICT and Japanese technologies into future technology trend surveys, and to reflect on the “IMT Vision for 2030 and Beyond” Recommendation, the next step in standardization, while improving the specificity of technologies and building partnerships.

The agreed standardization process at the WP5D meetings (respectively in February and October 2020) is shown in Figure 6.2. A study of future technological trends in the advanced form of IMT-2020 is scheduled to be completed in June 2022. Concurrently, a study of the vision that was scheduled to start in June 2021 will also be completed in June 2023.

The Ministry of Internal Affairs and Communications established the Beyond 5G Promotion Consortium in December 2020, which is planning to publish a Beyond 5G White Paper. It has also been submitting proposals, as Japanese contribution documents, for future technology trends and vision recommendations since the 38$^{th}$ meeting of WP5D in June 2021.

NICT plans to incorporate its technology seeds into its Future Technology Trends and the vision until 2023, positioning them as Beyond 5G/6G technology, and contributing to standardization for early commercialization. After that, in the standardization of specific technical specifications, it is considered that private companies developing products and services using NICT's technology seeds will carry out standardization activities together with intellectual property strategies from the business side. Therefore, it is important to smoothly bridge the gap with private companies that will become NICT's partners.

In addition to securing the necessary frequencies at the World Radiocommunication Conference in 2023 (WRC-23), we plan to collaborate with the 3GPP and private-sector forums to establish technical requirements.

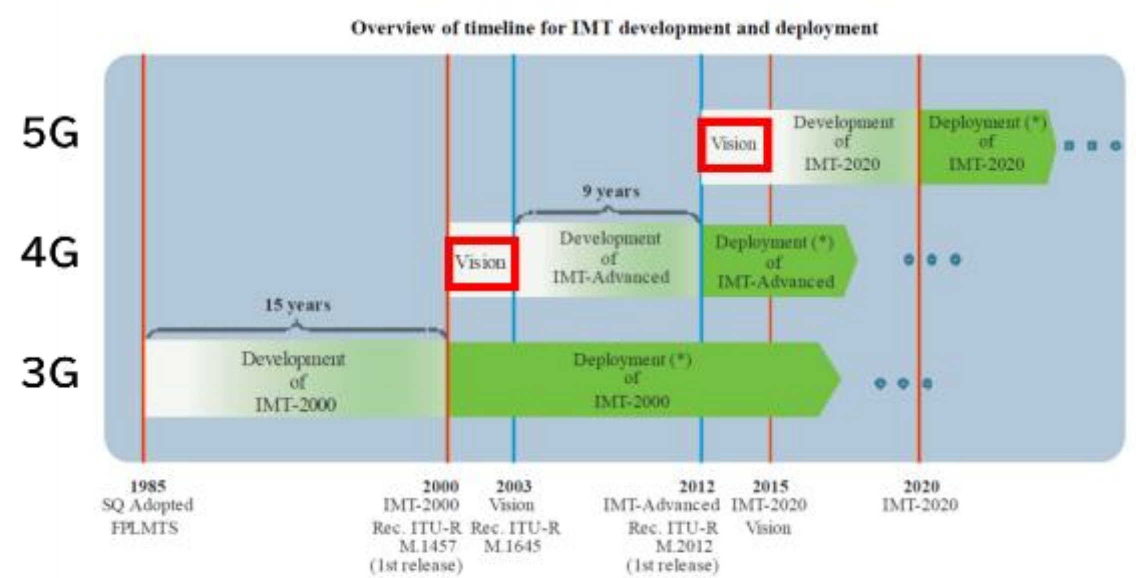



Figure 6.1 Processes in 3G, 4G, and 5G (Ref. ITU-R Recommendation M. 2083)
(The red frames around Vision and 3G, 4G, 5G on the left side were added by NICT)

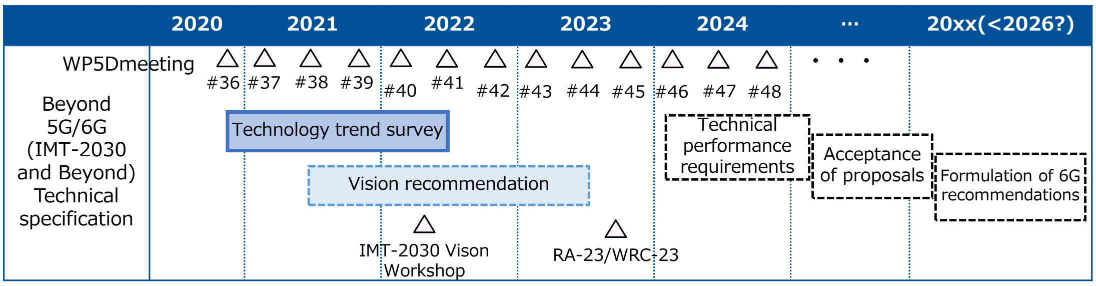



Figure 6.2 Agreed standardization process at the 34th WP5D

## 6.2 National Projects for Beyond 5G Research and Development

In the “Beyond 5G Promotion Strategy - Roadmap to 6G” announced by the Ministry of Internal Affairs and Communications in June 2020, activities up to the introduction of Beyond 5G/6G around 2030 are described in two phases: the “Proactive Action Phase” and the “Acceleration Phase.” As part of the “Proactive Action Phase,” the “Beyond 5G R&D Promotion Program” is strongly supported by the government, in accordance with the R&D policy published in February 2022 by the Ministry of Internal Affairs and Communications, in order to focus on strengthening R&D capabilities for technologies that are advanced in Japan and technologies that are indispensable for Japan to have.

Under the program, the following three sub-programs will be implemented in accordance with the three basic policies of “Global First,” “Creation of an Ecosystem that Generates Innovation,” and “Intensive Allocation of Resources”

- “Beyond 5G Function Realization Program”
- “Beyond 5G International Joint Research Program”
- “Beyond 5G Seeds Creation Program”

Among these, the “Beyond 5G Function Realization Program,” which researches and develops elemental technologies that are necessary and

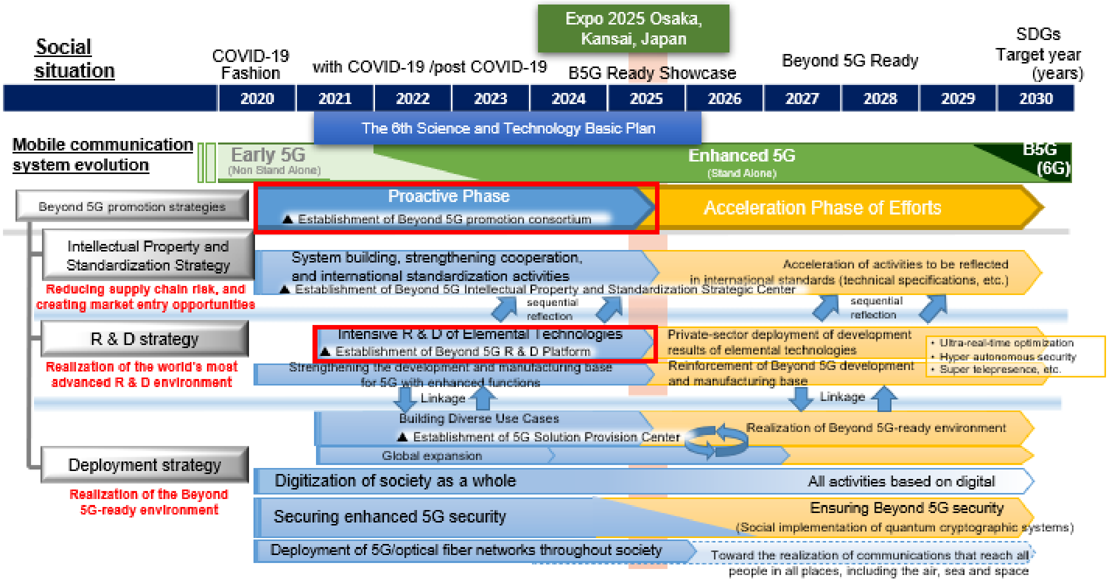



Figure 6.3 Beyond 5G promotion strategy – roadmap to 6G

strategically important for the realization of Beyond 5G, is classified into the following two categories.

1) "Key issues" with the aim of creating high-level R&D achievements by setting specific and clear development goals (numerical targets, etc.)
2) "General issues" widely called for ideas within specific R&D topics, leaving the development targets (numerical targets, etc.) to the free ideas of the proposers.

In particular, with regard to the implementation of the "Key issues" mentioned in 1) above, as stated in the Research and Development Policy, R&D themes are selected and a research plan for the selected R&D themes is formulated with reference to the R&D Theme Candidate List (2nd Edition) (Fig. 6.4) of the "Beyond 5G Function Realization Program."

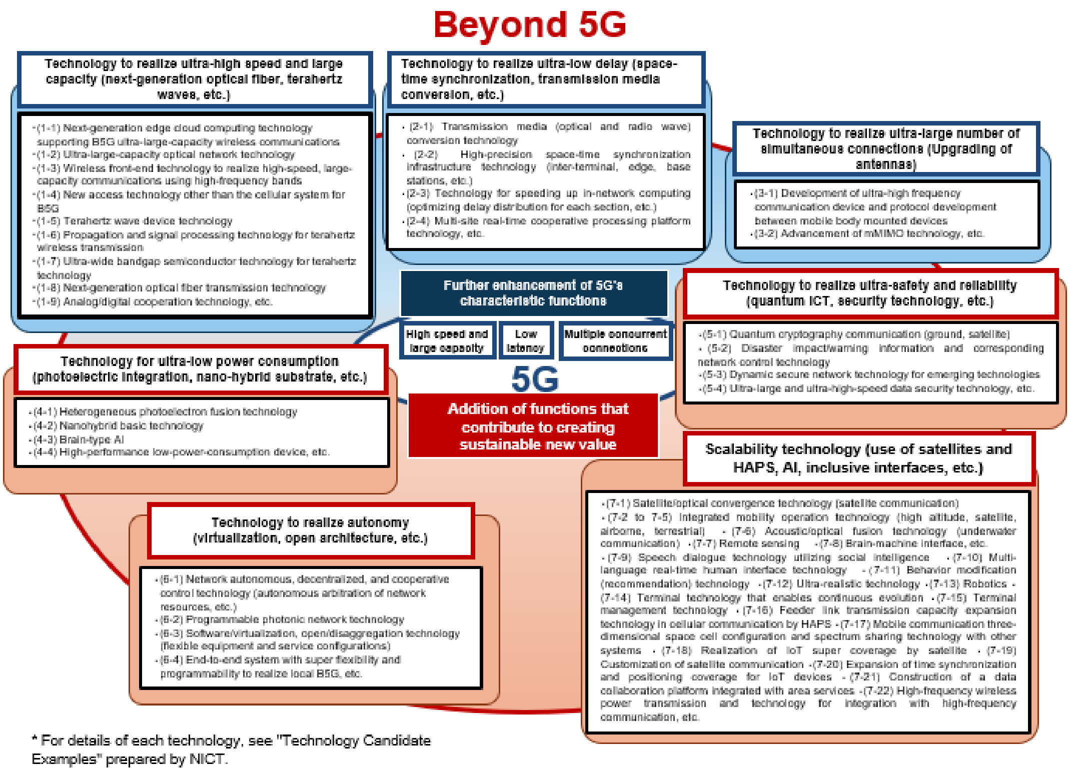



Figure 6.4 Candidate List of Research and Development Issues under the Research and Development Policy (2nd edition)

In the commissioned research of this project, the total amount selected so far is 44 themes, of which six were "Beyond 5G Function Realization Program (Key Issues)" (of which one theme was selected in FY 2020), 20 were “Beyond 5G Function Realization Program (General Issues),” three were “Beyond 5G International Joint Research Program”, and 15 were “Beyond 5G Seeds Creation Program (Commissioned Research)” (of which four were for young people and SMEs). These themes (the distribution of the themes is shown in Fig. 6.5) cover a wide range of technical fields. In particular, commissioned research contributing to the realization of Beyond 5G is being carried out mainly in the fields of wireless and optical communications, which form the network infrastructure of Beyond 5G.

In addition, in order to provide subsidies to small- and medium-sized enterprises (SMEs), such as venture/start-ups, which have innovative technology seeds and ideas but are willing to take on difficult challenges, among the “Beyond 5G Seeds Creation Programs,” “the Innovative Venture Grants Program (SBIR)” was publicly solicited and three projects were selected in February 2022. By actively supporting not only commissioned Beyond 5G projects, but also venture/start-up and other SME research projects, opportunities to create innovation through the creation of technology seeds are increasing.

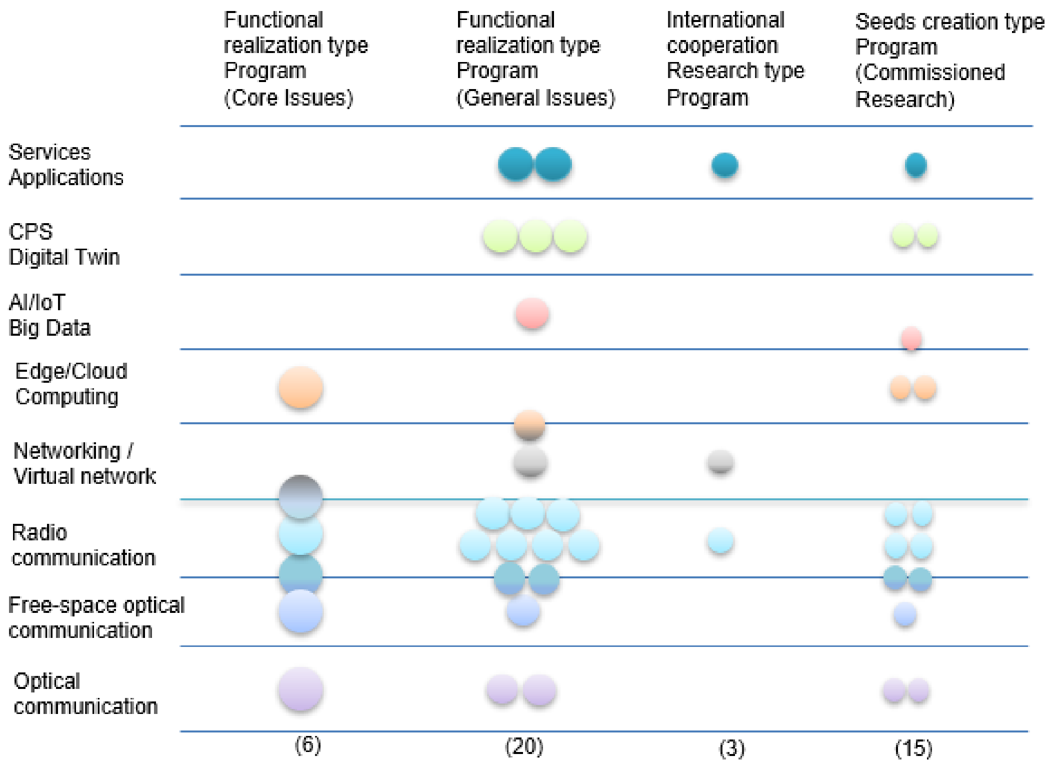



Figure 6.5 Distribution of Beyond 5G R&D promotion projects

In order to examine new R&D issues for realizing Beyond 5G, proposals were invited from October to November 2021 on initiatives to materialize an innovative social image around 2030 and pioneering R&D issues that need to be intensively strengthened. Based on the results, the “Beyond 5G R&D Workshop” was held in February 2022. At the workshop, opinions were exchanged among industry, academia, and government officials regarding promotion measures and future images of Beyond 5G.

Through the implementation of each program of this project, elemental technologies for Beyond 5G have been gradually established since around 2025, and efforts are being made to realize Beyond 5G around 2030 by contributing to international standards such as 3GPP and ITU-R.

# Chapter 7: Conclusion

In this white paper, four scenarios of social life after 2030 are created, and by backcasting from the future society described in these scenarios, the concepts and use cases of Beyond 5G/6G and the elemental technologies supporting them were summarized, and the R&D roadmap was presented. Furthermore, the open platform necessary for R&D and the deployment strategy were shown, and the overall picture of future R&D was presented.

In order to develop, implement, and use the future technologies necessary to realize the social life and world view depicted in the vision, it is necessary to focus on technological evolution not only in the information and communications field but also in a wide variety of other fields, to hold discussions with various stakeholders, and to realize specific goals. We would like to continue discussing this white paper with many stakeholders.

## Appendix 1: Pseudocode Example (Service Enabler)

As a specific example of the use of a service enabler, when equipment repair is performed by utilizing an avatar robot in a factory in a remote location, a case is considered where a plurality of engineers from all over the world are connected to the avatar robot and cooperatively operate it. In this case, it is considered that delay compensation by AI is necessary in order to share the sense of presence and to alleviate the sense of incongruity caused by the difference in the communication delay between workers in order to enable real work from various viewpoints among the working members.

The implementer of the service can easily construct the service by simply describing the program code of the main function to be realized, such as "group super presence sharing," "delay compensation remote control" and function, and "AI/ML processing" of optimum control.

As an example of how to use a service enabler, Appended Figure 1 shows an image of a program implementation in pseudocode. Regarding the instances, "av" of the Avatar class, service enablers for GroupVR and DelayCompensateAI are added and the necessary parameters are set.

```
#create instances for Avater Class and ServiceEnabler Class
Avatar av;
ServiceEnabler vr, delay;

#create an instance for avatar
av.createAvatar(myProfile, FACTORY, JAPANESE);

#create two instances for service enabler
vr.setMode(RealPresenceMode);
vr.setGroup(userList);
delay.setMode(DelayCompensateAI);
delay.setMode(FactoryRobot, 0.1ms);

#add service enablers to avatar and run it
av.addServiceEnabler(vr);
av.addServiceEnabler(delay);
```

```
av.run();
```

Appended Figure 1. Example of Service Enabler Call for Remote Control of an Avatar Robot

## Acknowledgment

The NICT Open Summit 2020 was held for two days, January 20–21, 2021, to present the first release of this White Paper and engage in discussions with the experts listed below. NICT expresses its deep gratitude to them for their valuable advice on the R&D direction of Beyond 5G/6G R&D that NICT should pursue.

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