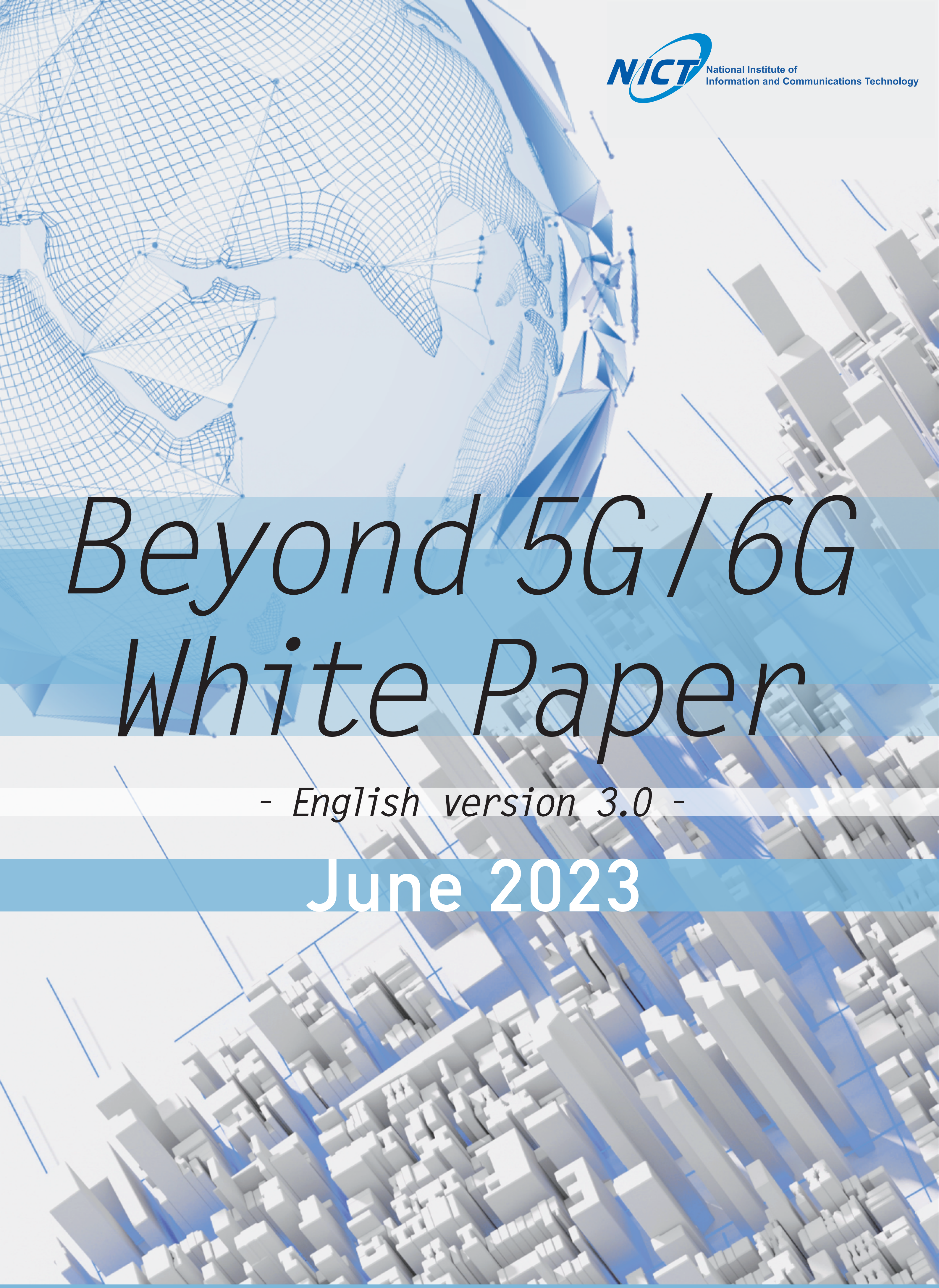

National Institute of Information and Communications Technology

Beyond 5G/6G White Paper

- English version 3.0 -

June 2023

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(English version 3.0)

National Institute of Information and Communications Technology (NICT)

June 2023

Contents

Release of the Third 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 second edition of the White Paper based on the contents of internal and external discussions by NICT and activities.

This third edition focuses on the following points: Chapter 2 presents the concept and roles of architecture, focusing on orchestrator and digital twin linkage. In Chapter 3, in addition to the four scenarios in the second edition, we added a fifth scenario, the "Path for Life" scenario, which describes an incomer who performs fishing-related services in a local city. The details of the use cases that were previously described in each scenario are now included in an appendix. In Chapter 4, only a brief overview of the elemental technologies of Beyond 5G/6G is presented, with details in an appendix. On the other hand, we added a technical description of the key elemental technologies that are expected to be utilized particularly in Beyond 5G/6G as a new Section 4.2. Chapter 5 presents the concept of social implementation of research results. Chapter 6 reflects the latest information on international standardization activities related to Beyond 5G/6G 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

In order to achieve the SDGs and realize Society 5.0, Beyond 5G/6G, next-generation information and communications infrastructure, is essential. 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. 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 five scenarios of social life after 2030 and beyond, and several use cases related to the scenarios are introduced in an appendix. The following scenarios are included: “Cybernetic Avatar Society,” which depicts a society that makes advanced use of avatars; “City on the Moon,” which depicts a society in which human activities extend to the moon, “Transcending Time and Space,” which

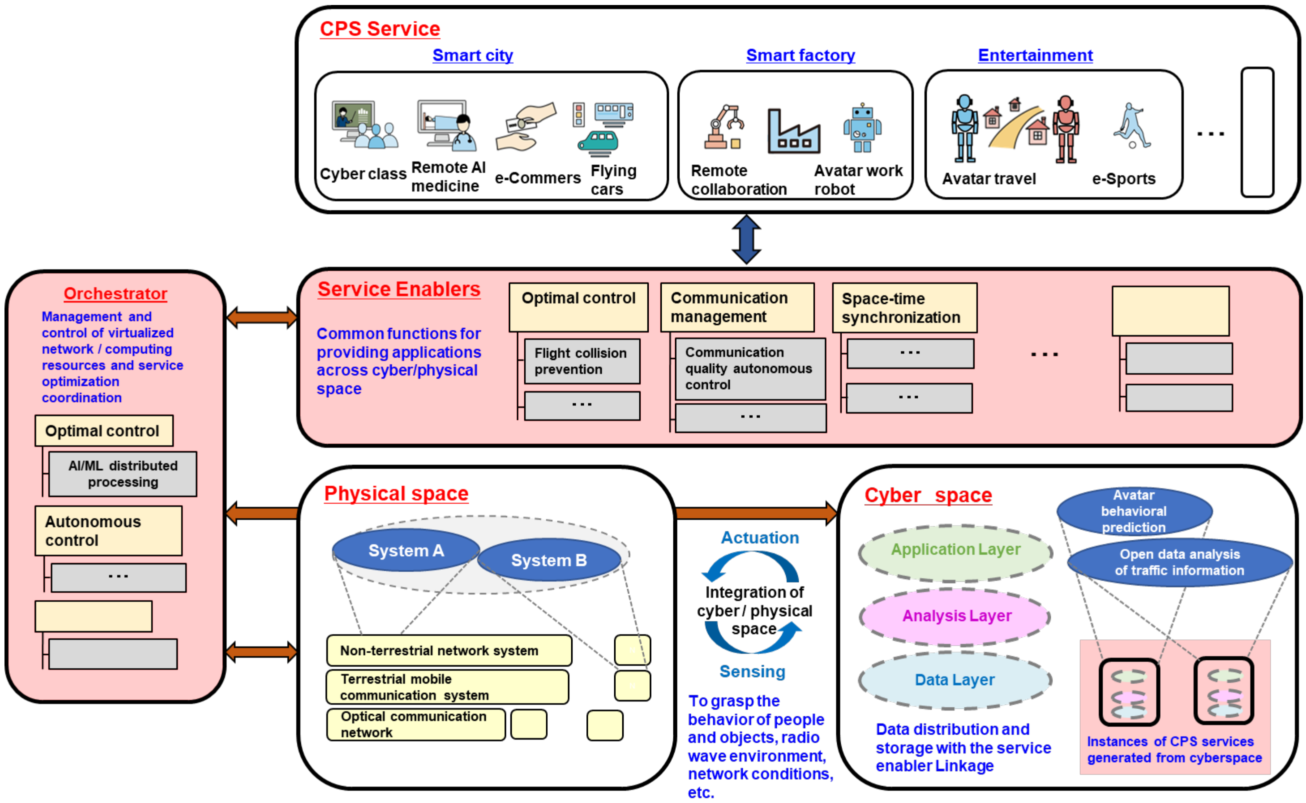


Figure A: Functional Architecture of Beyond 5G/6G (Figure 2.1 in the text) depicts a society in which space-time synchronization is realized; "The Light and Shadow of the Cyber World," which depicts the case study of a cyber counseling room; and "Path for Life," which depicts an incomer who performs fishing-related services in a local city. An image of each scenario is shown in Figure B. In Section 4.1, Chapter 4, we attempt to identify the required elemental technologies by backcasting from the future society depicted in these scenarios and present their overview, and details are shown in an appendix. Among such elemental technologies, Section 4.2 in particular describes the key elemental technologies that are expected to be utilized in Beyond 5G/6G. Chapter 5 describes the concept of social implementation of research results, and Chapter 6 summarizes the status of international standardization activities related to Beyond 5G being conducted by NICT.

This white paper was prepared by NICT as a group of experts in information and communications technology. The contents are the results of discussions on the realization of the Beyond 5G/6G world. Based on the white paper, we would like to further discuss the theme with many of you going forward.

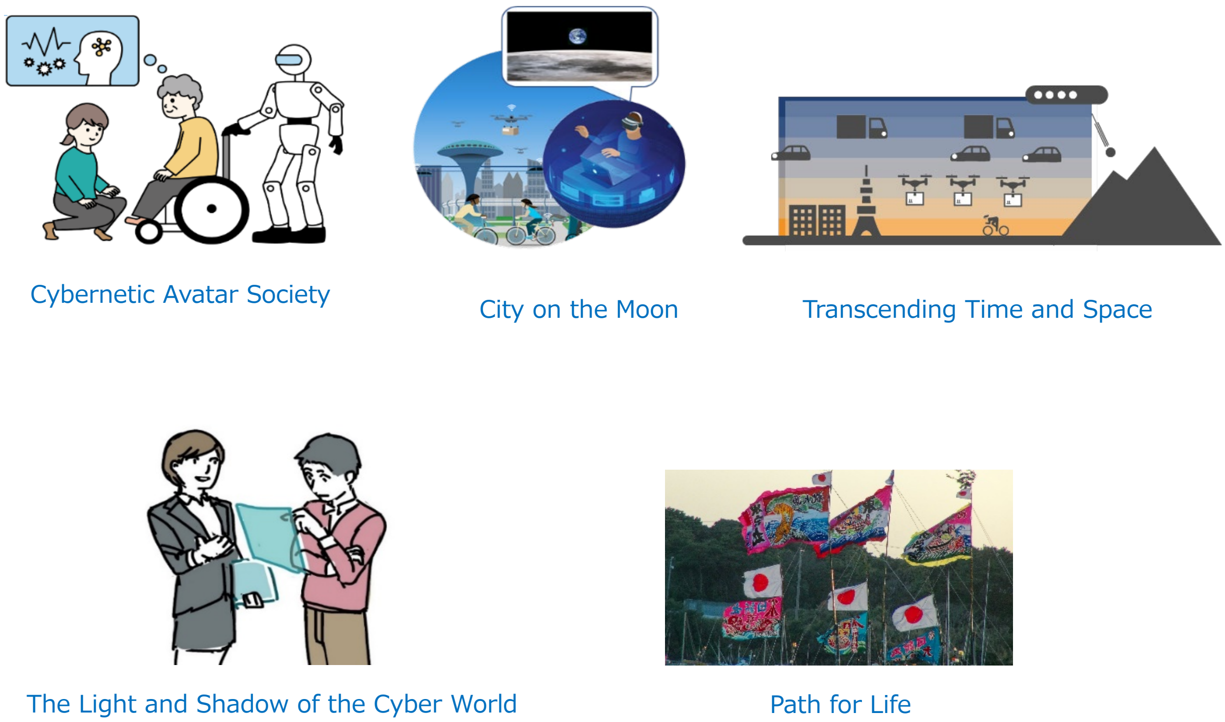


Figure B: Scenarios of Beyond 5G/6G that envision social life after 2030

Chapter 1: Introduction

1.1 Background of the White Paper

1.1.1 Mobile communication system evolution

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.

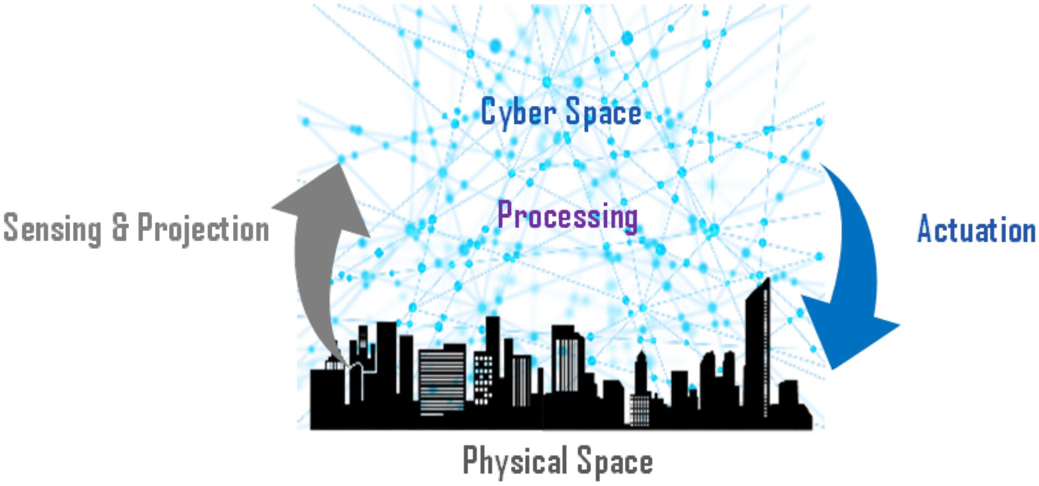


Figure 1.1 Realization of a "cyber-physical system" that measures events (big data) in physical (real) space, projects them into cyberspace, finds solutions (optimal solutions), and actuates the physical space event.

1.1.2 COVID-19 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.

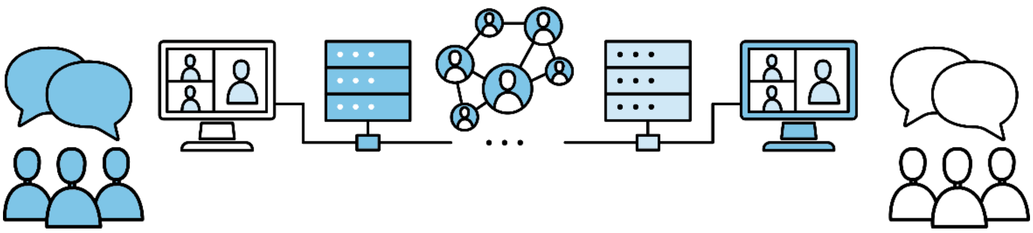
Against this background, interest in Beyond 5G/6G has greatly increased compared to the transition point of previous generations. This has triggered a debate on how to proceed with research and development. As if competing for the lead, white papers have been published by various organizations, forums 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.

Each scenario and the use case that appear in each scenario are presented (Chapter 3), and the elemental technologies to realize them (Chapter 4) are organized, and especially the key elemental technologies that are expected to be utilized in Beyond 5G/6G are explained. In addition, the concept of social implementation of research results (Chapter 5) and trends in Beyond 5G-related standardization-related activities (Chapter 6) are summarized. In order to develop, implement, and utilize the future technologies necessary for realizing the social life depicted in this white paper, 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. We will continue to discuss this white paper with many people, and will revise this white paper as the discussions progress.



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- The 5G Infrastructure Public Private Partnership (5G-PPP)
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Chapter 2: Future Society After 2030 and Beyond

2.1 Information and Communications Networks and Society

Japan today faces many social issues, including a declining birthrate and an aging population, as well as a disparity between urban and rural areas caused by the concentration of population in urban areas. The areas of such social issues are diversifying. Examples of such diversifying social issues include handling both child rearing and career, educational disparity due to family socioeconomic status, deindividualization due to uniform and passive education, increasing social security costs due to unhealthy longevity, and caregiver fatigue. In addition, a sense of stagnation has arisen in industries, not limited to the information and communications industry, due to employment restrictions based on place of residence and physical limitations, and an organizational structure in which individual efforts and achievements are not rewarded due to external factors.

In the Beyond 5G/6G era, innovations in information and communications networks are expected to solve these social issues and realize a "resilient and vibrant human-centered society" as follows.

(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 human-centered society in which safety and security are ensured and the bonds of trust are unwavering, even in the case of unexpected events (high reliability).

The realization of such society requires an environment in which each industry and business can work together flexibly and in unison, performing appropriately assigned roles in order to create services with new value that solve social issues. To achieve this, it is necessary to establish a mechanism based on information and communications networks with Beyond 5G/6G that will promote technology convergence and cross-industry collaboration.

2.2 Direction of Changes in ICT Networks

In the Beyond 5G/6G era, it is necessary to measure the real world through information and communications 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.

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. Network virtualization and hardware openness will extend not only to network equipment but also to the terminal side.

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 described in Section 2.1, the social issues to be solved by the technological progress of Beyond 5G/6G will cover a wide range of fields. 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 conventional wisdom considered difficult to overcome, thereby, embodying so-called human augmentation, it will be possible to solve many new social issues. 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.

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 to the upper air regions by space communication systems and non-terrestrial mobile communication systems, which will also be expanded to mountainous areas and the oceans. These wireless communication

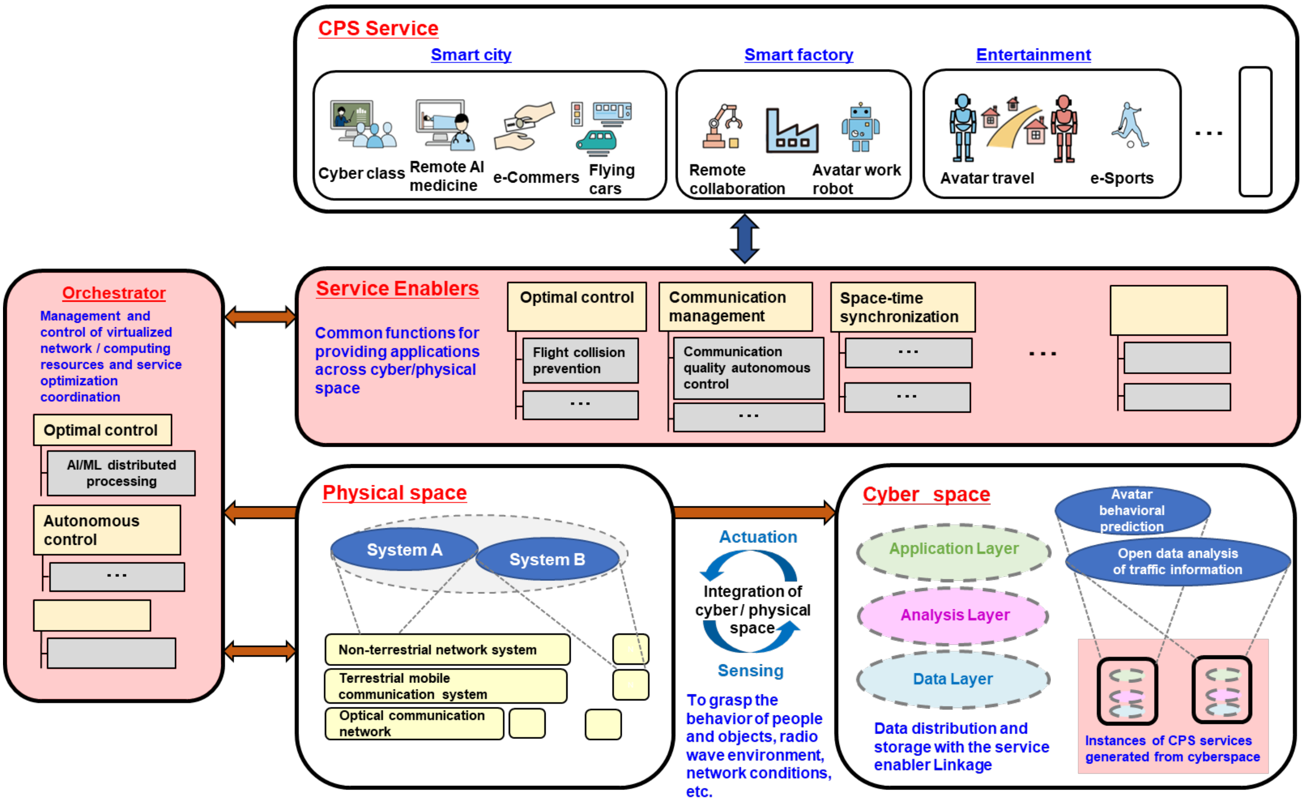


Figure 2.1 Beyond 5G/6G Functional Architecture

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.

Figure 2.2 illustrates the concept of a Beyond 5G system as an aggregate of all systems. In order to achieve the services required by users, it is necessary to be able to combine multiple systems across industries and configure them appropriately. The industries depicted here are terrestrial mobile communication systems, HAPS, satellite communication systems, Metaverse, and digital twins, each of which has multiple operators. Therefore, one or more systems are offered from the same industry. In addition, multiple industries will provide systems to constitute services.

To achieve this, an arbitrator is needed across systems, such as discovering, selecting, and configuring systems according to the services required by users. In Figure 2.2, such an arbitrator is shown as an orchestrator, which communicates with each system through a common interface. Moreover, since it is impossible for users to handle such a complex system directly, a service enabler exists to act as an intermediary. The service enabler has an interface to exchange service level requests with users, as well as break them down and pass them on to the orchestrator. It is necessary to define these concepts as the Beyond 5G architecture, and work to materialize the necessary functions and interfaces.

Such a Beyond 5G system concept will make it possible to realize easy connection to platforms for existing players and operators, freeing up excess capacity in their own businesses, for example, to earn incentives. The emergence of cross-industry orchestrators and service enablers will also lower barriers to entry. By bringing together a wide variety of resources on this platform, new services can be offered. The more companies and businesses that are connected to this platform, the more combinations of services and functions will be offered, and the newer services will increase. The following sections provide a detailed description of physical space, cyberspace, service enablers, and orchestrators.

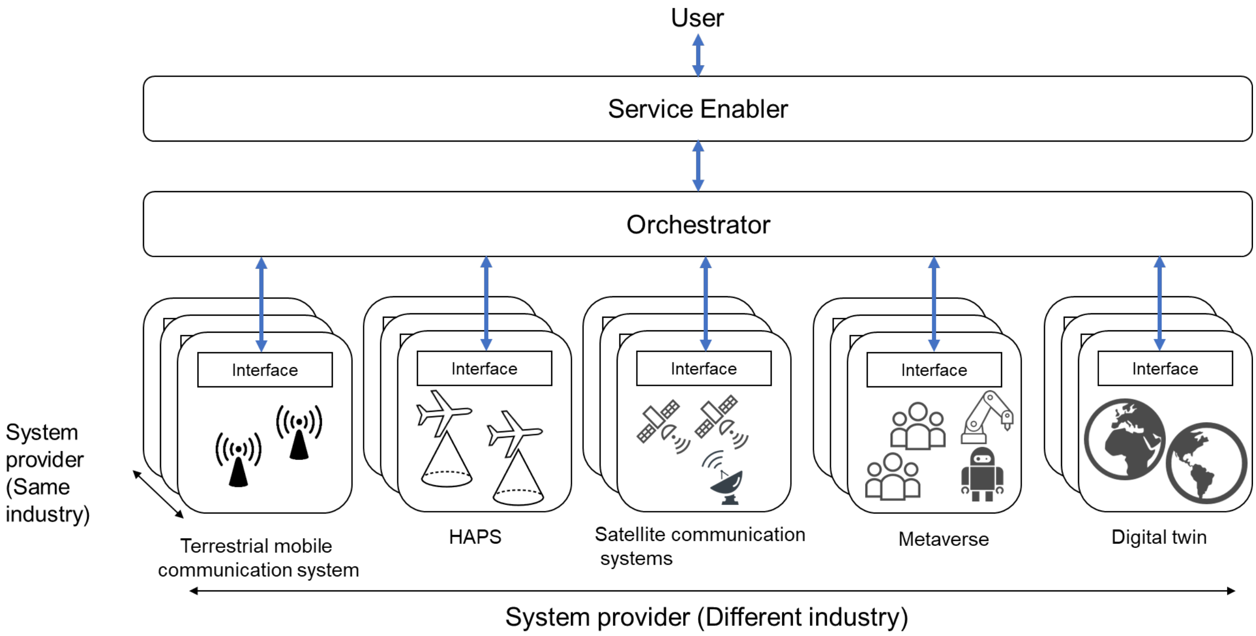


Figure 2.2 Beyond 5G/6G Ecosystem Configuration

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).

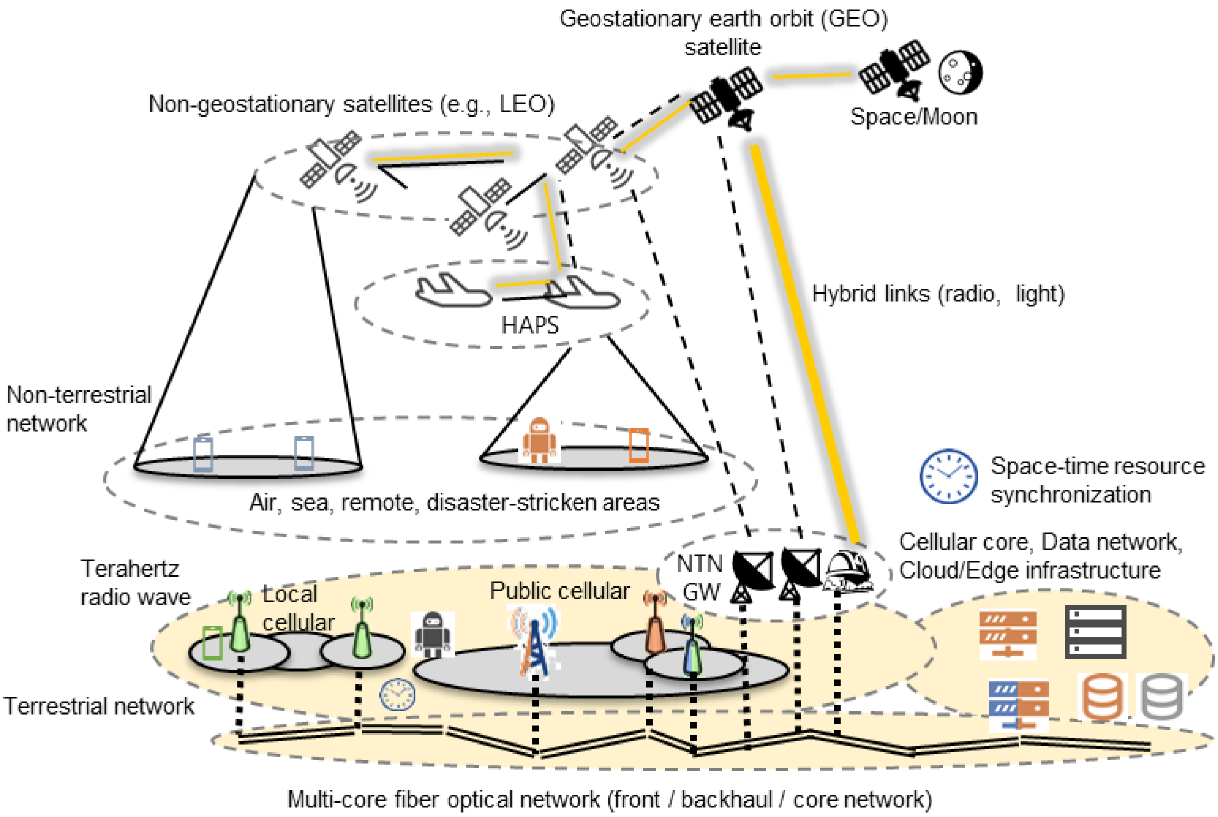


Figure 2.3 Physical space

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.

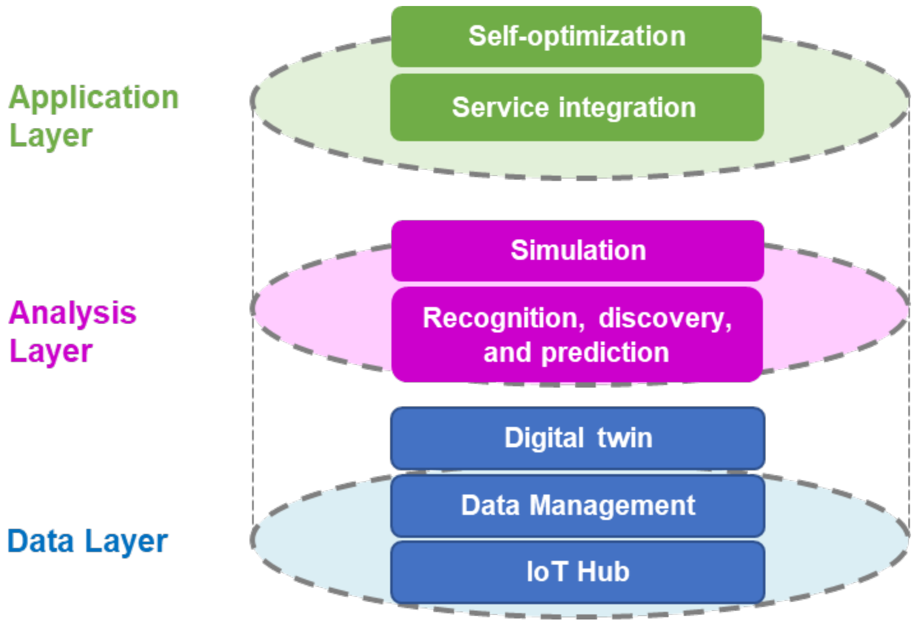


Figure 2.4 Cyberspace

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 avoidance” and “ultra-realistic sharing.” Such service enablers may be added as needed and opened to multiple users with appropriate access control.

Table 2.1 Examples of Service Enabler Functions

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

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 3).

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.

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.

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 Table 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.

In the next section, the digital twin linkage shown in Table 2.2 is presented in detail.

Table 2.2 Examples of Orchestrator Functions

Category	Individual function
Optimal Control	Digital twin linkage, AI/ML distributed processing, Low power consumption control
Autonomous Control	Zero-touch configuration management, Automatic failure recovery, Disaster communication control
Communications Resource Management	Frequency resource management, Communication quality management
Computing Resource Management	Edge computing resource management, Delay compensation remote control

2.10 Digital Twins Collaboration with Orchestrator

Digital twins aim to create virtual "twins" (models) of physical space entities (devices, objects, humans, etc.) in cyberspace and simulate and reflect their states and behaviors through modeling and simulation analysis. Digital twins can keep abreast of what is happening in the physical world through real-time updates from the physical entity and surrounding digital twins. In addition, by freely using various IoT data integration, big data analysis, and AI, hidden patterns and unknown correlations can be discovered, which makes it possible to record, control, and monitor the state and changes of entities, as well as to verify solutions and self-optimization through simulations.

In digital twins, communication takes place 1) between entities in physical space and models in cyberspace, and 2) between digital twins and different digital twins around them. As the scope of application of digital twins expands, communication evolves from the above 1) communication that synchronizes a single object to the above 2) communication that shares information among a group of objects with complex interactions. Communication further evolves from single segment (domain) communication to communication across multiple segments. An example of cross-segment communication is urban digital twins. Today, many cities are introducing digital twins, using IoT sensors to collect and monitor urban data, which supports decision-making and optimization through simulation and facilitates solutions to various issues such as urban planning, environmental management, traffic control, and energy management. To facilitate information sharing and interaction between digital twins in these various domains, orchestrators are required to have the functions shown in Table 2.3.

Table 2.3 Functional Requirements for Digital Twins Collaboration with Orchestrator

Category	Main Requirements
Brokering	A highly reliable and fault-tolerant intermediary (broker) is needed because if incorrect information is shared among multiple digital twins, there is a risk that an accurate model cannot be established, and incorrect information is fed back to the physical object. This broker identifies and authenticates digital twins, relays data transmission and reception, and performs data filtering, real-time delivery, and guaranteed delivery.
Synchronization	To achieve interaction between physical space entities and cyberspace models, it is necessary to establish data flow between the two and guarantee synchronization. The conventional method of uniquely identifying entities and performing one-to-one synchronization with models is extended to many-to-many synchronization between digital twins. Collision avoidance in such cases is also important.
Federation	Privacy protection is an important issue in digital twins collaboration. Enhancing trust and security by configuring and managing a federation of digital twins (federation) that updates shared virtual models while maintaining the confidential data generated by physical objects in individual digital twins.
Translation	Communication between digital twins in different segments requires not only formal transformation of data, but also semantic transformation (translation). Transformation rules for the purpose of digital twins collaboration should be developed based on established approaches such as ontology.

Figure 2.5 shows an image of how urban digital twins are linked by an orchestrator with mobility digital twins, environmental digital twins, and energy digital twins, and the various functions of the orchestrator shown in Table 2.3 enable the optimization of power supply and safe and comfortable mobility support, etc.

In addition, ethical issues associated with digital twins linkage need to be considered. For example, Gemini Principle 0 in the UK National Digital Twin lists information management issues in terms of purpose (public good, value creation, insight), trust (security, openness, quality), and function (federation, curation, evolution), which will be a guide to designing and implementing the above functions of the orchestrator.

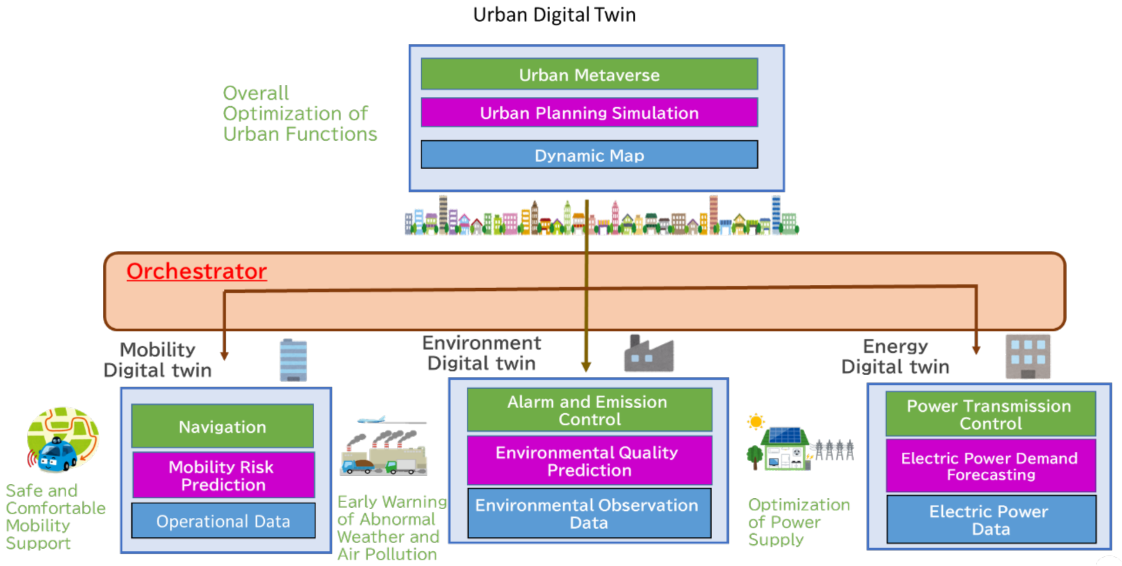


Figure 2.5 Image of Digital Twins Collaboration with Orchestrator

[References]

[2-1] Bolton A, Enzer M, Schooling J et al.: The Gemini Principles: Guiding values for the national digital twin and information management framework, Centre for Digital Built Britain and Digital Framework Task Group, DOI: 10.17863/CAM.32260 (2018).

Chapter 3: Future Life in the Beyond 5G/6G Era

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). 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.

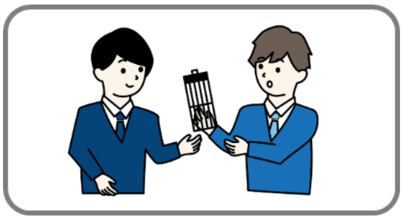


Figure 3.1 Telepresence meeting

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

Remotely participated in large-scale training event for simulating natural disasters (UC1-3). Using global core network technology, experts from various countries gathered in XR space to discuss matters further (UC1-1), 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) 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.

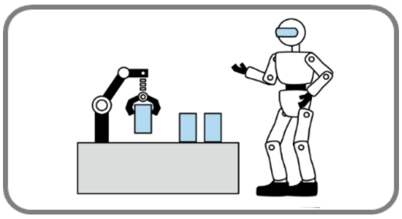


Figure 3.3 Remote response to emergency problem

■ 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). 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.

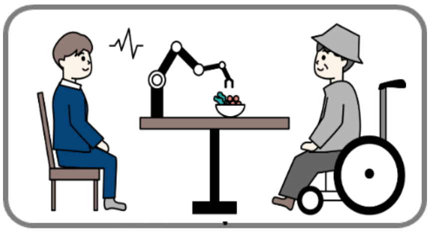


Figure 3.4 Remote assistance

■ 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). 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!

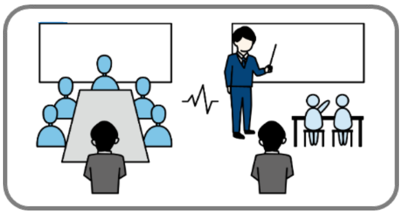


Figure 3.5 Company meeting and class visit

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

Petit-XR Mt. Fuji climbing for refreshment (UC1-3). 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.

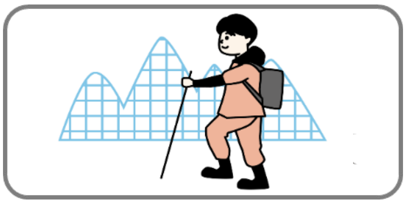


Figure 3.6 XR Mount Fuji climbing

■ 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).

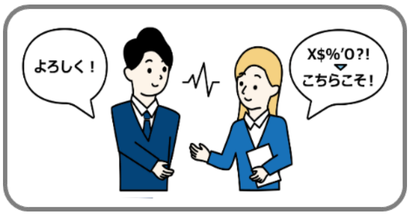


Figure 3.7 Remote negotiation across languages, cultures and customs

■ 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.

* See Appendix 1 for the following.

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

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

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

3.2 Scenario 2: City on the Moon

3.2.1 People Cultivating the Moon

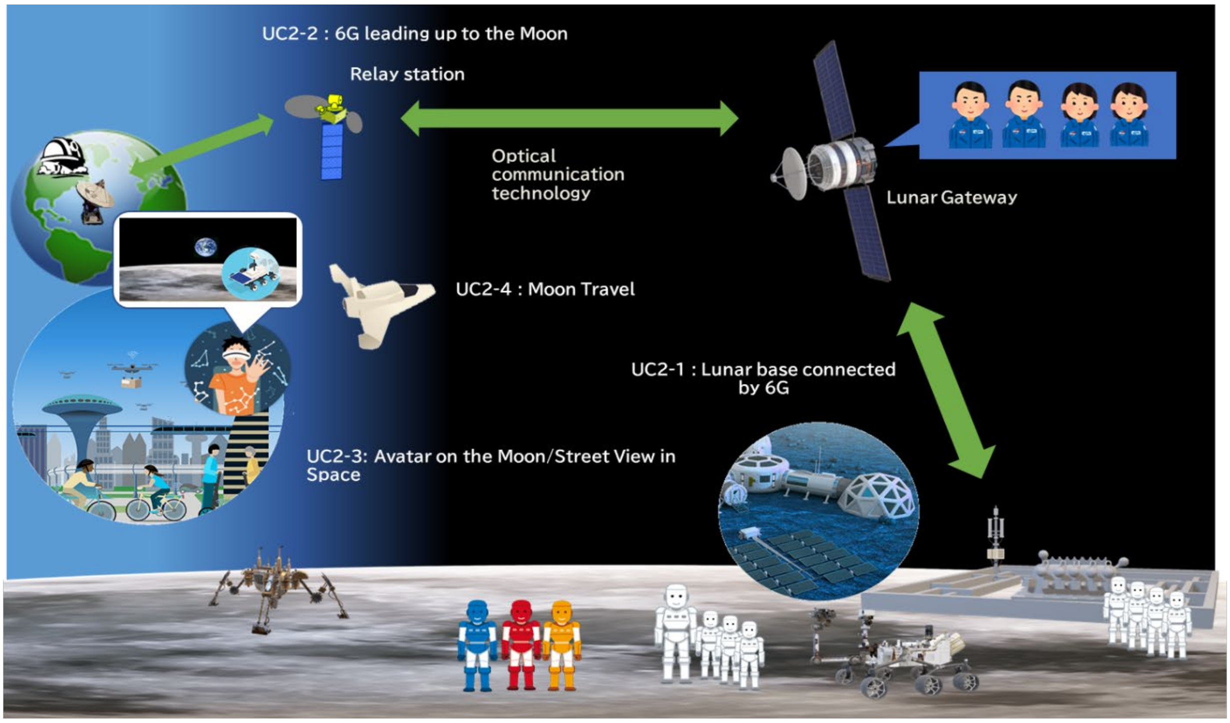


Figure 3.8 Image of scenario – City on the Moon

<At the 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.

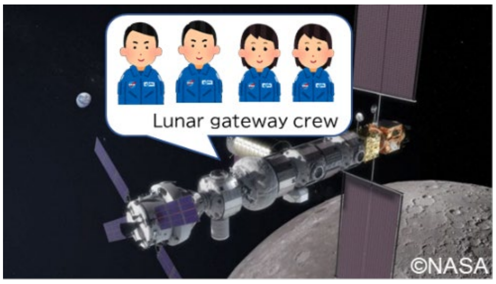


Figure 3.9 Future lunar gateway

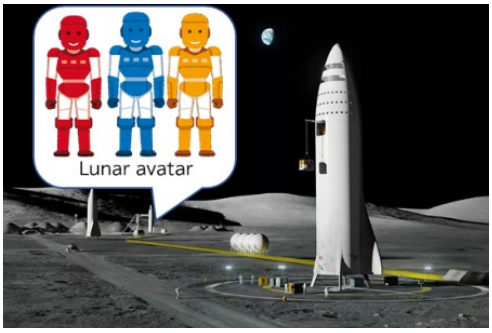


Figure 3.10 Image of lunar settlement and lunar base development*
*Space-X Base α: https://www.theverge.com/2017/9/28/16382716/spacex-elon-musk-moon-base-alpha-mars-colonization-interplanetary-transport-system

<From the Lunar Gateway to the Surface>

As I look at the horizon, I can clearly see the boundary between the black universe 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.

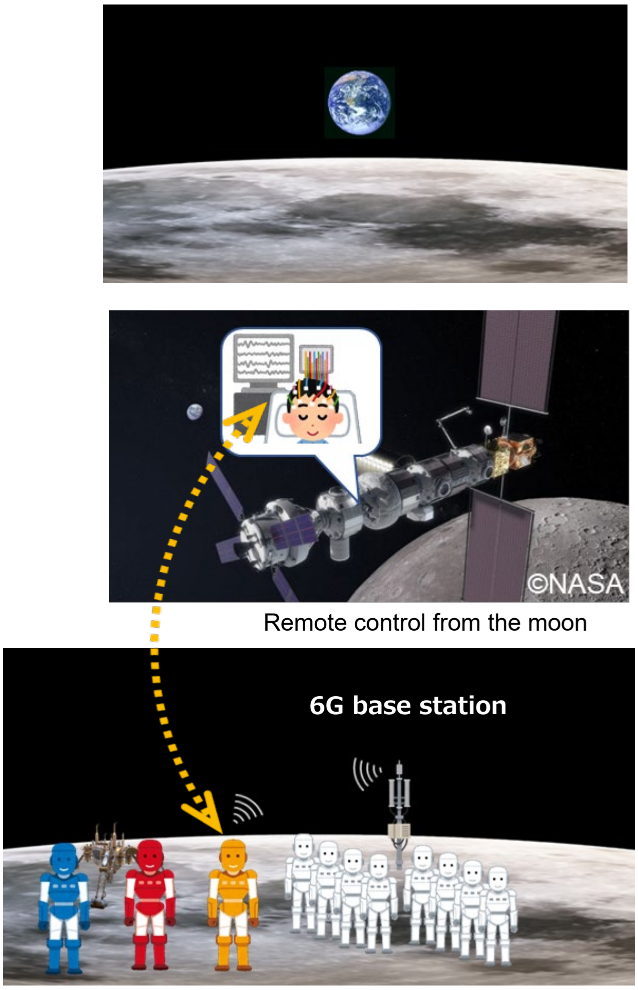


Figure 3.11 Remote work with lunar avatars

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 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 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 3.12 Remote work with lunar avatars

* See Appendix 1 for the following.

UC2-1: Lunar base connected by 6G

UC2-2: 6G leading up to the Moon

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

UC2-4: Moon Travel

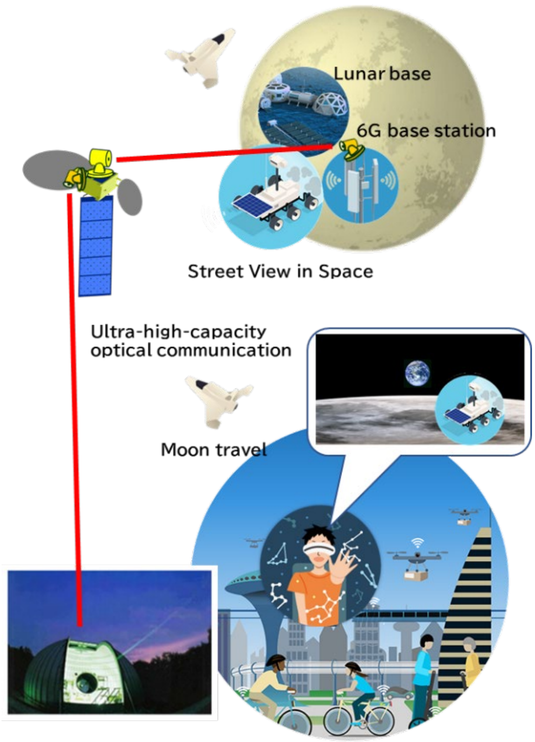
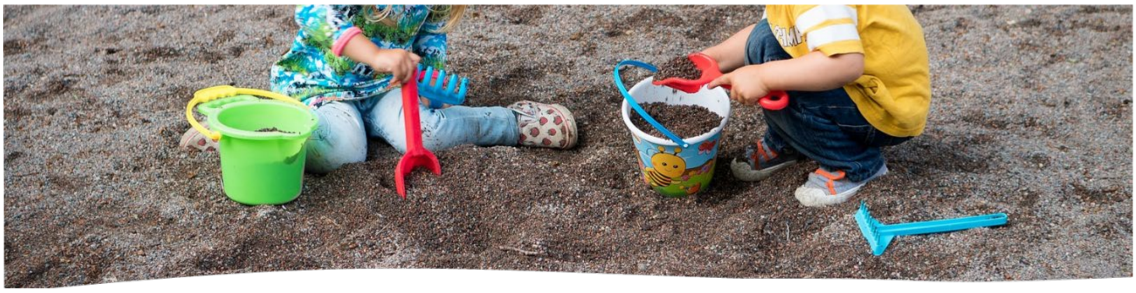


Figure 3.13 Accessing street view in space from Earth

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 77th 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

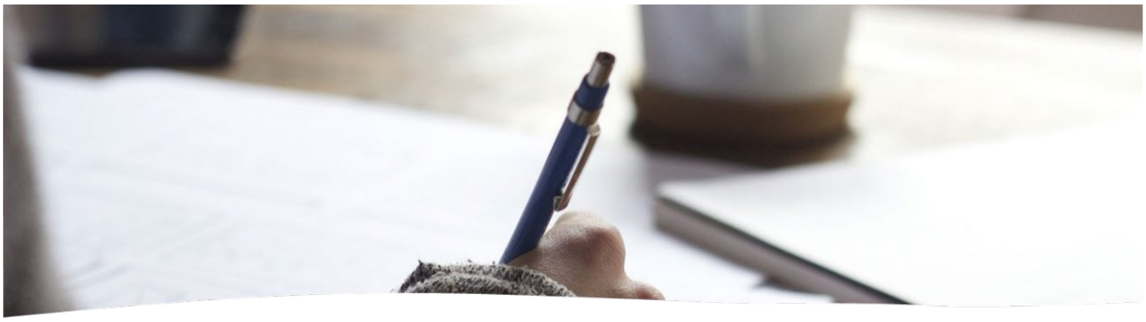
In the stratosphere warehouse that orbits around 20 km above the ground, I (an autonomous AI system) put the requested cargo in my backpack and dive to the ground (UC3-1). The moment I step out, I always get nervous, but I am also filled with a sense of freedom. After I leave the warehouse, the sky gradually 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).

* See Appendix 1 for the following.

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

UC3-2: Resilient Village Forest (Satoyama)

UC3-3: 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.

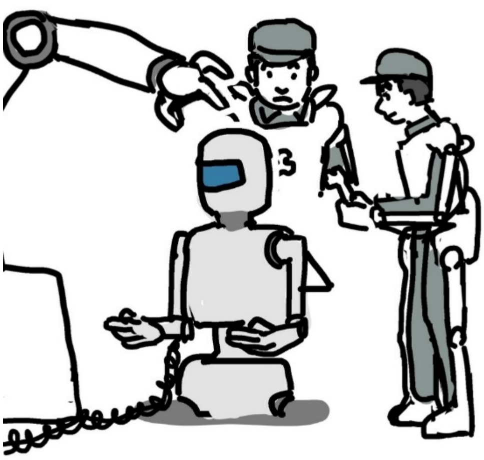
[Second person] Male, 40 years old, robot assembler

(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.

* See Appendix 1 for the following.

UC4-1: AI Agent

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

UC4-3: Avatar Identity Verification

UC4-4: Nudge Changing Behavior to Solve Social Issues

3.5 Scenario 5: Path for Life

3.5.1 A migrator who continues to take on a challenge in a regional city

It has been almost three years since I moved to this city, which is called a regional city. I have managed to get my job on track, and I feel that my life in the new place, which was unfamiliar to me at first, is gradually becoming more stable. At first, I thought that a senior like me would not be welcomed after moving to a rural area, but I have frequently been invited to local events, which makes me feel that I fit in reasonably well in this town.

For quite some time now, Japan's population decline has been unstoppable, and the economies of regional cities have been declining as the population has become increasingly concentrated in metropolitan areas and income disparity and differences in the educational environment have grown. Although progress has been made in the development of local infrastructure through public spending, it has not generated sufficient power to attract people to move to regional cities.

At the same time, services using remote-controlled robots, self-driving cars, drones, etc. were mushrooming in conjunction with the wondrous development of AI technology, and people's jobs were gradually being replaced by these services. The impact of AI on people's jobs has been particularly strong. As services that do not require labor costs were provided one after another at low cost with marginal costs being kept as low as possible, people were beginning to realize that the nature and roles of their jobs were gradually changing. In response to the situation where giant platformers called "Big Tech" were exclusively providing platforms for these services, there was a growing momentum to somehow shift the right to provide services using such platforms from the giant platformers to individuals.

Fearing that AI and robots would take people’s jobs, while some countries debated an issue on which public opinion was starkly divided, there was a country that has actively tried to utilize AI and robots for the development of humanity. That country is Japan.

About 10 years ago, a local city (actually the city where I live) started a new initiative called the "CPS Commons.”

“Commons" means “common land” and refers to land that is shared by a group of members in a village or hamlet, and what is gained from it. In the "CPS Commons," local industries and people’s businesses are regarded as “common land,” where locally unique platforms are created by using the CPS concept so that such industries and businesses freely collaborate with each other. In this way, a system is built, allowing various stakeholders, including individuals, to provide services according to the needs of each client. Thus, a unique economic zone is built, spreading its benefits throughout the region under the CPS concept.

This regional city was one of the first to take this approach, and by strongly emphasizing its regional characteristics both internally and externally, while also taking advantage of its unique local strengths, many people have come to appreciate the services it offers. This has led to the attraction of new companies and an increase in the number of incomers wishing to start their own businesses, which in turn has enhanced the educational environment to the point where it rivals that of large metropolitan areas. The tax revenues of the local government also increased. The positive effect of the active enhancement of public services has in turn led to many healthy seniors moving to the area in search of jobs in which they could play an active role. I had planned to start full-fledged volunteer activities after I retire in the Tokyo metropolitan area where I had lived for many years. But after witnessing the success of this regional city, I decided three years ago that I wanted to give up city life and take on the challenge of a second life by moving with the trend.

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I now run my own service business using the CPS Commons system. I also participate in a commons' organization (a type of non-profit organization, called a "Decentralized Autonomous Organization" (DAO)) and earn an income.

The service that my business provides is to buy fresh fish caught in fishing grounds directly from a fishing boat, transport them by drone from the fishing boat to a processing and cooking facility operated by the commons' organization, quickly process and cook the fish using avatar robots at the facility, and deliver the foods and dishes made from the fish directly to consumers by drone, etc. I have received many positive comments from clients about my fish saying that they taste better than fish landed at the port or from fish tanks. Building these services requires business partnerships with many stakeholders, which may at first seem difficult for individuals, but since the CPS Commons has various infrastructures and systems that make it easy to start such services, it was easy to get started.

In this service, based on clients' orders, the fishing fleet is informed in advance of the species and quantity of fish I wish to purchase, as well as the minimum purchase unit price. Each landed fish is given an individual ID after its condition is checked with a scanner, and then auctioned off in cyberspace in real time, with buyers being determined on the spot. Fishermen also believe that this method is very good for the future of their business because they can know the demand before they go out to fish, and conversely, they can optimize a catch based on the demand, which leads to the conservation of resources in fishing grounds.

The operation of avatar robots in the processing and cooking facility operated by the commons' organization is performed by people (pilots) who are matched in real time on the platform and who signed an instantaneous contract with the organization. Various people, including part-timers and young cooks, etc. start a shift when they want to work.

One of the pilots is a retired chef from a high-class restaurant in Ginza. This person is elderly and has some difficulty with eye and finger movements. But since an AI-assisted avatar robot functions to compensate for this disadvantage, the avatar robot's movements are as skillful as that provided by the chef when he was in active service. As a result, the chef has become so popular that clients who know him from the times of the Ginza restaurant request him to be a pilot. This retired chef has enough income to live on, thanks in part to his popularity, and he has not had to receive his pension not even once.

A young chef, who calls the retired chef the "master" and admires him, is working hard every day to acquire the master's knife skills by using a data set of the chef’s knife skills and handicrafts learned by AI. The young chef’s earnest attitude seems to have generated public awareness and he is beginning to attract regular customers.

There is a limit to the number of people who can be taught in such a teacher-apprentice relationship in the real world, but there is no limit to the number of people who can learn skills using AI data sets. The resources of the "CPS Commons" in such cyberspace have become a hub of culture and tradition that passes experience, skills, and craftsmanship acquired by masters to many people without creating the "tragedy of the commons.” Furthermore, the effect of such human resource development, combined with the branding strategy of the region, has made the attractiveness of the region more conspicuous and has become a driving force to further attract people to the region. The CPS Commons refers to this effect as Human-life Transformation (HX). In addition, a series of activities to gradually integrate cyberspace into people's lives is called a "migration program.” The program takes into account people's acceptance and social norms, while resolving ethical, legal, and social issues that arise when human life shifts from living only in conventional real space to living in cyberspace with AI and avatar robots that operate without time and space limitations.

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Recently, there was a real meeting at a commons’ organization that runs an apple farm. The apple farm run by the commons’ organization has decided to introduce a “Community Supported Agriculture” (CSA) system in which consumers will be directly involved in the operation of the organization. This was the kick-off meeting for the introduction of CSA. Apple cultivation is seasonal work, and there were a large number of fallow fields in this area due to a lack of successors. Now, students from the faculty of agriculture are using the avatar robot to help prune branches of apple trees and harvesting apples as part of their practical training. When difficult decisions have to be made, experts can provide guidance remotely via avatar robots. In addition, the commons’ organization intends to secure manpower by getting consumers involved in apple cultivation through the CSA system and establish a system for taking on the challenge of increasing brand power and product value, such as limited cultivation of diversified apples and using no pesticides or fertilizers.

There is an information asymmetry in that one cannot tell whether fresh food tastes good until one tries it. In economics, such asymmetry is called a "lemon market." For example, since we, as producers, know the entire process of apple growth, we can predict to some extent what the quality of this year's apples will be, and we can taste them when harvesting them. However, consumers do not know if they will like an apple or not until they actually buy and eat it. Of course, the brand name and sugar content of an apple can be used as a reference, but even with the same brand name, the taste and texture of apples will vary slightly depending on the growing conditions of each region. Taste and texture are also affected by the conditions under which apples are hermetically sealed and stored in a CA refrigerator, a warehouse with a special air composition used for long-term storage. Even if they spent a lot of time and money to produce high-end apples, the sugar content and texture of each individual apple will inevitably vary. Even after closing the annual sales, it is difficult to visualize the cost-effectiveness relationship, therefore, they have been reluctant to proceed with producing high-end apples by adding value to apples.

On the other hand, it was found that there is a latent desire among consumers to grow and care for their own apples from seedling to mature tree, and to eat freshly harvested apples that they have grown themselves, if they can eat the apples of their own liking. The commons' organization plans to launch a pilot service that will allow consumers to become owners of saplings, prune mature trees themselves using an avatar robot, harvest and select apples, and purchase all of the apples as part of a single set.

A member of the commons' organization who has been running a farm for a long time said that deciding on apple varieties to newly plant every year is a source of worry as it is like taking a gamble. The member is pleased that under the new CSA framework, consumers will decide on apple varieties, select apples themselves, and purchase all of the apples, thus, reducing the risk. In the conventional production method in the past, all harvested agricultural products are put on the market to be bought and sold, and unsold products are discarded. If a fabless production method, in which assets such as mature trees are sectionally owned by consumers and they produce only what they need, is expanded to agriculture in the future, this may also contribute to the reduction of food waste.

The issues raised on the day are the apple harvesting season is concentrated in a relatively short period of time, and not enough avatar robots are available to handle the large number of clients accessing the farm; and whether sufficient wireless communication lines are available to accurately control the avatar robots. To resolve the issue of an insufficient number of avatar robots, it was decided that clients will fund the purchase one avatar robot, which will be sectionally owned by the clients, and to subscribe to a general-purpose sharing robot owned by the municipality during the harvest period. As for the issue of wireless communication lines, there is a method such as installing a temporary base station and using satellite links, and if necessary, real-time frequency usage right (a kind of timed radio station license, called a "Quick License") is also issued. (This method is apparently limited to this area, which has been designated as a special zone.)

As an example of another problem that occurred at another farm, an incident was discussed in which an avatar robot, which was supposed to be piloted by a consumer, went haywire and uprooted saplings. This was apparently caused by someone with malicious intent taking over the control of the avatar robot from the consumer. This was a problem beyond the response capability of the members of the commons' organization and communities within this area.

This commons' organization has members with various skill sets necessary for normal businesses, such as the science of agriculture, civil engineering, law, economics, distribution, etc. On the other hand, in response to areas where no experts are available, such as the problem of someone taking over the control of avatar robots, the CPS Commons provide a service called "Tornada," in which AI matches and finds people with the necessary skill sets to solve problems from across the country and involves them as business partners. The service is very powerful, and the experts involved, with the help of AI, can make accurate judgments based on the special circumstances of each individual project and the characteristics of the region, and proceed with the project. We were able to involve a network security expert as a partner to help us deal with the problem of someone taking over the control of avatar robots.

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In the real world in the past, when unexpected circumstances arose that could not be handled by a small entity such as ours, nothing could be done about it if we did not have experts nearby. But the CPS Commons has been able to organize and promote projects by quickly gathering in skill sets comparable to those of large companies, utilizing avatar robots, AI, etc. Since I have been daily engaged in the agile operations of such an organization, I have come to think a lot. First of all, it is the sense of security that the service provides, created by the exquisite harmony between the AI, with general-purpose knowledge that transcends human knowledge, and the avatar robot, with which the pilot has a warm hearted and close bond, unlike previous frustrations or hardships in his or her life. In addition, by using avatar robots, individuals can now have greater freedom in their lifestyles to work free from space and time constraints. Furthermore, even if people have various complicated personal circumstances and difficulties, they can have the means to contribute to the community and society with the help of AI, avatar robots, etc., and live with equal roles and dignity. It might be a bit of an exaggeration to say that reforms are underway to create a social structure that is resilient enough to enable each citizen to carve out his or her own path for life in difficult situations that may come his or her way in the future.

As I contemplate the fact that my second life is beginning to launch smoothly now that I have finished raising my children, I quietly feel that the long-forgotten passion that I had in my youth is beginning to reignite.

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

Chapter 3 introduced five scenarios and several use cases within each scenario. In Chapter 4, the elemental technologies supporting these use cases are explained, and in Section 4.1, the outline of each Key technology area is presented, and its details explained in Appendix 2. In addition, Section 4.2 provides a technical description of the key elemental technologies that are expected to be utilized particularly in Beyond 5G/6G, among those elemental technologies.

4.1 Outline of Key technologies

The use cases will be extracted from the various scenarios presented in Chapter 3, and the elemental technologies that need to be researched and developed to realize these use cases will be summarized. In particular, elemental technologies considered to realize the three major characteristics of 5G: (1) High speed and large capacity; (2) Low latency communications; and (3) Multiple concurrent connections. Elemental technologies related to ultra-high speed and large capacity include high-capacity optical fiber communications and optical/wave fusion technology. There is also a communication technology that uses terahertz wave, which is higher in frequency than conventional wireless communication frequencies. In addition, there are adaptive wireless network, autonomous M2M network construction technology, and edge computing related to low latency and ultra-multiple concurrent connections.

Besides these technologies, there is network control technology related to wired and wireless networks, multi-layered wireless systems including satellite, such as non-terrestrial networks, space-time synchronization technology, and other security-related technologies related to ultra-safety and reliability, as well as various applications such as ultra-high realistic sensation used in the Beyond 5G/6G. applications. Table 4.1 summarizes these elemental technologies. Refer to Appendix 2 for more details.

Among these technologies, terahertz communication, Non-Terrestrial Networks (NTN), space-time synchronization technology, and high-capacity optical fiber technology (multi-core fiber) as key elemental technologies expected to be utilized in Beyond 5G/6G, in particular, are presented in the following Section 4.2.

Table 4.1: Key Technologies for Beyond 5G/6G

T1.		Ultra-high-speed and high-capacity communication
	T1.1	Terahertz wave
	T1.2	High-capacity optical fiber communication
	T1.3	Optical and radio convergence
T2.		Ultra-low latency and ultra-multiple simultaneous connections
	T2.1	Edge computing
	T2.2	Adaptive wireless access
	T2.3	Adaptive wireless application
	T2.4	Autonomous localization, tracking and reservation for radio wave radiation space
	T2.5	Autonomous M2M network construction with super multi-connection
T3.		Wired/Wireless communication and network control
	T3.1	Network control (Zero-touch automation)
	T3.2	Frequency allocation and sharing management
	T3.3	Private wireless system management (Local Beyond 5G)
	T3.4	Advanced wireless emulation
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	Generating and sharing for reference time
T6.		Ultra-security and reliability
	T6.1	Emerging security
	T6.2	Cyber security based on real attack data
	T6.3	Quantum cryptography
	T6.4	Electromagnetic environment
	T6.5	Resilient ICT
	T6.6	Sensing
T7.		Ultra-realistic and innovative applications
	T7.1	Brain information reading, visualization, and BMI
	T7.2	Intuition measurement, transmission and assurance
	T7.3	Real 3D avatars, multisensory communication, and XR
	T7.4	AI analytics and dialogue using language and extra-linguistic information
	T7.5	Edge AI behavioral support
	T7.6	Simultaneous multi-lingual interpretation, paraphrase, and summarization
	T7.7	Autonomous driving
	T7.8	Drones and flying cars

4.2 Key Elemental Technologies

4.2.1 Terahertz communication

Terahertz communication, discussed in each agency's Beyond 5G/6G white papers, could be a hallmark of Beyond 5G/6G. On the other hand, the 8K ultra high-resolution video is being promoted. The full spec 8K uncompressed data rate is 144.3 Gbps, which is consistent with the 100+ Gbps that terahertz communication aims for in Beyond 5G/6G. In addition, significant progress has been made in the development of a Head Mounted Display (HMD) for use in Metaverse and XR (VR: virtual reality, AR: augmented reality). HMD, 8K, and terahertz communication are considered to be compatible with each other, and related development will likely advance in the future. It is said that 8K reaches the limit of human visual capabilities in terms of resolution, and the combination of the above is the ultimate achievement of technology for human vision and is expected to have a wide range of applications.

Figure 4.1 Ultra-high-speed, high-capacity terahertz wireless needed to utilize 8K in HMD

<Characteristics of terahertz wireless>

In order to meet the demand for the realization of faster and larger capacity wireless communications, the frequencies used in wireless communications are gradually becoming higher and higher. 5G has made possible the use of frequency bands below 100 GHz. In Beyond 5G/6G, in which further ultra-high speed and large capacity will be demanded, a bandwidth from a dozen GHz to several dozen GHz in the frequency band above 100 GHz is expected to be used. The maximum bandwidth for 5G was 400 MHz, but if, for example, a continuous 44 GHz width [4-1] from 252 GHz to 296 GHz (300 GHz band) is used, it is 110 times the 400 MHz width. Therefore, if a data rate of 10 Gbps can be achieved using a bandwidth of 400 MHz for 5G, that means 1.1 Tbps using a bandwidth of 44 GHz could be achieved, 110 times that bandwidth. In reality, due to the limitation of semiconductor devices, radio wave propagation, system technology, etc., the target data rate of 100 Gbps, which is about 10 times higher than 5G, is set.

The wavelength of the aforementioned 300 GHz band is very short, roughly 1 mm. A shorter wavelength, i.e., a higher frequency, has two main effects. The first is that even small antennas have high antenna gain. High antenna gain indicates the degree to which energy is concentrated in a particular direction. In terahertz bands, since even a small antenna concentrates energy in a specific direction, a beam of radio waves is used for transmission and reception. Therefore, it is necessary to align the direction of the beam when transmitting and receiving. Second, the higher the frequency, the greater the free-space propagation loss. For this reason, it is not suitable for transmission over a long distance. Depending on the system under consideration, it is important to properly design the transmitting and receiving antenna gain and free-space propagation loss (propagation distance). For example, a parabolic antenna of about 15 cm in diameter has an antenna gain of about 50 dBi in the 300 GHz band (10^5 times higher in the directivity direction compared with an isotropic ideal antenna), which can offset free-space propagation loss when used for transmission and reception, enabling a transmission of about 1 km.

<Use case>

Communications between two points with a fixed beam [4-2] include kiosk downlink, device-to-device communications, communications within data centers, and fronthaul and backhaul in mobile communication systems. Next-generation mobile communications (Beyond 5G/6G) and next-generation WiFi (WiFi-X) [4-3], etc. are being considered as communications in which beams are controlled as needed, and related R&D is being conducted in many countries.

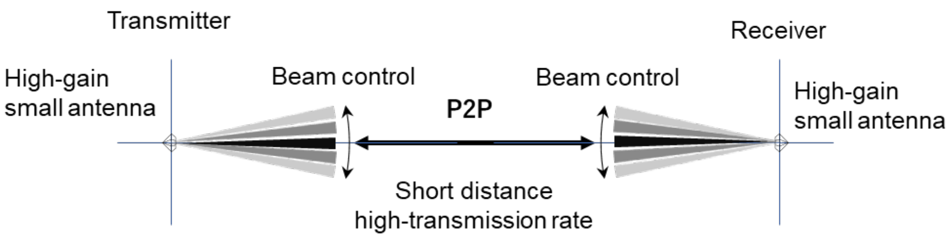

Figure 4.2 Characteristics of terahertz wireless

[References]

[4-1] Radio Regulation Chapter II, Article 5, No. 5.564A, 2020 Edition.

[4-2] IEEE 802.15.3d-2017 - IEEE Standard for High Data Rate Wireless Multi-Media Networks Amendment 2: 100 Gb/s Wireless Switched Point-to-Point Physical Layer

[4-3] Ministry of Internal Affairs and Communications R&D for Expansion of Radio Wave Resources (https://www.tele.soumu.go.jp/j/sys/fees/purpose/kenkyu/)

4.2.2 Non-Terrestrial Networks (NTN)

Non-Terrestrial Networks (NTN) extend the communication range of Terrestrial Networks (TN), which have been deployed mainly on the ground. In order to enable the provision of new services, NTN construct communication networks from the ground to the sea, in the air, and in space by placing communication equipment on mobile vehicles such as ships, aircraft, and satellites. In particular, in the Beyond 5G/6G network utilizing NTN, not only ground-based vehicles, but also ships, drones, and other mobility devices, High Altitude Platform Stations (HAPS), satellites, deep space probes, etc., will be connected in three dimensions while taking advantage of their respective characteristics. Compared with TN, since the performance of NTN, such as communication speed and delay time, etc., differs greatly from platform to platform, various technological developments are required to build a beneficial network by taking advantage of the characteristics of each. NICT is conducting research and development on key technologies in the application of NTN from the viewpoints of radio wave technology, digitalization technology, optical technology, and network technology in satellite and non-terrestrial communications from the ground to air to space. Furthermore, not only for ground to air to space but also for undersea and underwater communications, research and development of short distance communications and sensing technology using radio waves is underway.

Radio wave technology in satellite and non-terrestrial communications

NTN, which communicate from the ground or sea to platforms in the sky or space, have a longer communication distance than TN, which only communicate within the earth's atmosphere. For example, the transmission distance between a satellite in geostationary orbit (Geostationary Earth Orbital (GEO) satellite, etc.) and the ground is about 40,000 km, which is the same distance as circling the globe. Therefore, when using radio waves to connect with NTN platforms, it is necessary to consider how to achieve the required communication quality, such as communication capacity and transmission speed, over a long distance. Currently, satellite communications, which is one of the typical long-distance communications, uses radio waves in the frequency band below 30 GHz to achieve high-speed and high-capacity communications. However, as frequency resources below 30 GHz are in short supply, it is expected to shift to higher frequency bands of Q/V/W (40/50/70- 80 GHz band) to achieve even higher speeds and capacities. However, the higher the frequency of radio waves, the greater the attenuation during rainfall. Therefore, rainfall attenuation countermeasures and higher device efficiency are essential to use this band for satellite and non-terrestrial communications. For this reason, NICT is developing satellite-mounted equipment for use in the Q/V/W bands, as well as conducting research and development of antennas for various platforms such as ships, aircraft, and HAPS.

Digitalization technology in satellite and non-terrestrial communications

In low earth orbit satellites (non-geostationary orbit satellites such as Low-Earth Orbit (LEO) satellites, etc.), since the platform moves in the sky in a short period of time, technology for transmitting and maintaining radio waves concentratedly in a specific direction is essential for communicating with devices on the ground. In addition, as ships, ground mobility, and aircraft in the sky move, if changes occur in the target area for radio wave emissions and the number of communication devices in the area, it will necessitate flexible changes in the area where radio waves are emitted from onboard satellite equipment and frequency allocation. However, since the power and weight of the onboard equipment of satellites such as LEO, etc. are limited, how to achieve these functions will be a challenge.

NICT has been conducting research and development of onboard equipment with digital beam forming (DBF), which strengthens the directivity of antenna only in a specific direction, as well as with a digital channelizer function that can change the allocation of communication resources such as frequencies. NICT is also planning a technology demonstration using the Engineering Test Satellite-9 (ETS-9).

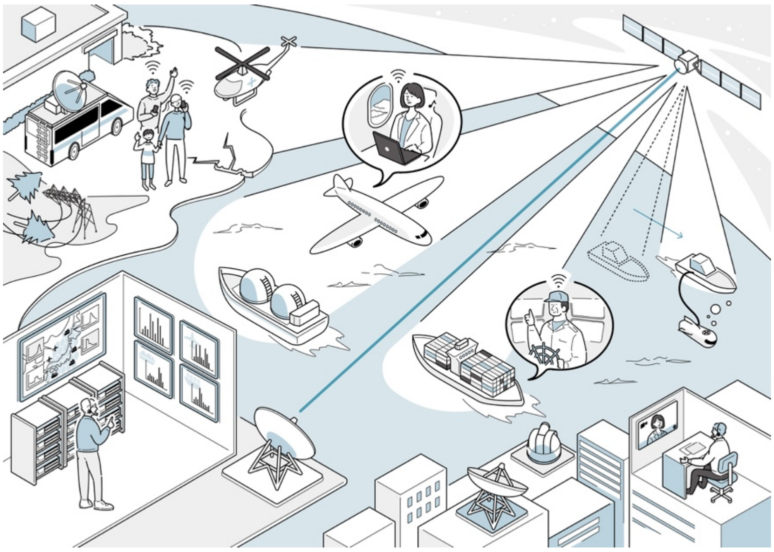

Figure 4.3 Image of high-throughput satellite communication system

Optical technology in satellite and non-terrestrial communications

Optical space communication using light is a means of solving the problem of radio frequency shortage and achieving high-capacity communication. Optical space communication identifies the location of the other party and communicates by emitting a sharply directed laser beam in that direction, allowing high-speed communication if there is no shielding or other obstruction. Therefore, when using optical space communication between satellites or HAPS and optical ground stations, etc., it is essential to realize site diversity technology to avoid locations with poor weather conditions such as clouds or rain, and to select optical ground stations in clear locations.

NICT has a track record of successful 100 Mbps transmission between a small optical communication device installed in the Japanese Experiment Module "Kibo" of the International Space Station (ISS) and an optical ground station in 2020. NICT is now conducting research and development of a small optical communication device for further high-speed, large-capacity transmission and installation in HAPs, etc. In addition, research and development of site diversity technology is underway. The site diversity technology maintains multiple optical ground stations interconnected by networks in Japan and selects and uses optical ground stations according to weather conditions. Other research and development projects are also ongoing, including a cloud recognition system, cloudiness forecast, and line control, etc. to avoid the impact of weather conditions such as clouds and rain, which are necessary for practical application of the site diversity technology. Furthermore, since light waves propagating in the atmosphere are distorted by atmospheric fluctuations in optical space communication, we are also working on research and development of compensation technology to cancel out the effects of atmospheric fluctuations and enable precise observations.

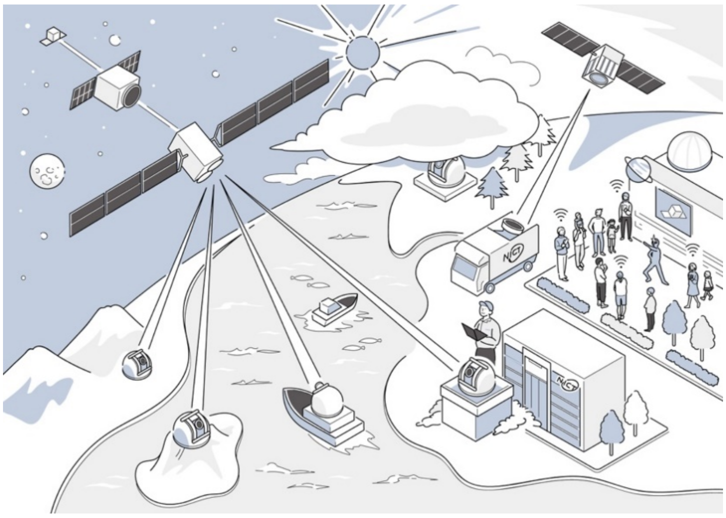

Figure 4.4 Image of optical satellite communications

Network technology in satellite and non-terrestrial communications

In NTNs, there are cases in which a terminal (UE: User Equipment) communicates directly with a satellite, and a terminal communicates with a satellite not directly but via a ground station that serves as a gateway. For each case, the NTN network needs to be controlled in consideration of the characteristics of platforms such as delay, LEO, etc. In addition, in order to expand networks, networks not only with LEO satellites but also with GEO satellites that can cover a wider area of the earth than LEO satellites are necessary, as well as optimal routing control via multiple same/different types of NTN platforms and network control across multiple operators' networks. NICT is conducting research and development of orchestrator functions to appropriately arbitrate between these TN-NTNs, between NTNs, and between multiple operators, as well as developing technologies to reliably operate networks consisting of many links with different performance.

Undersea and submarine communication technology

Japan has one of the world's largest exclusive economic zones and has the potential to become a major marine resource power. In future marine resource surveys, there are growing expectations for undersea communications, such as remote control of undersea robots and sub-seafloor exploration. In anticipation of the coming of such an era, NICT is conducting research and development of undersea wireless technology using radio waves. So far, NICT has been conducting the following research: research on modeling and analysis of undersea radio propagation by electromagnetic field simulation using frequencies from 10 kHz to 10 MHz; measurement of undersea radio propagation; research on undersea high-speed communications using multi-level modulation; research on sub-seafloor sensing using electromagnetic waves; and research on applied technologies using radio waves.

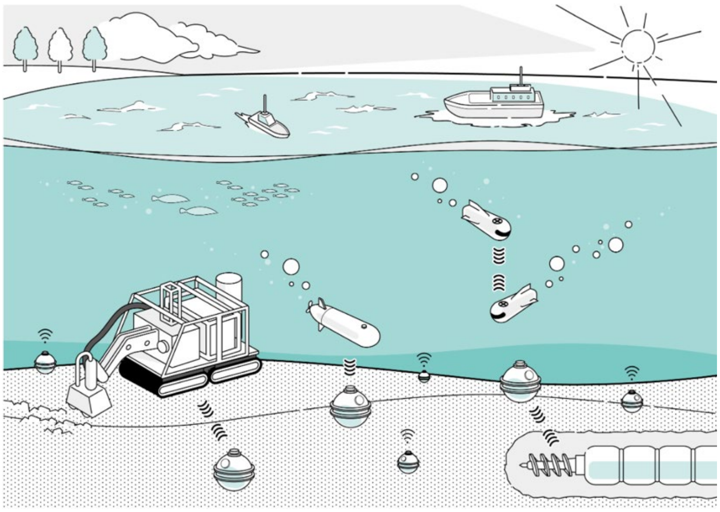

Figure 4.5 Image of undersea and submarine communications

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4.2.3 Space-time synchronization

Information and communication technology has eliminated the gap between time and place. On the other hand, it is also very beneficial to accurately recognize time and place through information and communication technology. For example, a smartphone equipped with a GNSS receiver chip (†) as typified by GPS makes it possible to locate the caller, which has made it easy for an ambulance to identify its destination, saving many lives. In this way, accurately determining real time and location has become possible. By making use of such benefits, space-time synchronization technology supports a wide variety of applications.

Time synchronization is easy to understand, but what is spatial synchronization? Of course, it does not mean that each individual synchronizes the space around him or her to become one. What meant by synchronization in this case is not matching time or space itself, but rather "matching the coordinate axes of time and space that everyone has." If everyone has a common coordinate axis, we can communicate with others by using a small amount of digital data to express time and place, which, as a result, will allow us to accurately grasp the relationship before and after an event, the relationship of objects in terms of location, etc. When there are many players, they can accomplish one large task without interfering with each other's space, or they can take turns to do a small task seamlessly, thus, they can achieve the same results by efficiently using resources such as energy, etc.

Coordinate axes of time and space are not independent. Since electromagnetic waves have the speed of light and propagate through space over time, we can measure space by measuring the propagation time of radio waves. GNSS makes use of this. GNSS satellites are equipped with accurate atomic clocks, and we can determine their positions based on time information from GNSS and satellite orbital information. This is made possible because we share the coordinate axis of time, which is the GPS time, and the coordinate axis of space based on the earth, and the satellite sends us its positional information along with time.

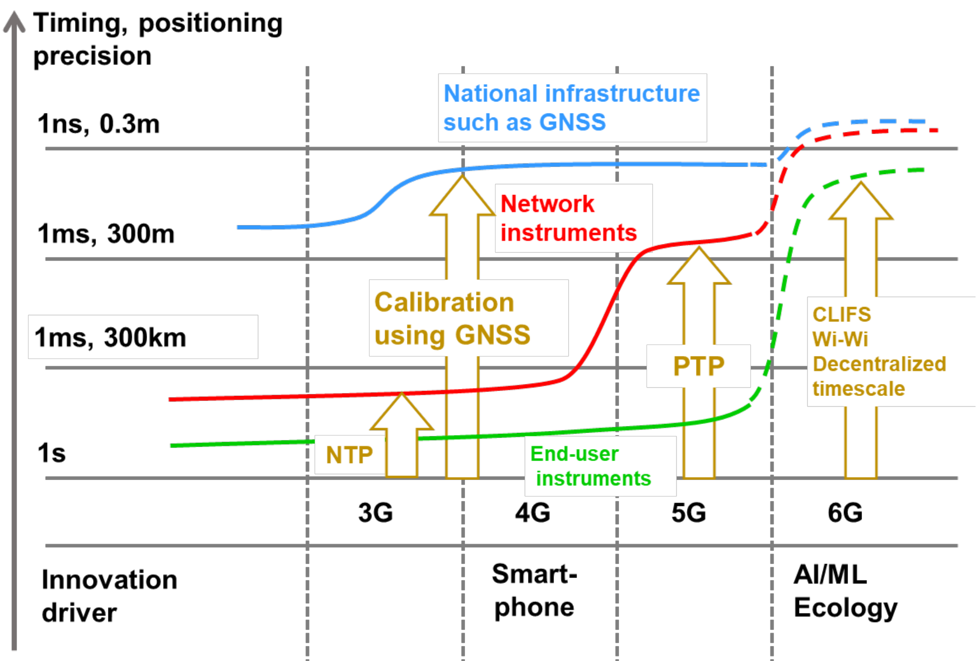

Figure 4.6 Improvement of time and location accuracy with each generation
(New time synchronization technology and positioning technology will be introduced gradually.)

How accurately can we share time and spatial information? Figure 4.6 schematically depicts how the accuracy of time and location information has improved since the year 2000. Multiplying the time accuracy by the speed of light gives the spatial accuracy (a time accuracy of 1 ns gives a positional accuracy of 0.3 m). GPS satellites are equipped with atomic clocks and have nanosecond-level time accuracy and 30 cm-level position measurement accuracy. But we know that a smartphone equipped with a GPS receiver chip has an error of more than a few meters. In the 3G and 4G era, mobile terminals had not yet reached the point where they could fully utilize the performance of GNSS, and to do so required special dedicated equipment that could never fit in a pocket, and signal integration time of several minutes or longer. In addition, as GNSS is completely ineffective in areas where satellite signals cannot reach, and the dangers of interference and GNSS spoofing have recently been pointed out, the necessity of space-time information infrastructure other than GNSS has been discussed. On the other hand, one evolution of 5G is the improved time accuracy of base stations. This is due to the increased importance of time-division duplexing, which switches between transmission and reception separated by time, to cope with the increase in upstream traffic. However, the clock held by the final user has not yet reached the point where everyone can share the time and space coordinate axes.

As NICT is a research institute for information and communications and has provided Japan Standard Time, it has a certain amount of experience in generating and distributing accurate time. NICT has also led the VLBI space geodetic technique (††) in Japan and has certain capabilities in spatial measurement. We believe that this experience can be developed into space-time synchronization technology as Beyond 5G/6G technology, and we are developing the following three main technologies.

(1) Chip-scale atomic clock (Chip level integrated frequency standard, CLIFS) [4-10] [4-11]

A pendulum that does not deviate is the most basic form of timekeeping. However, the oscillation frequency of a typical crystal oscillator deviates due to temperature, acceleration, and aging. Therefore, by dramatically reducing the size of the atomic clock used to generate standard time through MEMS technology (†††) and optical technology, the clock can be installed in devices used by end users (self-driving cars and, ultimately, mobile terminals), enabling them to have a much more stable clock than those used at present.

(2) Wi-Wi (Wireless Two-Way Interferometry) [4-12] [4-13]

This is a technology of accurately measuring the propagation time of radio waves along with the time deviation of each other's clocks, which is in other words the distance between terminals, by mutually transmitting time information. It can be said that measuring a distance is sharing a coordinate axis that connects two points. Adjusting one of the clocks with zero-time deviation achieves synchronization, which is in other words sharing a coordinate axis of time.

(3) Cluster clock [4-13]

This is a technology that generates and shares a more stable and resilient local virtual time among participating clocks by collecting digital data of time differences among many clocks connected to a network and numerically obtaining their weighted average. This will create an environment where everyone can benefit from stable time through the power of numbers and software, even in an environment where clocks with good performance and clocks with poor performance are mixed. Also, by linking a virtual time to a standard time such as Coordinated Universal Time, etc., everyone can easily access the standard time in a single hop. The improved accuracy and resilience that can be achieved through the power of numbers and software will benefit not only time, but also space, which is indivisibly linked to time.

Figure 4.7 shows an image of a world realized by establishing these space-time synchronization technologies. In the Beyond 5G/6G era, it is expected that our mobile devices will have absolute time and position accuracy of nanosecond or submeter. Furthermore, sharing more precise coordinate axes (cm, several 10ps) can be expected within a certain local time and space (e.g., in a factory). This will enable cooperative work by multiple robots and communications that do not waste packets or energy due to strict time management. Furthermore, by combining space-time synchronization technology with prediction and estimation technology such as AI, ensembles, etc. with multiple performers at a distance may become a reality.

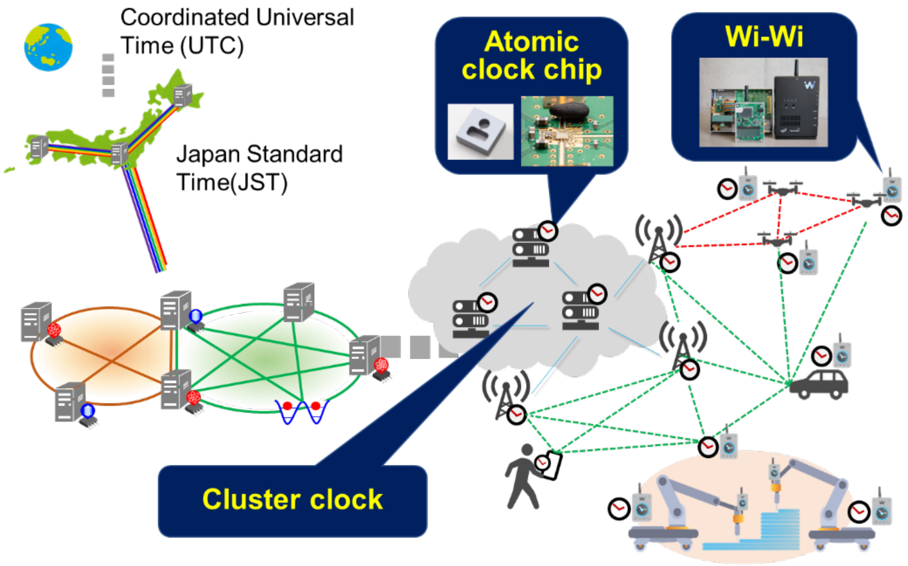

Figure 4.7 A world where space-time synchronization is realized.
(By sharing absolute time and coordinate systems, such as Coordinated Universal Time and the global geodetic coordinate system, and local relative time and coordinate systems, according to the purpose, networks can become distributed and coordinated, and energy efficiency and resilience can be improved).

(†) GNSS receiver chip typified by GPS: Although the first globally available positioning satellite was the Global Positioning System (GPS) of the United States, there are now four types: GLONASS of Russia, Galileo of Europe, and Beidou of China. These are collectively called Global Navigation Satellite Systems (GNSS), and a GNSS receiver chip is an IC device that receives these signals.

(††) VLBI geodetic technology: Technology of receiving radio waves from distant points in space at multiple points on Earth and measuring the positional relationship between observation points based on the difference in arrival times. (VLBI: Very Large Baseline Interferometry)

(†††) MEMS technology: Technology of creating tiny mechanically moving parts using microfabrication technology such as semiconductor manufacturing technology (MEMS: Micro Electro Mechanical System)

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4.2.4 High-capacity optical fiber

In the 2030s, a highly information-oriented Society 5.0 [4-14] is expected to arrive, where smart cities, smart factories, and disaster and crime prevention systems will be realized to solve various social issues, stimulate and streamline economic activities, and create a safe and secure society. Currently, research and development are being conducted on Beyond 5G/6G, which will serve as the information and communication infrastructure for Society 5.0. In addition to mobile communication systems, the following are also important R&D targets: wired and wireless access networks to which a large number of users are connected; and optical networks in core and metro areas that accommodate the data of data center networks that handle large amounts of data. Currently, optical fiber communication systems using standard-type single-mode optical fibers (Figure 4.8(a)), which consists of a core that serves as the optical signal path and a cladding around it, are being utilized, but Beyond 5G/6G requires a significant increase in capacity. In order to realize high-capacity transmission, multicore fibers (Figure 4.8(b)), which incorporates multiple cores in a single optical fiber, are expected to be the next-generation optical fiber. Research on high-capacity transmission technology known as space division multiplexing (SDM) technology, which transmits signals using multicore fibers, is being actively conducted.

In conventional optical fiber communication systems, transmission capacity of several tens of terabits per second per optical fiber was achieved by wavelength division multiplexing technology, which increases the number of optical channels that are simultaneously inputted into to a single optical fiber by using many wavelengths. This is the capacity to send data equivalent to approximately 100 Blu-ray discs per second. On the other hand, more than 10 times the current transmission capacity is needed for Beyond 5G/6G. To increase transmission capacity, more high-power optical signals must be inputted into an optical fiber. However, there is a problem that the waveform of the optical signal is degraded due to a phenomenon called nonlinear optical effect caused by the interaction between the optical signal with high optical power and the optical fiber. In addition, if the core of an optical fiber is heated by high optical power and becomes locally very hot, the core may melt sequentially (fiber fuse phenomenon) and the fiber may be destroyed. To solve these problems, SDM technology using multicore fiber, etc. is expected to be introduced.

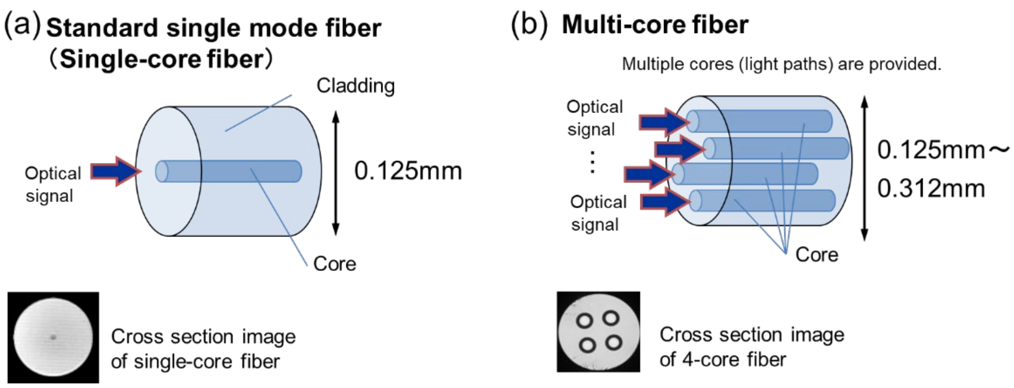

Figure 4.8 (a) Standard single-mode fiber (b) Multicore fiber

As shown in Figure 4.8 (b), a multicore fiber has multiple cores in the same cladding, and each core is used to transmit optical signals. Therefore, optical power can be dispersed, allowing for a larger capacity according to the number of cores. Another SDM technology is multimode transmission technology, which uses multiple optical paths in the core, called propagation mode, to transmit different optical signals simultaneously. By increasing the core diameter, multiple modes can propagate, thus increasing the capacity according to the number of modes. However, since coupling occurs between optical signals of each mode during fiber transmission, complex signal processing is required to separate the modes at the optical receiver. It is also possible to incorporate multimode transmission technology into multicore fiber, and by fully utilizing these SDM technologies, dramatic increases in optical fiber capacity can be achieved.

NICT has been studying a future high-capacity optical communication system based on the SDM method such as multicore fiber. An overview of the system is shown at the bottom of Figure 4.9. Compared with the system that extends conventional technology for higher capacity (upper part of Figure 4.9), this system can combine multiple optical fibers into a single multicore fiber, making it smaller and lighter. The development of an optical amplifier for multicore fiber is also underway. As a single optical amplifier can handle optical signals from multiple cores, including the sharing of excitation light sources and excitation fibers for optical amplification, space and power savings can be expected, compared with conventional methods. Since the SDM system tends to have a large number of components, such as optical transmitters and receivers, and their costs tend to be high, it will be essential to develop highly integrated technologies to combine multiple devices into a single unit in the future.

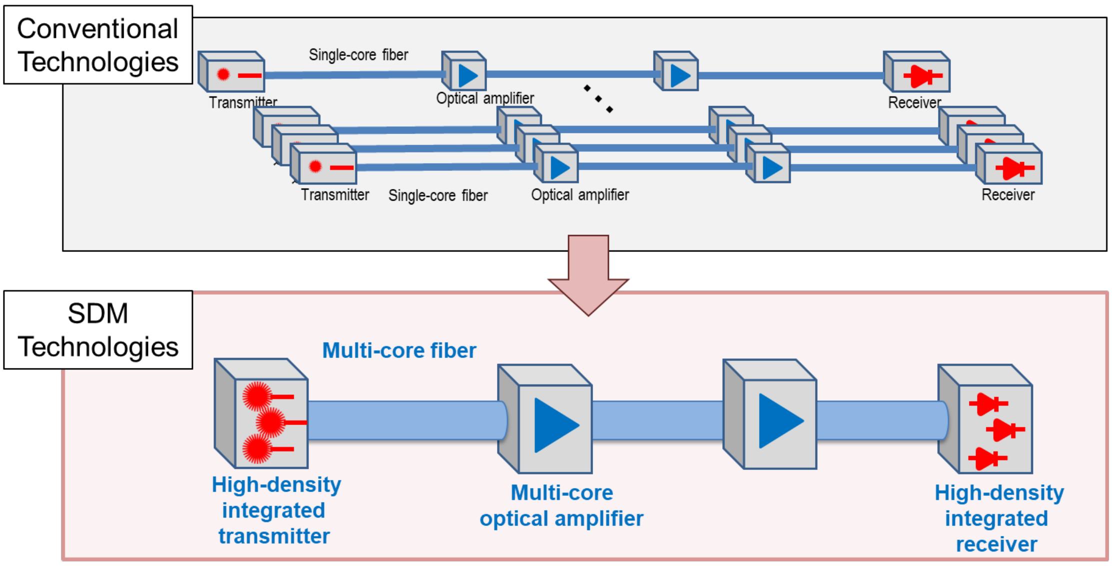

Figure 4.9 A system that extends conventional technologies, and a future SDM-based optical communication system.

To date, several research institutes have conducted high-capacity optical transmission experiments using various multicore fibers. Figure 4.10 shows the evolution of typical transmission experiments. In these experiments, we have achieved transmission capacities exceeding 100 to 150 terabits/s, which is considered the transmission capacity limit of single-mode fibers, by using various multicore fibers and transmission technologies [4-15]- [4-17]. In 2020, using an optical fiber with 38 cores and each core having three propagation modes (cladding diameter: 0.312 mm), a transmission experiment of 10.66 petabits/s, which is still the world record transmission capacity per optical fiber today (as of January 2023), was successfully conducted [4-18]. The distance of fiber transmission in this experiment was 13 km, and further development of long-distance technology is required. However, the transmission capacity of 10 Pbit/s is more than 50 times the transmission capacity per optical fiber in the current commercial optical communication system. This is an important achievement that suggests the feasibility of high-capacity optical networks required beyond 5G/6G.

While the aforementioned high-capacity transmission experiment demonstrated the potential of multicore fiber transmission systems, research and development of multicore fiber with the same cladding diameter (0.125 mm) as standard single-mode fiber (called standard outer diameter multicore fiber) is actively underway, aiming for early practical application of multicore fibers. While standard O.D. multicore fibers have fewer than 10 cores, existing optical fiber and cable manufacturing technologies and existing peripheral technologies such as connectors can be utilized, so early commercialization is expected. Currently, efforts are being made to standardize standard outer diameter multicore fiber, mainly by domestic organizations. This standard outer diameter multicore fiber optical communication system is expected to be deployed for Beyond 5G/6G, which will achieve high capacity.

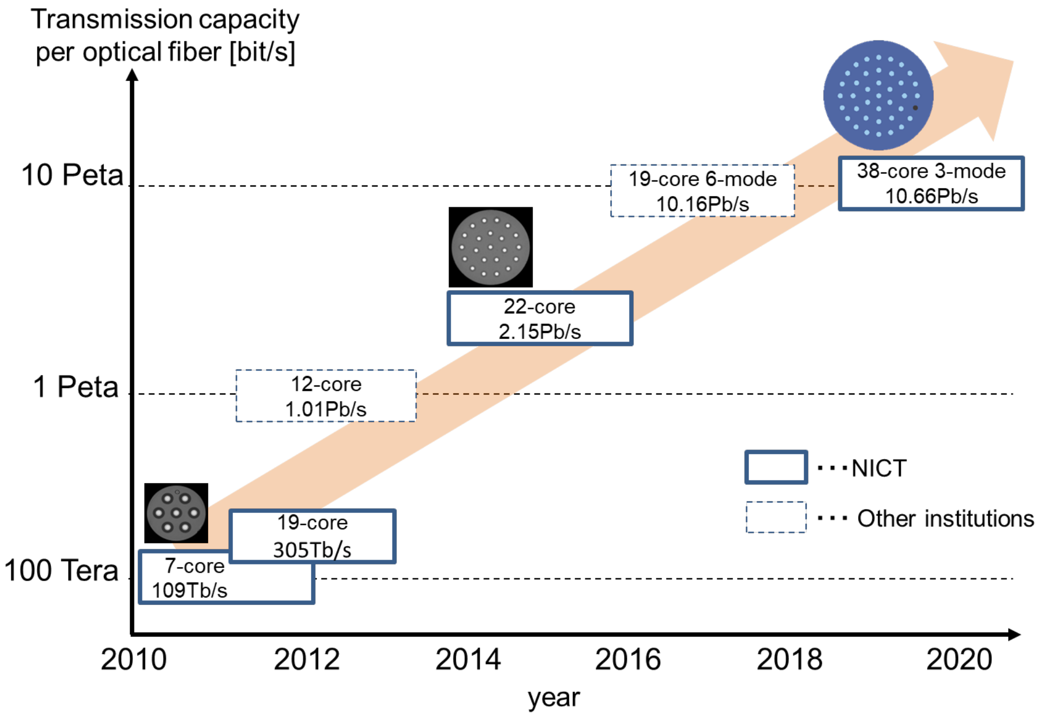

Figure 4.10 Evolution of high-capacity multicore fiber transmission experiments

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Chapter 5: Testbed Utilization in Social Implementation

5.1 Migration Path for Social Implementation

The purpose of research and development of elemental technologies is that they will be utilized in society (social implementation), such as being used in business, and as a result, humans will benefit from various perspectives. In this case, it is important to think about how to relate R&D to social implementation.

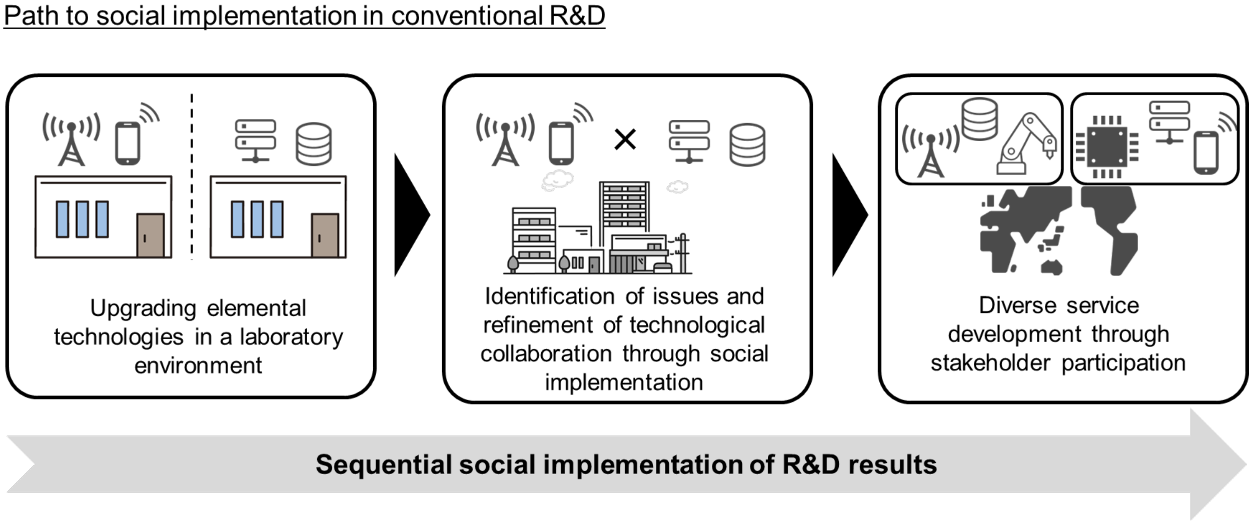


Figure 5.1 Path to social implementation in conventional R&D.

Figure 5.1 shows a path to typical social implementation for conventional R&D. In a laboratory environment, experts create technology, improve functionality and performance, and upgrade them. The next step is to demonstrate technologies by applying them to limited use cases in society, and then link and refine them. Then, technologies will be commercialized in business and further developed into a variety of services by involving stakeholders. This is, so to speak, social implementation along a sequential path of R&D results. The problem here is that with such sequential implementation, it takes a long time for developed technologies to be socially implemented. As a result, it is often the case that such technologies lag behind projects with greater implementation capacity and ultimately fail to achieve their objectives. What is even more problematic is that the number of companies and research institutes that have the strength to independently carry out the entire process from R&D to social implementation has become extremely limited. It is no longer possible to achieve purposes by following this path alone. There is also a concern that even if a variety of support to accelerate R&D is gained, ongoing activities may cease as soon as their contents to be implemented and the given time frame deviate from the plan and schedule. Especially in the fast-moving development of Beyond 5G R&D, since it will be difficult to create a game-changer with traditional sequential R&D, it may be necessary to review the concept of R&D itself.

An example is shown in Figure 5.2 to discuss the path to social implementation that should be pursued. From the initial stage of research and development, with an eye toward commercialization, all necessary partners will be brought together on the same playing field, which is the testbed, to make a concerted effort. The testbed includes experimental facilities where research results can be tested openly, as well as social demonstration environments such as living labs. While utilizing them, research and development proceeds while maintaining a state of "semi-social implementation," so to speak. In this case, the business side can monitor the progress of the R&D efforts, and it is possible to discuss the commercialization of the developing technologies together while "checking and testing such technologies." Various forms of support, including funding, could be provided for potential R&D. This rapid iteration of taking on technological challenges and societal expectations can be expected to lead to the integrated growth of R&D and social application.

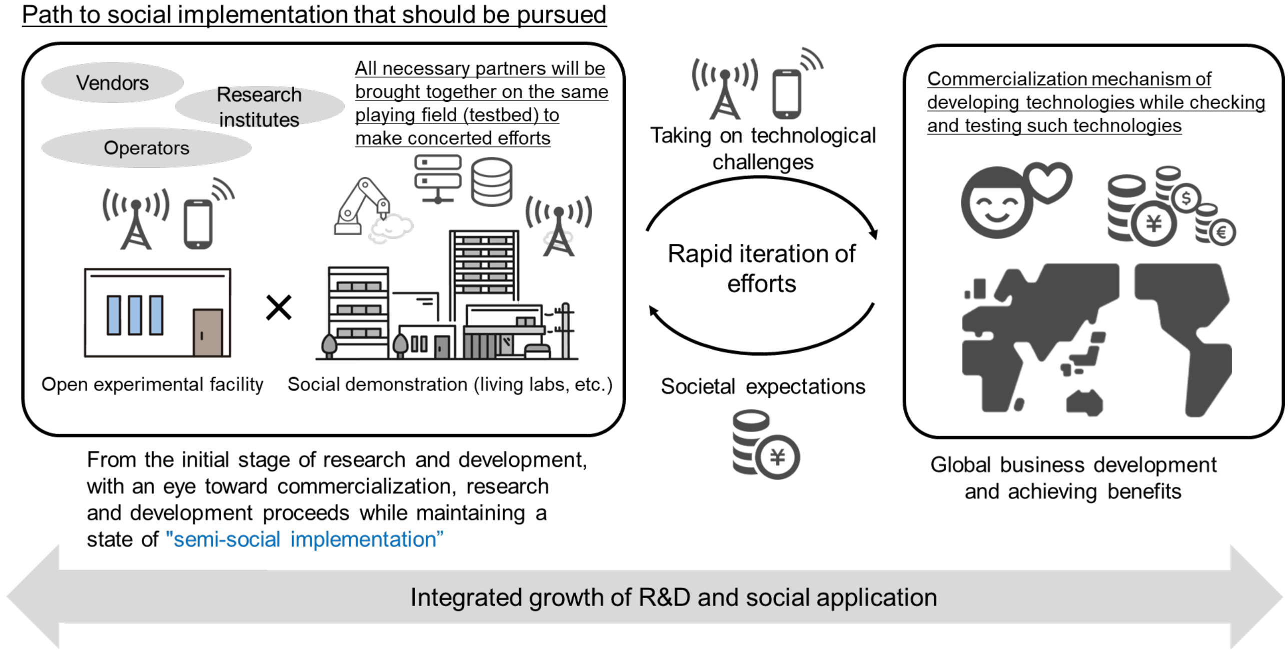


Figure 5.2 Path to social implementation that should be pursued in Beyond 5G.

5.2 Beyond 5G R&D Promotion Project and Shared Testbed

NICT has established a fund for publicly solicited R&D to support research and development of cutting-edge elemental technologies, etc. necessary for the realization of Beyond 5G, and is implementing the Beyond 5G R&D Promotion Project. At the same time, NICT is developing a shared testbed to promote the Beyond 5G research and development, and is providing a scheme that research institutions can use. This shared testbed can also be used as an open experimental facility, as described in the previous section. The testbed will make it possible to conduct research and development while aiming for social implementation.

Reference: Beyond 5G R&D Promotion Project. (https://b5g-rd.nict.go.jp/)

Chapter 6: Beyond 5G/6G-related International Standardization Trends

6.1 Standardization Trends in ITU-R

Standardization of mobile communications conducted by the ITU Radiocommunication Sector (ITU-R) has so far been conducted by WP5D (IMT System) of ITU-R SG5 (terrestrial services). The international distribution of frequencies is decided at the World Radiocommunication Conference (WRC), which is held approximately every four to five years.

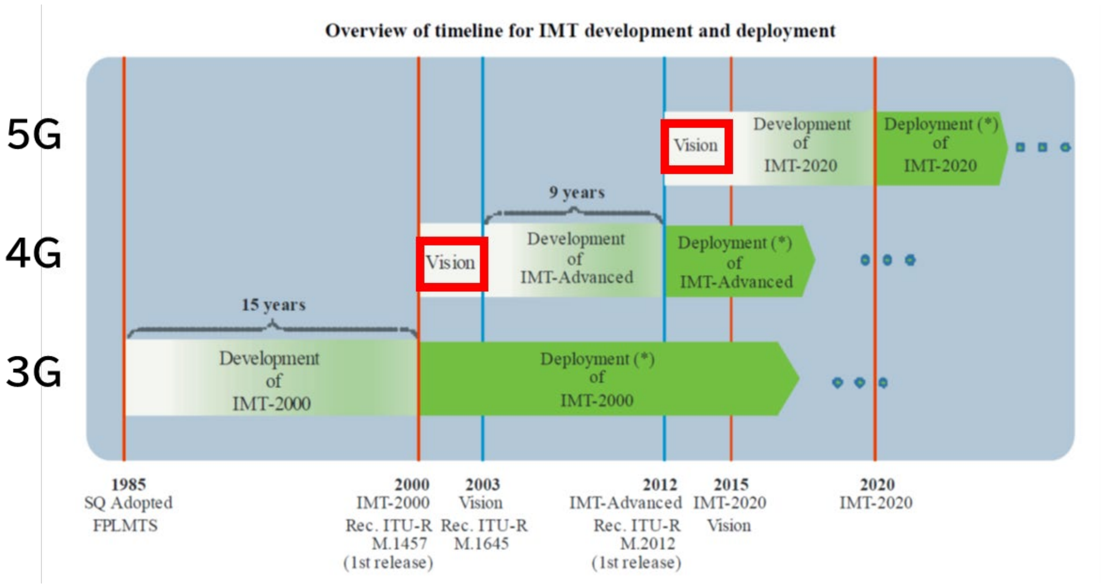


Figure 6.1 Processes in 3G, 4G, and 5G (Ref. ITU-R Recommendation M. 2083 Figure 1. Vision's red frames and "3G, 4G, 5G" on the left are added by NICT).

The agreed standardization process at the WP5D meetings (respectively in February and October 2020) is shown in Figure 6.2. WP5D completed a draft in June 2022 for the ITU-R Future Technology Trends Report, the first step in the standardization of Beyond 5G/6G from October 2020. The proposal was approved as ITU-R Report M.2513 at SG5 in November of the same year. In parallel with this, the study of vision recommendation started in June 2021, which is scheduled to be completed in June 2023.

The Ministry of Internal Affairs and Communications established the Beyond 5G Promotion Consortium in December 2020. The content of the Beyond 5G White Paper, which was developed by the Consortium, was proposed in the ITU-R Future Technology Trends Report and the vision recommendation as Japan's contribution document from WP5D in June 2021 (38th meeting).

With regard to the ITU-R Future Technology Trends Report, NICT made an early contribution to the compilation activities of the report by inputting technology trends centered on NICT's Beyond 5G-related technologies prior to the Beyond 5G Promotion Consortium. In this process, for Section 5.7 "Technologies supporting real-time services and communications" of the report, we not only incorporated technologies that are expected to be applied in future IMT, such as NICT's space-time synchronization technology and chip-scale atomic clock, but also contributed to standardization activities at ITU as an editor and compiled future technologies related to this section. In addition, as a public research institute on telecommunication technology in Japan, we actively contributed to compiling the report by entering paragraphs on the brief description of related technologies in Section 6.5 "THz communications" and Section 7.5 "Technologies for interconnection with non-terrestrial networks.” NICT will continue to participate in these standardization activities in cooperation with the Beyond 5G Promotion Consortium, and will contribute to the vision recommendation, the next step in standardization.

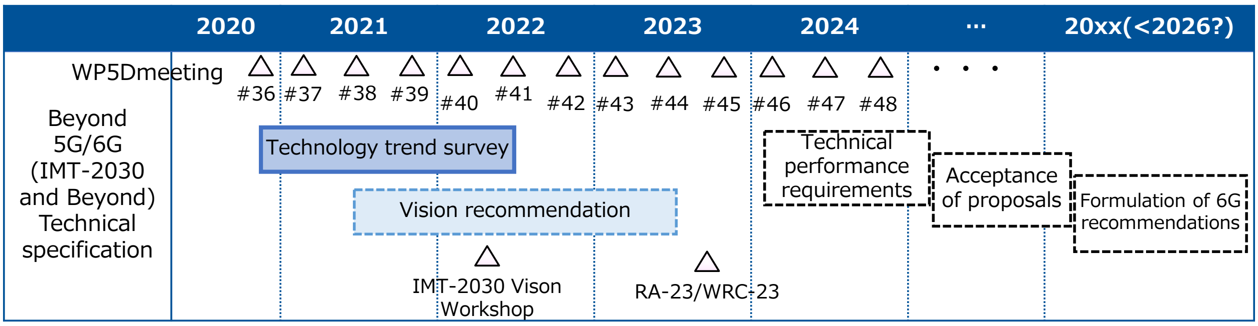


Figure 6.2 Agreed standardization process at the 34th WP5D

Through these contributions to the ITU-R Future Technology Trends Report and the vision recommendation, NICT is working to position its technology seeds as Beyond 5G/6G technology, with a view to contributing to standardization for the early practical application of such technologies. In the standardization activities of specific technical specifications, etc. after 2023 and beyond, 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, NICT plans to work on securing the necessary frequencies at the ITU World Radiocommunication Conference 2023 (WRC-23) and continue its efforts toward the ITU World Radiocommunication Conference 2027 (WRC-27). We will also work on activities to formulate technology performance requirements, etc. in cooperation with 3GPP and private forums, etc.

6.2 Standardization Trends in 3GPP

After 3G, 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. Among such bodies, 3GPP is one of the most influential.

3GPP issues a release number (Release) for each set of standard technological specifications established for a specified period of time. Since Release 15, 3GPP has been enhancing 5G functionality and improving performance in the Release 16 and 17 specifications in stages. In order to further enhance mobile broadband, realize new use cases, and advance device development to the entire network, the standards are being vigorously developed, with Release 18 and beyond positioned as "5G Advanced" (Figure 6.3). In 3GPP, specifications are developed by study groups (Working Groups (WG) including RAN (Radio Access Network), SA (Service and Systems Aspect), and CT (Core Network & Terminals)) according to the technical fields they are in charge of. Normally, Study Item and Work Item are set as study subjects, and as outputs of each subject, a Technical Report (TR) is developed, and a Technical Specification (TS) is also developed based on the TR. At present, various TRs and TSs are being developed for the completion of Release 18, and in parallel with this, studies of the service requirements and use cases that will serve as the basis for the next specification, Release 19, have started in order to establish related technical issues in the future.

In the standardization activities of the 3GPP, NICT has participated in discussions with focus on Beyond 5G-related technologies such as mobile communications, space-time synchronization, NTN, and terahertz. NICT has also been involved in the activities, including making contributions in the initial stages, reviewing the activities, and participating in meetings. Specific activities for Release 18, which started in 2022, are as follows:

- Participation in the discussion of SA2 (architecture) related issue "5G Timing Resiliency and TSC & URLLC enhancement [FS_5TRS_URLLC]" (Space-Time Standards Laboratory).
- Participation in discussions on "Study on enhanced support of Non-Public Networks phase 2 [FS_eNPN_Ph2_SEC]" related to SA2 (architecture) and "Access Traffic Steering, Switching and Splitting support in the 5G system Architecture [FS_ATSSS_Ph3]" (Wireless Systems Laboratory).
- Contribution to the development of RAN-related "TR (Technical Report) 38.867 v0.2.0 for Study on NR network-controlled repeaters" (Resilient ICT Research Center).

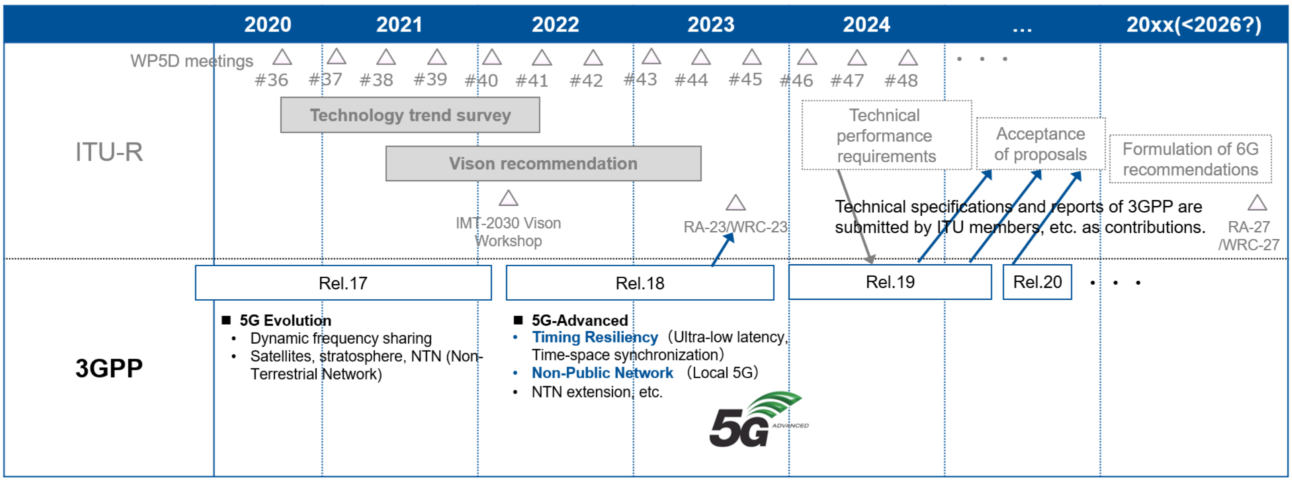


Figure 6.3 3GPP standardization process

In preparation for Release 19, service requirements and use cases that will serve as the basis for Release 19 were discussed at the TSG 96th meeting in June 2022 to establish related technical issues in the future, and the 13 issues shown in Figure 6.4 were established as the main issues. Since then, the formulation of each TR has been in progress, and is now in the process of moving forward to the consideration of developing TS. It is assumed that workshops will be held in the RAN and SA around June 2023 to discuss technical issues related to Release 19, and that future discussions will proceed in the direction of deciding the initial 3GPP issues to be considered by the end of the same year. For the establishment of technical issues for Release 19 and the next Release 20, it is necessary to foster a common understanding of future issues among 3GPP members for future proposals and further participation in discussions to reflect NICT-related technologies in 3GPP. For this reason, it is important to strengthen the so-called "friend building" among 3GPP-related stakeholders, involving not only NICT itself but also companies involved in joint research activities and partner companies.

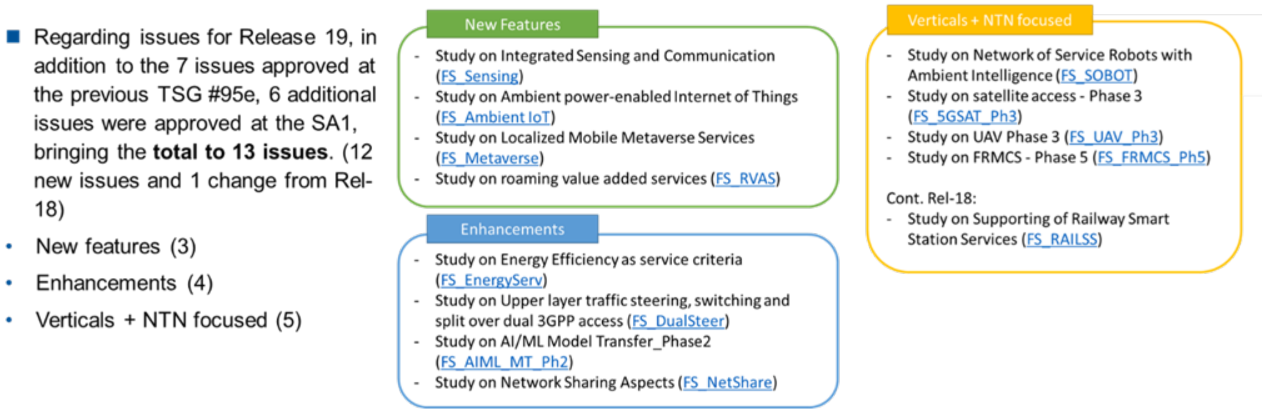


Figure 6.4 Release 19 Study Item in 3GPP SA1

Chapter 7: Conclusion

In this white paper, five 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 necessary for realizing Beyond 5G are summarized. The concept of socially implementing research results and international standardization trends is also 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: Use Case Examples and Related Key Technologies

Scenario 1: Cybernetic Avatar Society

Use Cases and Key Technologies Required for Implementation

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

What kind of system? Why is it necessary?	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. ● Operation is performed by voice, brain-machine interface (BMI), multiple sensors, etc.
Required key technologies (Refer to Appendix 2)	(T3) Wired/Wireless Communication and Network Control (T6) Ultra-Security and Reliability (T7.1) Brain information reading, visualization, and BMI (T7.3) Real 3D avatar, multisensory communication and XR (T7.4) AI analysis and dialogue based on linguistic and extra-linguistic information (T7.6) Multilingual simultaneous interpretation, paraphrasing, and summarization (Technology not covered by NICT) XR hardware technology such as head-mounted display (HMD)

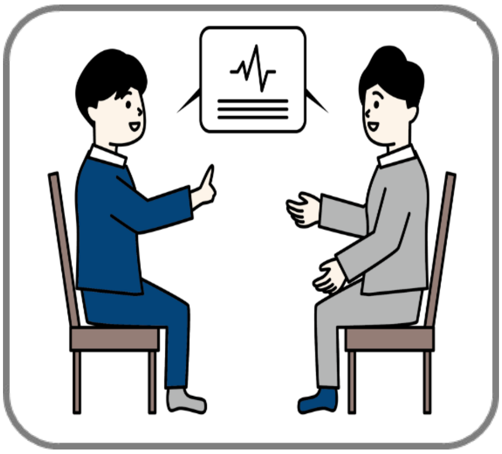


Figure S1.1 Mutual understanding promotion system

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

What kind of system? Why is it necessary?	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. ● Caregivers can remotely control avatars to support care-receivers.
Required key technologies (Refer to Appendix 2)	(T3) Wired/Wireless Communication and Network Control (T6) Ultra-Security and Reliability (T7.2) Intuition measurement, communication, and assurance (T7.3) Real 3D avatar, multisensory communication and XR (T7.4) AI analysis and dialogue based on linguistic and extra-linguistic information (T7.6) Multilingual simultaneous interpretation, paraphrasing, and summarization (Technology not covered by NICT) Hardware technologies such as home care robot and HMD

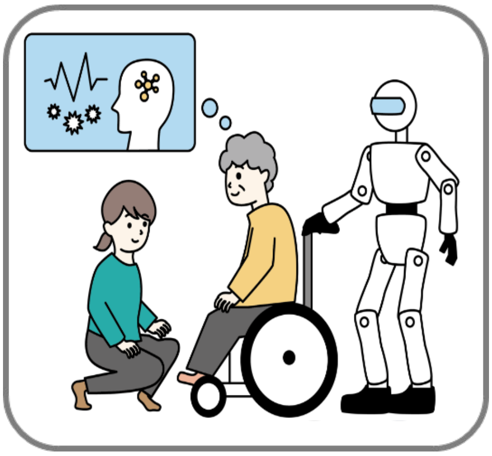


Figure S1.2 Mind and body support avatar

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

What kind of system? Why is it necessary?	This system allows the user to instantly move around the world as well as in Japan with 3D avatars while staying at 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. ● Multiple avatars can be switched by multiple operators.
Required key technologies (Refer to Appendix 2)	(T3) Wired/Wireless Communication and Network Control (T6) Ultra-Security and Reliability (T7.2) Intuition measurement, communication, and assurance (T7.3) Real 3D avatar, multisensory communication and XR (T7.4) AI analysis and dialogue based on linguistic and extra-linguistic information (T7.6) Multilingual simultaneous interpretation, paraphrasing, and summarization (Technology not covered by NICT) Hardware technologies such as remote-control robots and HMDs

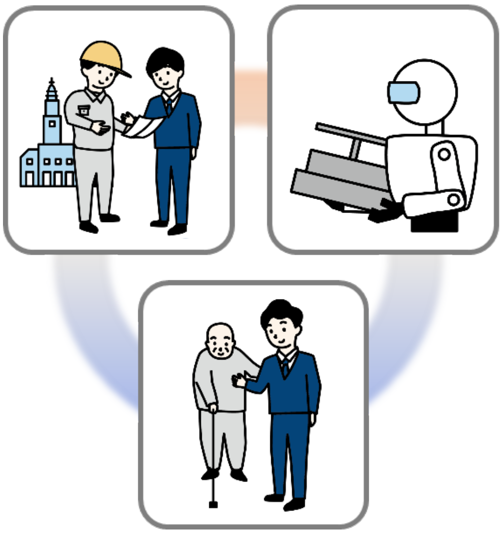


Figure S1.3 Working style revolution with telepresence

Scenario 2: City on the Moon

Use Cases and Key Technologies Required for Implementation

UC2-1: Lunar Base Connected by 6G

What kind of system? Why is it necessary?	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.
Usage	● Can be used in harsh environments on the Moon. ● Can be maintained remotely.
Required key technologies (Refer to Appendix 2)	(T1) Ultra-high-speed and high-capacity wireless communication (T2) Low latency and ultra-multiple concurrent connections (T3.1) Network control (Zero-touch automation) (T3.2) Frequency allocation and sharing management (T4.1) Satellite and non-terrestrial communication platforms (T4.2) Optical satellite communications (T4.5) Cooperative control of multi-layered networks (T5) Space-time synchronization (T6) Ultra-Security and Reliability

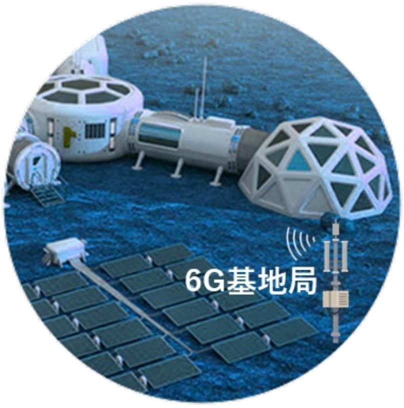


Figure S2.1 Lunar base connected by 6G

UC2-2: 6G leading up to the Moon

What kind of system? Why is it necessary?	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.
Usage	● Communication via the lunar gateway is required. ● Target transmission speed of 5 Gbps or faster. ● Earth-Moon delay must be taken into consideration.
Required key technologies (Refer to Appendix 2)	(T4.1) Satellite and non-terrestrial communication platforms (T4.2) Optical satellite communications (T4.5) Cooperative control of multi-layered networks (T6) Ultra-Security and Reliability

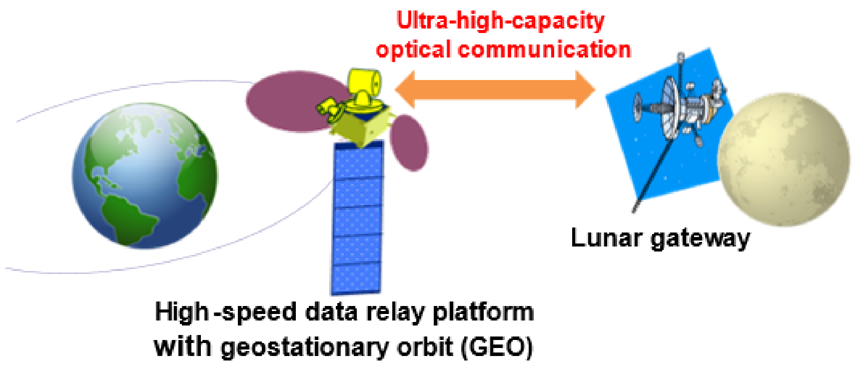


Figure S2.2 6G leading up to the Moon

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

What kind of system? Why is it necessary?	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.
Usage	● Conceptual translation is carried out by detecting inconsistencies in human-to-human conversation. ● Operation is performed by voice, BMI, multiple sensors, etc.
Required key technologies (Refer to Appendix 2)	(T1) Ultra-high-speed and high-capacity wireless communication (T2) Low latency and ultra-multiple concurrent connections (T4.1) Satellite and non-terrestrial communication platforms (T4.2) Optical satellite communications (T4.5) Cooperative control of multi-layered networks (T6) Ultra-Security and Reliability (T7) Ultra-Realistic and Innovative Applications

Figure S2.3 Street view in space

UC2-4: Moon Travel

What kind of system? Why is it necessary?	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.
Usage	● Communication lines can be used without any special skills. ● Measures are needed to ensure a safe return to the spacecraft even if the communication link for passengers is cut off during extravehicular activities. ● Measures against blackouts are needed when returning to Earth.
Required key technologies (Refer to Appendix 2)	(T1) Ultra-high-speed and high-capacity wireless communication (T2) Low latency and ultra-multiple concurrent connections (T4.1) Satellite and non-terrestrial communication platforms (T4.2) Optical satellite communications (T4.5) Cooperative control of multi-layered networks (T6) Ultra-Security and Reliability (T7) Ultra-Realistic and Innovative Applications

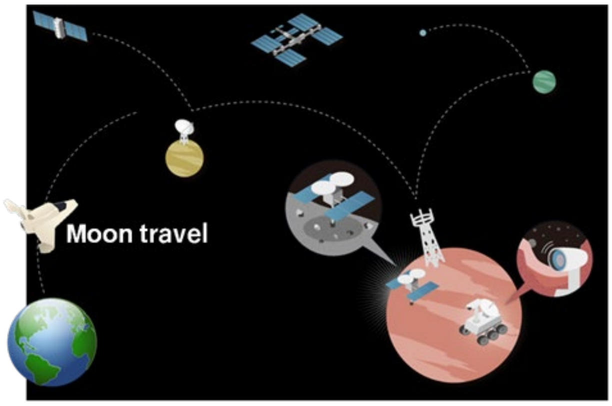


Figure S2.4 Moon Travel

Scenario 3: Transcending Space and Time

Use Cases and Key Technologies Required for Implementation

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

What kind of system? Why is it necessary?	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 (Refer to Appendix 2)	(T1) Ultra-high-speed and high-capacity wireless communication (T2) Low latency and ultra-multiple concurrent connections (T5) Space-time synchronization (T6) Ultra-Security and Reliability (T7.5) Edge AI behavioral support (T7.7) Autonomous driving (T7.8) Drone/Flying car

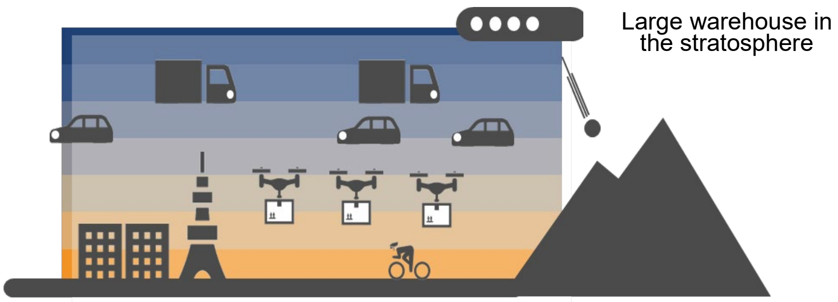


Figure S3.1 Vertical Flow of People, Things, and Information

UC3-2: Resilient Village Forest (Satoyama)

What kind of system? Why is it necessary?	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 (Refer to Appendix 2)	(T1) Ultra-high-speed and high-capacity wireless communication (T2) Low latency and ultra-multiple concurrent connections (T5) Space-time synchronization (T6) Ultra-Security and Reliability

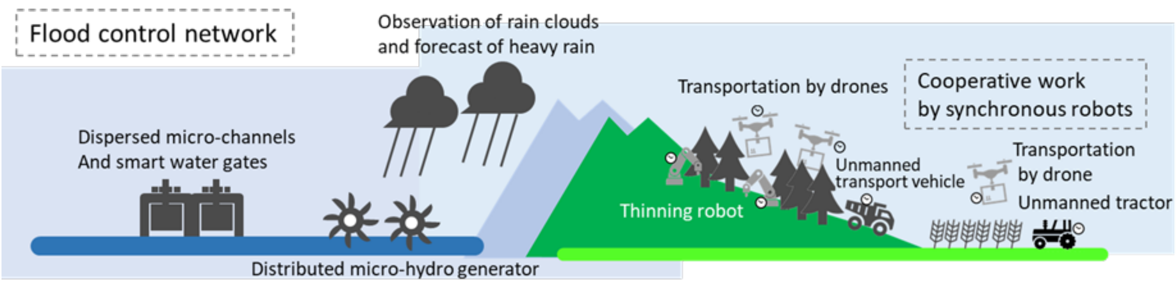


Figure S3.2: Resilient Village Forest

UC3-3: Omni-Cloud Gateway

What kind of system? Why is it necessary?	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 (Refer to Appendix 2)	(T1) Ultra-high-speed and high-capacity wireless communication (T2) Low latency and ultra-multiple concurrent connections (T5) Ultra-stable clock and high-precision synchronization (T6) Ultra-Security and Reliability (T7.8) Drone/Flying car (Technology not covered by NICT) High-accuracy inertial sensor

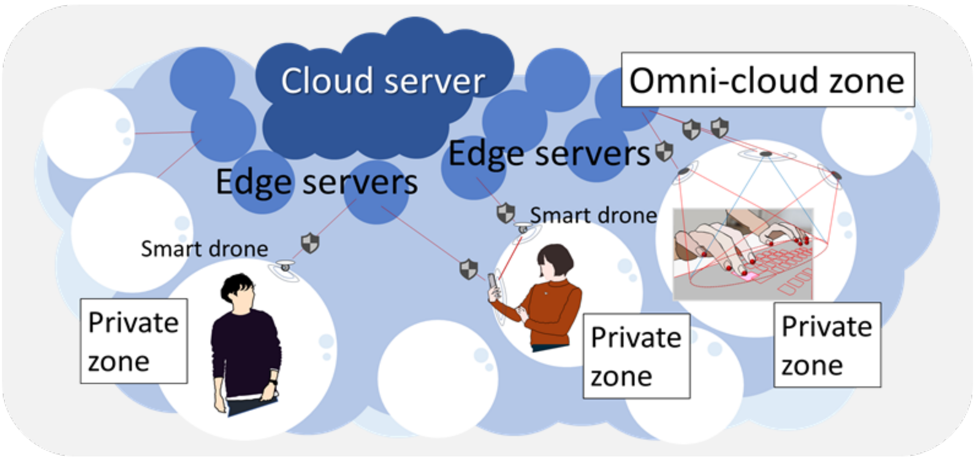


Figure S3.3 Omni-cloud gateway

Scenario 4: The Light and Shadow of the Cyber World

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," TechCrunch, 2022.1.23. 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. 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. https://www8.cao.go.jp/cstp/ai/aigensoku.pdf Ethically Aligned Design 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	

Appendix 2: Elemental Technologies for Beyond 5G/6G

T1 Ultra-high-speed and high-capacity communication

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	Conditions required for Beyond 5G/6G	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: Successfully developed a 300 gigahertz single-chip transceiver using silicon CMOS integrated circuits capable of transmitting data at 80 gigabits per second," February 19, 2019.https://www.nict.go.jp/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

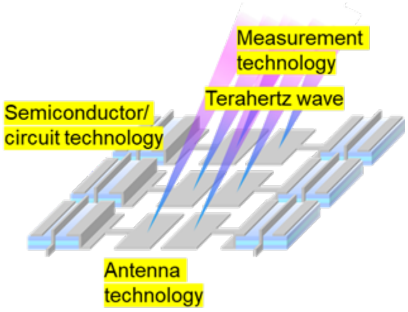


Figure T1.1 Key technologies for handling terahertz

T1.2 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	Conditions required for Beyond 5G/6G	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 Optical and radio convergence

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	Conditions required for Beyond 5G/6G	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.

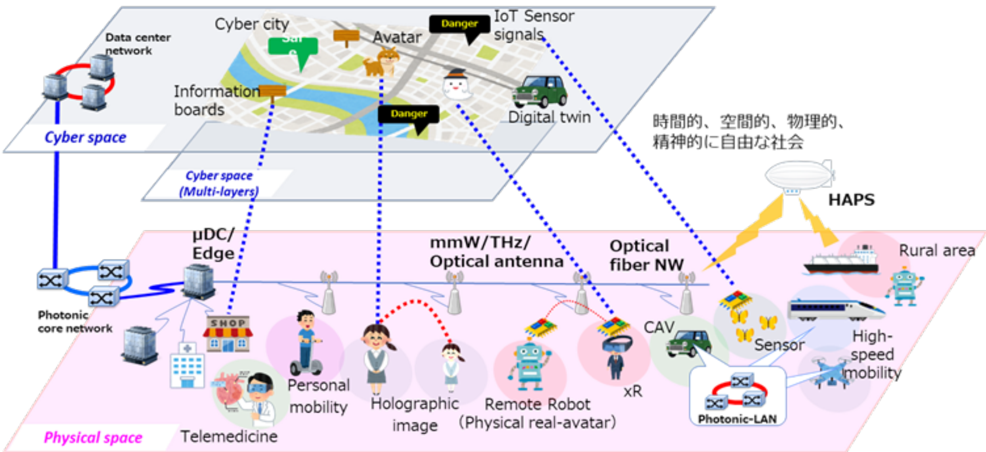


Figure T1.3 Cyber-physical society based on all-optical network

T2 Ultra-low latency and ultra-multiple simultaneous connections

T2.1 Edge computing

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	Conditions required for Beyond 5G/6G	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 access

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 NICT took the lead in standardizing. Furthermore, Wi-SUN, the world's first certified standard that references these standards, has already been established (NICT is a founder member).
4	Conditions required for Beyond 5G/6G	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.

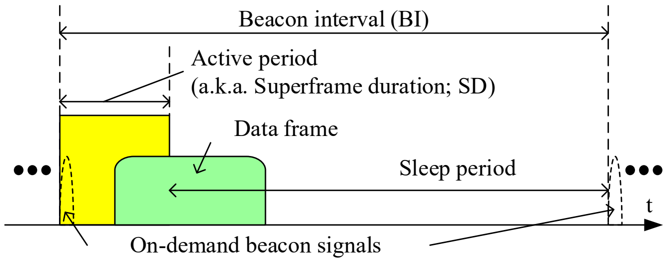


Figure T2.2a Intermittent waiting action for saving power

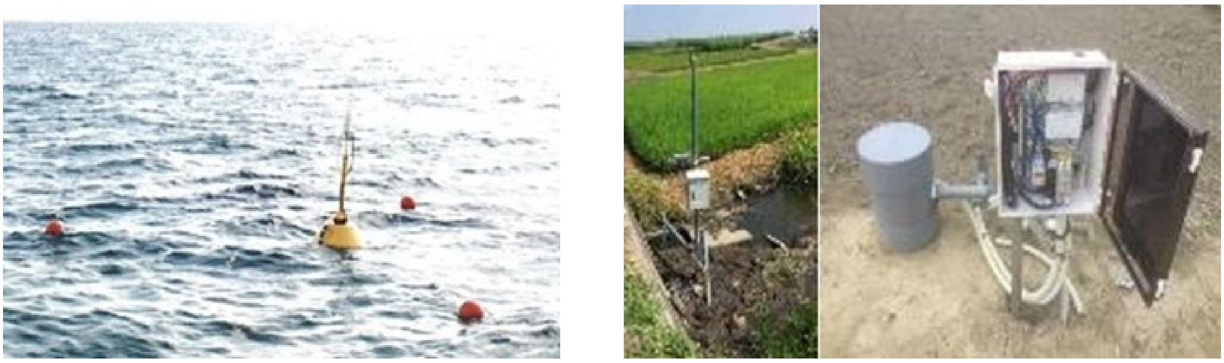


Figure T2.2b Demonstration of low-power operation (left: fishery, right: farming)

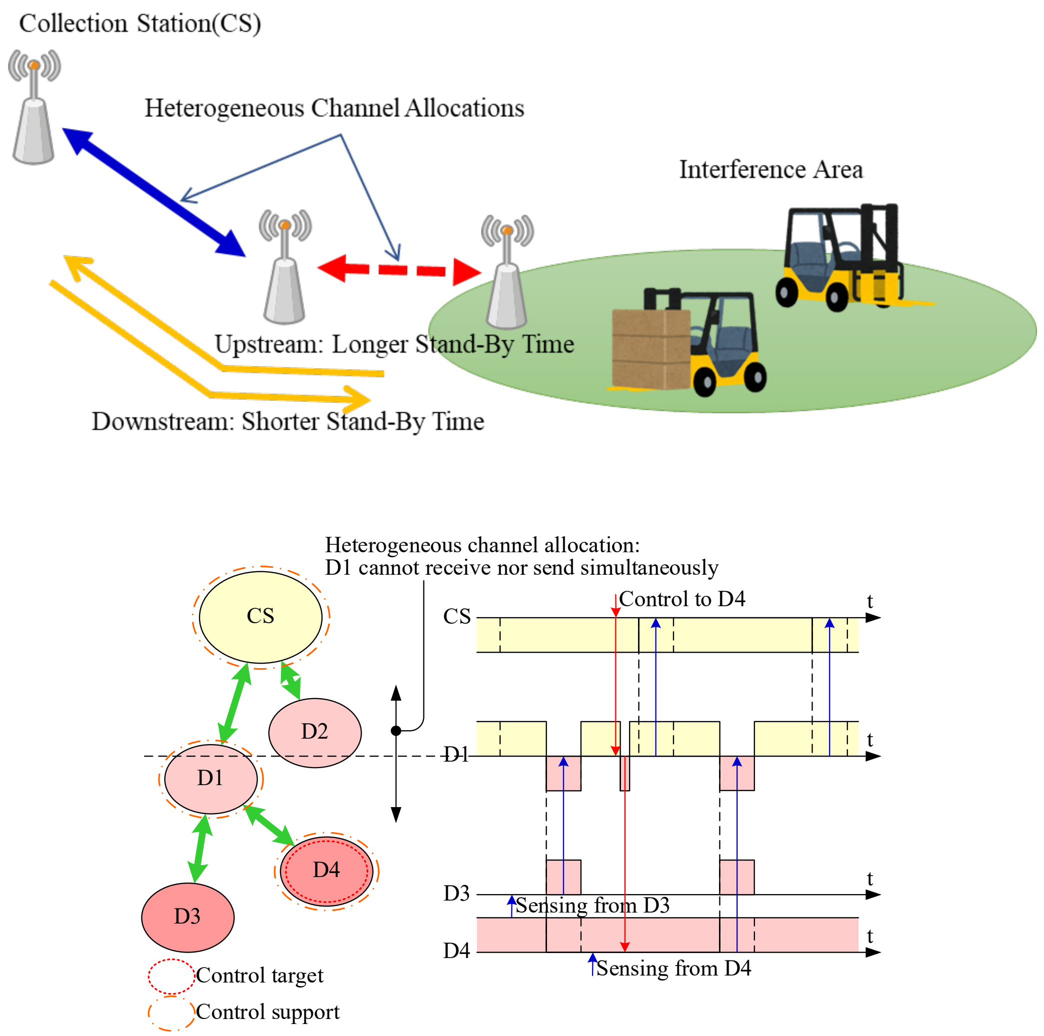


Figure T2.2c Application of in-network heterogeneous radio

T2.3 Adaptive wireless application

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).
4	Conditions required for Beyond 5G/6G	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/

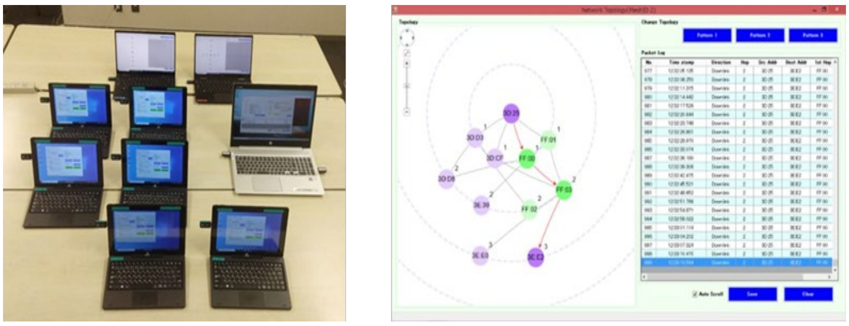


Figure T2.3a App interface for visualizing radio device operation (left: radio devices, right: connection status)

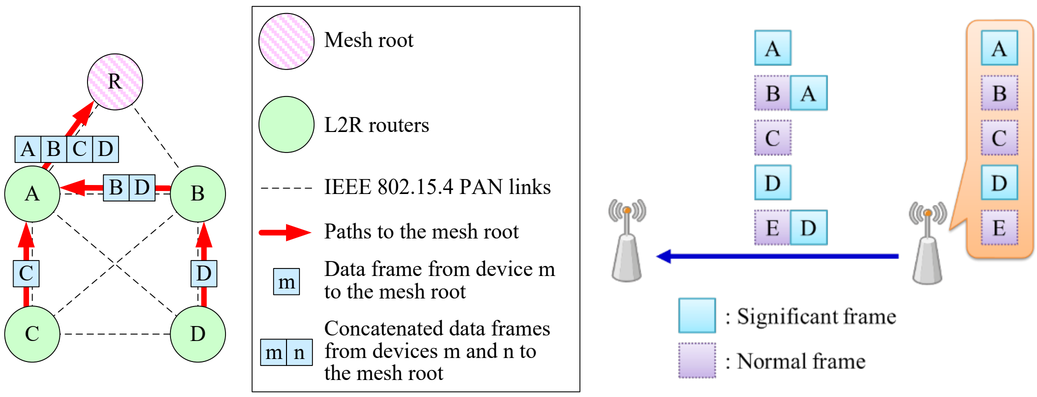


Figure T2.3b Overview of frame consolidation applications

T2.4 Autonomous localization, tracking and reservation 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 in 5G wireless communication systems.
4	Conditions required for Beyond 5G/6G	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 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].
4	Conditions required for Beyond 5G/6G	1) Autonomous M2M network with super multi-connection must be capable of autonomously discovering ultra-multi-hopping relays devices related to propagation paths, and frequencies suitable for information propagation according to environmental conditions, etc., securing and managing resources, as well as have an API (Application Programming Interface) and appropriate user interface for this purpose. 2) The ability to ensure a certain level of time synchronization performance, time tuning, and reliability in securing and managing resources related to the above. 3) It is required to have a function that can autonomously remove the distribution of information whose consumption value has already disappeared or information that violates discipline, etc.

[1] Wireless Mesh Network Technology for Smart Meters, Mitsubishi Electric Technical Report, Vol. 86, No. 11, 2012.

T3 Wired/Wireless communication and network control

T3.1 Network control (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 service management (ZSM), a European standards body. Also, Open Source MANO (OSM) that provides the virtualization of network function on an open source basis is said to be prepared for a scalable architecture for severance and closed-loop operations, leveraging a cloud-native version in Release 13 [2] announced in December 2022.
4	Conditions required for Beyond 5G/6G	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

[2] https://osm.etsi.org/news-events/news/76-etsi-osm-launches-release-thirteen-with-a-new-scalable-architecture-for-massive-closed-loop-operations

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 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	Conditions required for Beyond 5G/6G	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 [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 systems.
4	Conditions required for Beyond 5G/6G	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

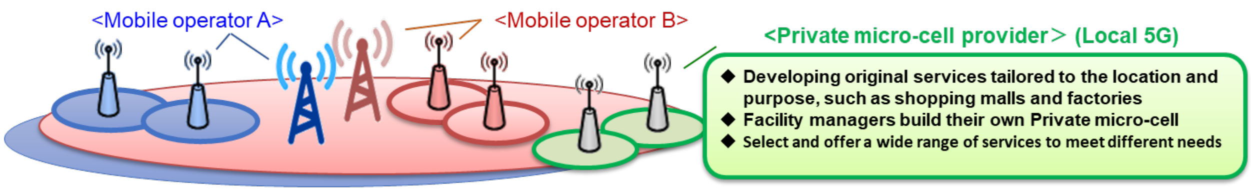


Figure T3.3 Private wireless system management (local 5G)

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 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.
4	Conditions	Quasi real-time emulation to set mobile routes during running scenarios, large-scale

	required for Beyond 5G/6G	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 the utilization of wireless emulatorshttps://pco-prime.com/cps_promo/

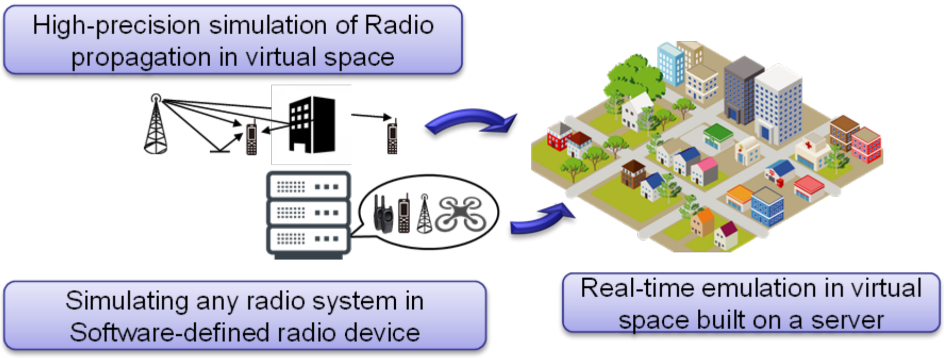


Figure T3.4a Advanced radio wave emulation

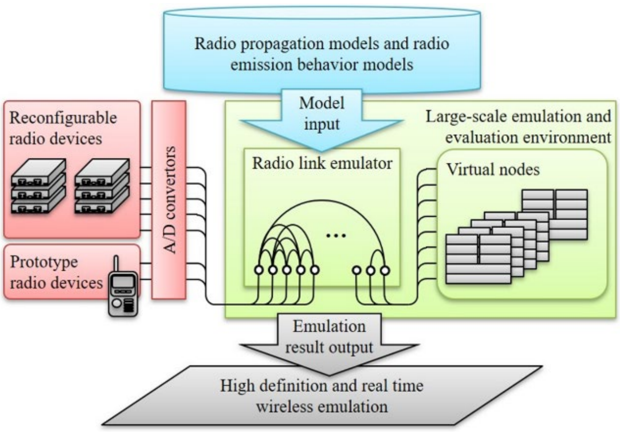


Figure T3.4b Overview of wireless emulation in large-scale virtual environment verification infrastructure

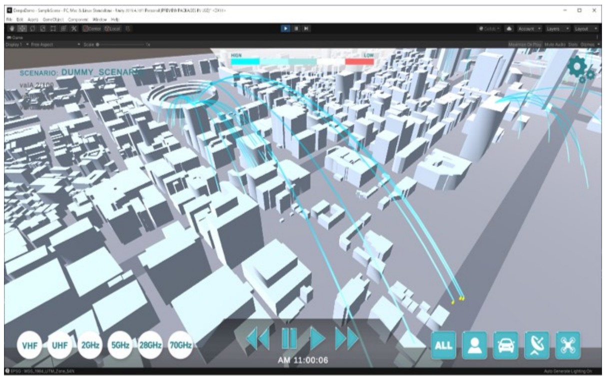


Figure T3.4c Visualization of wireless communication status through wireless emulation

T4 Multi-layer wireless systems – NTN

T4.1 Satellite and non-terrestrial communication platform

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	Conditions required for Beyond 5G/6G	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

[2] https://hapsalliance.org/

[3] https://www.3gpp.org/release-17

[4] https://www.3gpp.org/release18

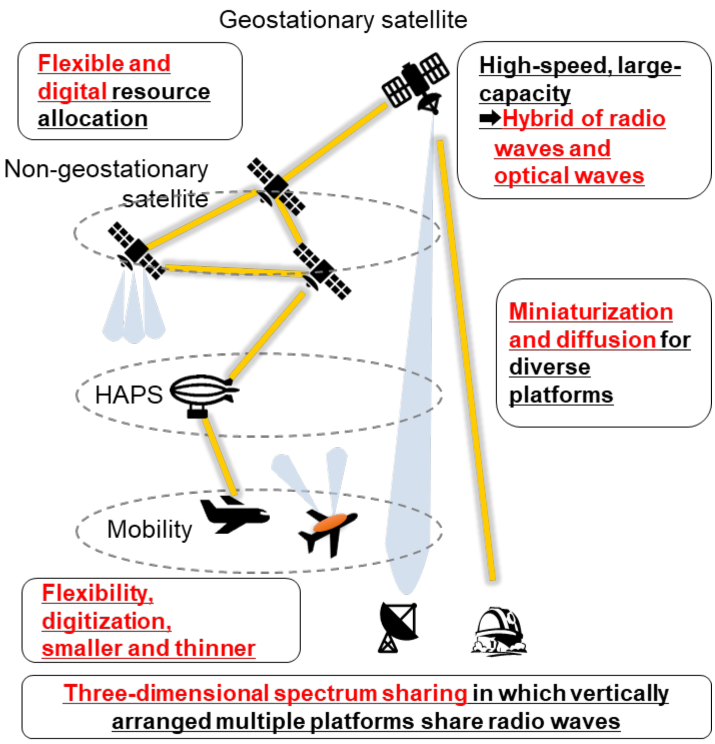


Figure T4.1 Satellite and non-terrestrial communication platforms and their requirements

T4.2 Optical satellite communication

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 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	Conditions required for Beyond 5G/6G	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/

[2] https://earth.esa.int/web/eoportal/satellite-missions/t/terrasar-x,
http://satcom.jp/44/reportj2.pdf

[3] https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8357402

[4]https://www.kantei.go.jp/jp/101_kishida/actions/202112/28space.html

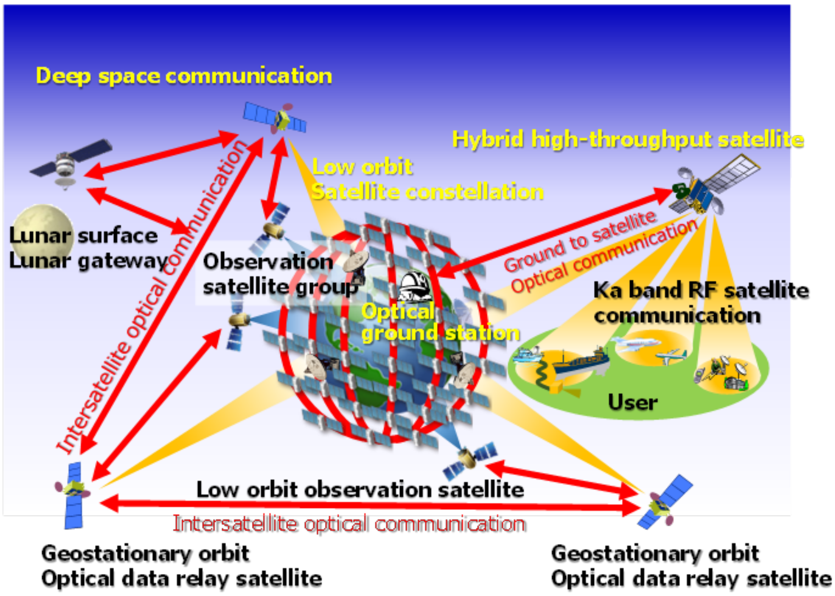


Figure T4.2 Use of optical satellite communications

T4.3 Maritime communication

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	Conditions required for Beyond 5G/6G	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.

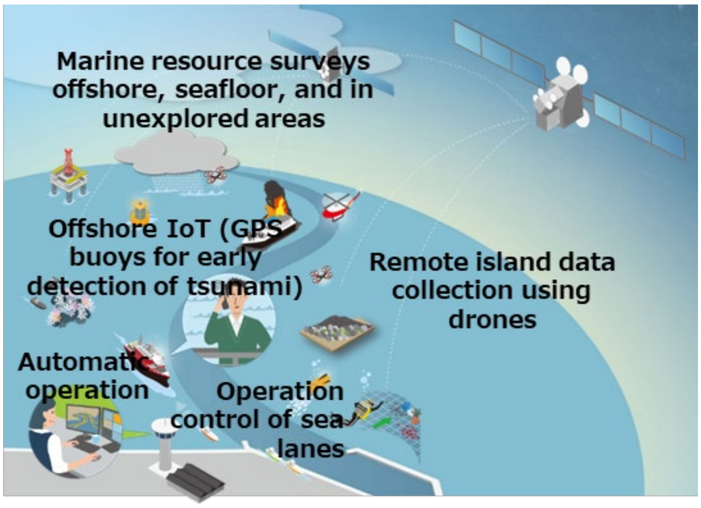


Figure T4.3 Image of maritime communications

T4.4 Underwater and submarine communication

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	Conditions required for Beyond 5G/6G	Higher speeds of several Mbps or more, longer 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 Beyond 5G/6G, and a Japan-Europe partnership project has begun [6].
4	Conditions required for Beyond 5G/6G	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

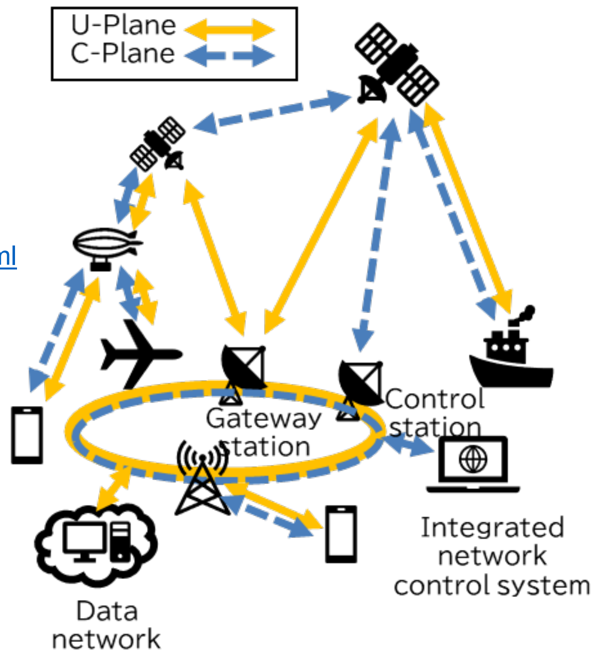


Figure 4.15 Cooperative control of multi-layered networks

T5 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 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	Conditions required for Beyond 5G/6G	Case 1) Inventory in warehouse/indoor robot coordination: ・ Time synchronization accuracy 1 microsecond, communication delay (end to end) < 1 millisecond, position measurement accuracy 1cm Case 2) Vertical traffic control: ・ Time synchronization accuracy 1 microsecond, communication delay (end to end) < 1 millisecond, position measurement accuracy 5m

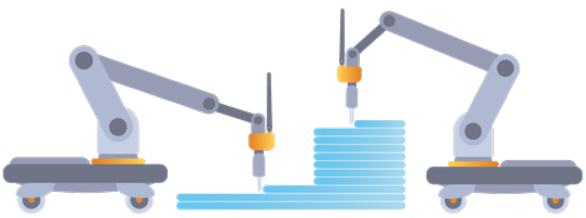


Figure T5.1 Space-time synchronized 3D printer

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 miniaturization and low-power-consumption expansion.
4	Conditions required for Beyond 5G/6G	・ Edge computing: size < 5 cc, power consumption < several hundred mW ・ Personal device: size < 1 cc, power consumption < several mW

[1] R. Lutwak et.al., “The MAC-a Miniature Atomic Clock,” in Proc. IFCS2005, pp.752.
[2] (H. Zhang et.al., "ULPAC: a miniaturizes Ultralow-Power Atomic Clock," IEEE JSSC, 54(11), 2019, pp.3135.

T5.3 Generating and sharing 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 considerable period of time in an isolated state, and to maintain the availability of clock management.
4	Conditions required for Beyond 5G/6G	・ 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.

T6 Ultra-security and reliability

T6.1 Emerging security

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	Conditions required for Beyond 5G/6G	Hardware (sensors, drones, satellites, etc.) security technology (anti-tamper technology, hardware trojan detection technology, measurement and 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 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.
4	Conditions required for Beyond 5G/6G	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	Conditions required for Beyond 5G/6G	Quantum key distribution (QKD) to share private keys, QKD networking, QKD using artificial satellites, as well as the establishment of 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 environment

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	Conditions required for Beyond 5G/6G	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 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 anytime 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	Conditions required for Beyond 5G/6G	As an emergency information-sharing platform, we aim to realize the communication requirements (end-to-end (E2E) delay of 0.1ms 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	Conditions required for Beyond 5G/6G	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, including high-frequency bands, which are increasingly used in communications. 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.

T7 Ultra-realistic and innovative applications

T7.1 Brain information reading, visualization, and BMI

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	Conditions required for Beyond 5G/6G	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, transmission, and assurance

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	Conditions required for Beyond 5G/6G	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, Univ. Oulu (2019)

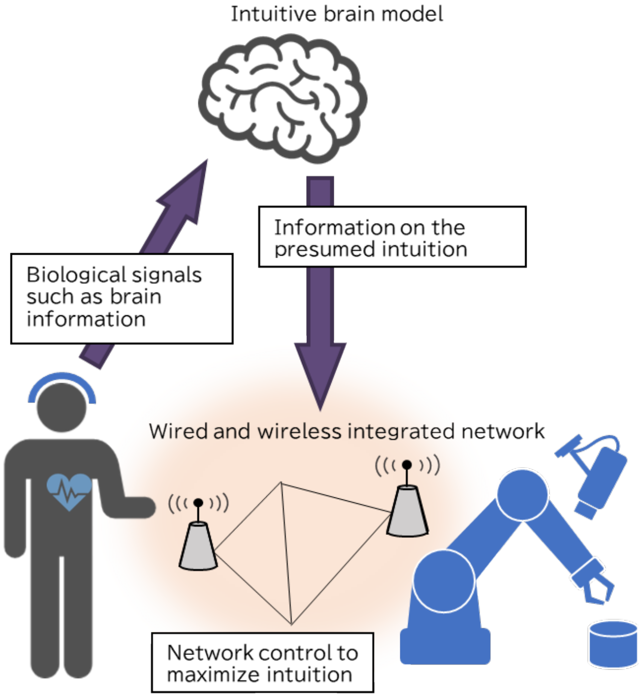


Figure T7.2 Intuition measurement, communication, and assurance technologies

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

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	Conditions required for Beyond 5G/6G	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)

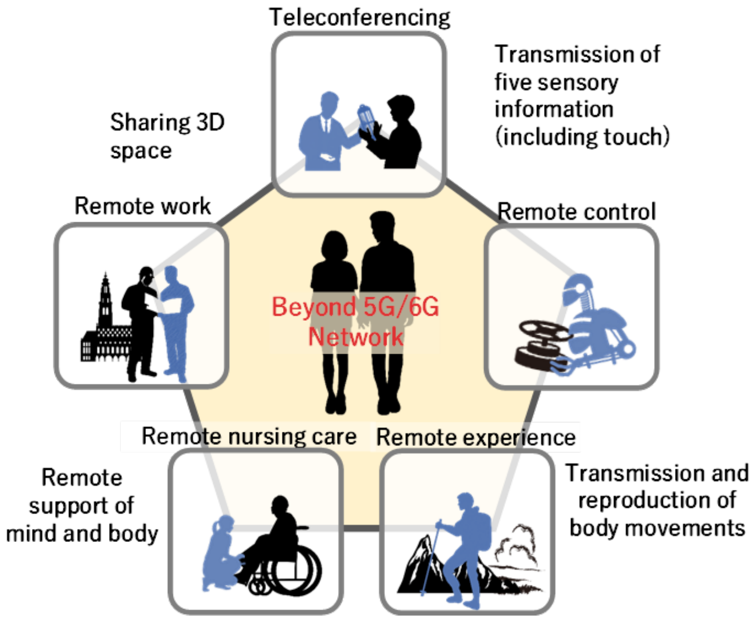


Figure T7.3 Ultra-reality communication transcending space, time, and physical barriers

T7.4 AI analysis and dialogue using language 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	Conditions required for Beyond 5G/6G	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.

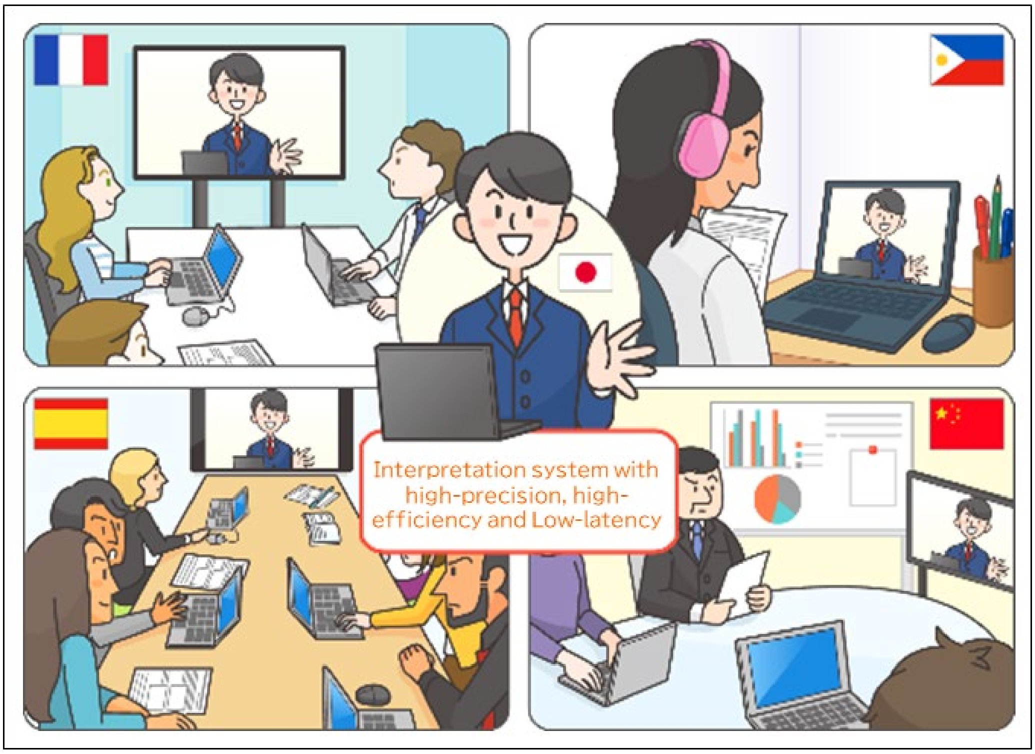
T7.5 Edge AI behavioral support

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	Conditions required for Beyond 5G/6G	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 that are optimized according to the situation by using digital twins and simulation is required.

T7.6 Simultaneous multi-lingual interpretation, paraphrase, and summarization

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	Conditions required for Beyond 5G/6G	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)



T7.6 Secure remote simultaneous interpretation

T7.7 Autonomous 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	Conditions required for Beyond 5G/6G	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 and flying cars

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	Conditions required for Beyond 5G/6G	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.

Appendix 3: 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 C3.1 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();
```

Figure C3.1. 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.

Dr. KONISHI Satoshi (KDDI Research/KDDI CORPORATION)
Prof. SAMPEI Seiichi (Osaka University)
Prof. NAKAO Akihiro (University of Tokyo)
Dr. NAKAMURA Takehiro (NTT DOCOMO)
Dr. MATSUI Yasunori (Sony Corporation)
Dr. WAKIKAWA Ryuji (SoftBank Corp.)
Prof. Andreas Dengel (Deutsches Forschungszentrum für Künstliche Intelligenz)
Prof. Matti Latva-aho(Univ. of Oulu)
Dr. Onur Altintas (Toyota Motor North America R&D)

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Update History

2021.3.31	Release of Japanese Version 1.0
2021.8.31	Release of English Version 1.0
2022.3.30	Release of Japanese Version 2.0 ・Updated architecture in Chapter 2 from an open platform perspective. ・Added one scenario on ELSI in Chapter 3. ・Added and organized the elemental technologies in Chapter 4. ・Updated Chapters 5 and Chapter 6 taking into account the latest situations.
2022.6.30	Release of English Version 2.0
2023.3.31	Release of Japanese Version 3.0 ・Added information about the architecture in Chapter 2 regarding updates to the orchestrator, and service enabler function and digital twins collaboration. ・Moved the various use cases for the scenarios in Chapter 3 to Appendix 1 and added Scenario 5. ・Moved the elemental technologies in Chapter 4 to Appendix 2, and added the description of key elemental technologies. ・Added the concept of socially implementing research results in Chapter 5. ・Updated international standardization trends in Chapter 6 to the latest information.
2023.6.28	Release of English Version 3.0

ISBN 978-4-904020-32-6

Beyond 5G/6G White Paper (English Version 3.0)
Published in June 2023

National Institute of Information and Communications Technology
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ISBN 978-4-904020-32-6