

# *Beyond 5G / 6G White Paper*

*- English version 1.0 -*

**August 2021**



# **Beyond 5G/6G White Paper**

(English version 1.0)

**National Institute of Information and  
Communications Technology (NICT)**

**August 2021**

## Contents

Executive Summary.....	i
Chapter 1: Introduction .....	4
1.1 Background of the White Paper.....	4
1.1.1 Evolution of Mobile Communication Systems .....	4
1.1.2 Covid-19 Pandemic.....	5
1.1.3 R&D Competition for Next-generation Mobile Communication Systems.....	5
1.2 Purpose and Positioning of the White Paper.....	6
Chapter 2: Future Society after 2030 (view of the Beyond 5G/6G world) .....	8
2.1 Information and Communication Networks and the Nature of Society .....	8
2.2 Migration of Information and Communication Networks .....	8
2.3 Integration of Cyber Space and Physical Space in Beyond 5G/6G	9
Chapter 3: What Will Daily Life Be Like in the Beyond 5G/6G Era? Scenarios and Use Cases .....	13
3.1 Scenario 1 – Cybernetic Avatar Society .....	13
3.1.1 A Day in 2035: From the Diary of a Technology Development Manager .....	13
3.1.2 Case Examples of Usage and Key Technologies Required for Implementation.....	16
3.2 Scenario 2 – City on the Moon .....	20
3.2.1 People Cultivating the Moon.....	20
3.2.2 Case Examples of Usage and Key Technologies Required for Implementation.....	24
3.3 Scenario 3 – Transcending Space and Time .....	28
3.3.1 Creative and Active Lifestyles .....	28
3.3.2 Dive to the Point.....	29
3.3.3 What Is in the Sky? .....	30
3.3.4 Case Examples of Usage and Key Technologies Required for Implementation.....	31
Chapter 4: Key Technologies for Beyond 5G/6G .....	35
4.1 Technologies Enabling Use Cases .....	35
4.2 Outline of Technology .....	36

4.2.1 Ultra-High-Speed and High-Capacity Wireless Communications .....	36
4.2.2 Ultra-Low Latency and Ultra-Massive Connectivity .....	39
4.2.3 Wired/Wireless Communication and Network Control .....	46
4.2.4 Multi-Layering of Wireless Systems - NTN .....	50
4.2.5 Space-Time Synchronization .....	54
4.2.6 Ultra-Security and Reliability .....	57
4.2.7 Ultra-Reality and Innovative Applications .....	63
4.3 R&D Roadmap .....	69
Chapter 5: R&D Open Platform.....	71
Chapter 6: Deployment Strategies.....	72
6.1 Trends in Standardization for Beyond 5G/6G .....	72
6.2 National Project for Beyond 5G/6G Research and Development .	74
Chapter 7: Conclusion .....	76
Acknowledgment.....	77

# Executive Summary

Beyond 5G/6G, which is the next-generation information and communications infrastructure, is essential for achieving the SDGs and realizing Society 5.0, and it is important to define its functional structure (Figure A). In physical space, a flexible and scalable communication environment is provided by combining not only conventional terrestrial mobile networks, but also satellite networks and multi-core fiber optical networks. In cyber space, a variety of spaces coexist depending on the application, and information processing is carried out based on accumulated past data and future forecasts.

In the Beyond 5G/6G era, space and time will be highly controlled in both physical space and cyber space, and the integration of the two spaces will make it possible to do things that have not been possible in

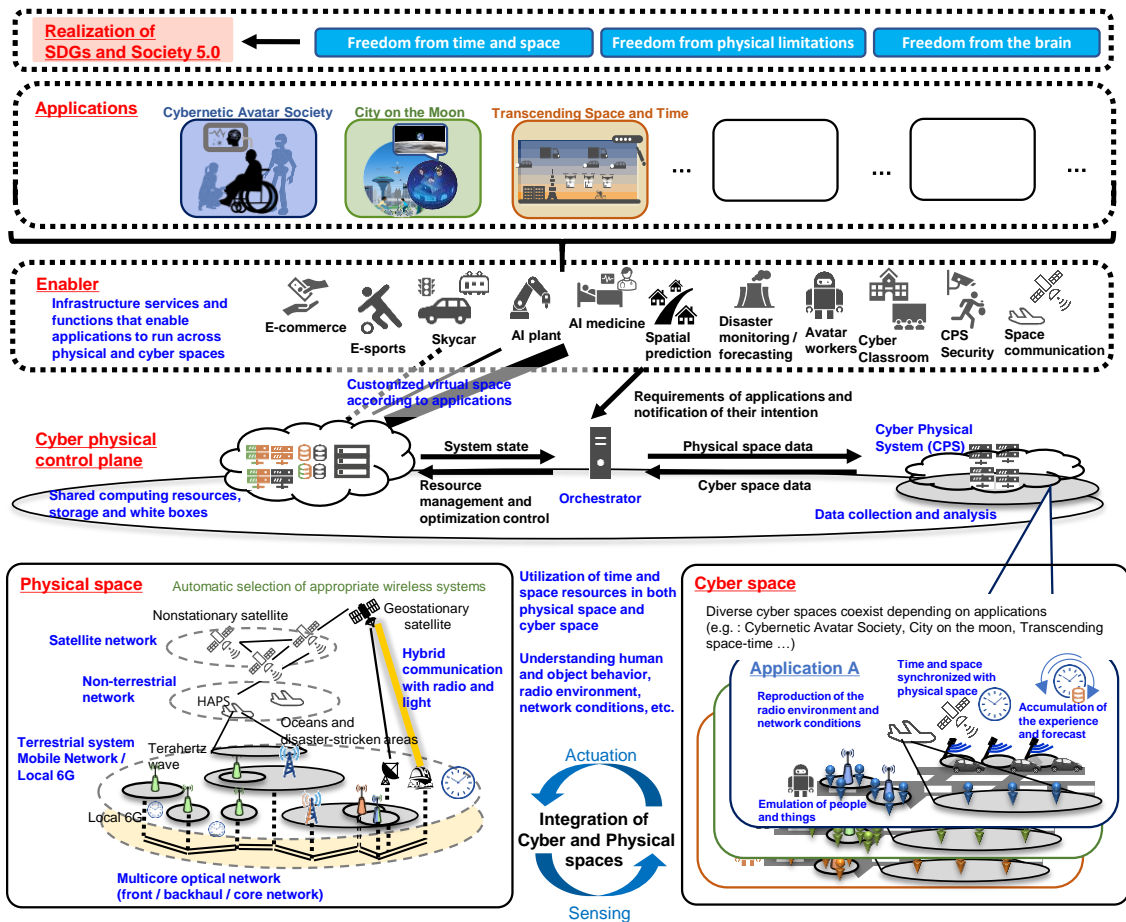


Figure A: Overview of the functional structure of Beyond 5G/6G to achieve the SDGs and realize Society 5.0 (Figure 2.2 in the text)

the physical space alone. The combination of enablers (platform services and basic functions) that can be implemented across the integrated physical space and cyber space is expected to provide new applications and help solve various social issues.

Chapter 3 of this White Paper introduces three scenarios and several use cases that illustrate social life around 2030 to 2035. Figure B shows images of the three scenarios: “Cybernetic Avatar Society,” which depicts a society in which avatars are widely utilized; “City on the Moon,” which depicts a society in which human activities spread to the Moon; and “Transcending Space and Time,” which depicts a society in which the limitations of space and time are transcended. The roadmap for each scenario is shown in Table C. The second half of the White Paper summarizes the key technologies and requirements to realize the use cases, the R&D roadmap (Chapter 4), and the deployment strategy

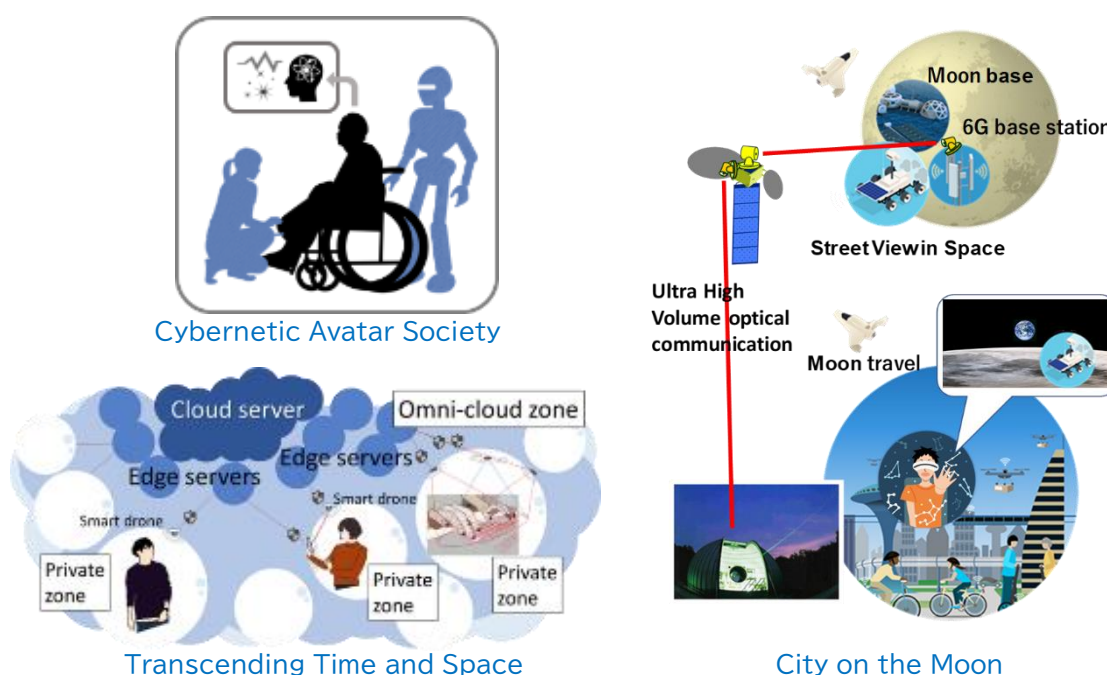


Figure B: Three scenarios of Beyond 5G/6G that envision social life around 2030–2035 (Figures 3.9, 3.16 and 3.23 in the text).

(Chapter 6).

This document describes the first initiative that NICT, a group of

experts in information and communication technologies, has studied for realization of the Beyond 5G/6G world. We will continue discussions with many people based on this document, and revise this White Paper as needed according to the progress of the discussions.

Table C: Expected roadmap for each scenario

		2020 - 2024	2025 - 2029	2030 - 2034	2035~
Science and Technology Basic Plan		Sixth Science and Technology Basic Plan			
Evolution of mobile communication systems		Early 5G (Non Stand Alone)	Enhanced 5G (Stand Alone)	Beyond 5G	
B5G Promotion Strategy		Phase of phase	Acceleration phase of efforts		
Scenario	Cybernetic Avatar Society (3-1)		▲ Real-3D Avatar Remote XR Simultaneous Interpretation Conference	▲ Support for the elderly based on language / non-language / brain information analysis	▲ Intuitive remote work by transmitting multisensory info including touch
	City on the Moon (3-2)		▲ Lunar Gateway ▲ Promotion of the Lunar Gateway / ARTEMIS Program	▲ Experimental demonstration	▲ Survey and development of moon
	Transcending Time and Space (3-3)			▲ Automatic driving support using edge servers	▲ Infrastructure conservation and environmental monitoring with the sensor network



# Chapter 1: Introduction

## 1.1 Background of the White Paper

### 1.1.1 Evolution of Mobile Communication Systems

Work on installing the fifth-generation mobile communication system (5G) started in around 2020 and is now fully under way (as of March 2021), and there are high expectations for its use.

Mobile communication systems have evolved from communication infrastructure (1G–3G) to living infrastructure (4G), and have become an indispensable element in the lives of individuals. 5G has become a social infrastructure that connects not only people but also things, such as in the Internet of Things (IoT).

Cyber physical systems (CPSs), in which people interact with each other, people with things, and things with things through cyber space, have become significant in various aspects of social life.

In the next-generation mobile communication systems (Beyond 5G/6G), the communication network supporting the CPSs will serve as the nerve network of society itself. In other words, it is expected that communications networks, which will be centered on mobile communications systems, will serve as the fundamental infrastructure of

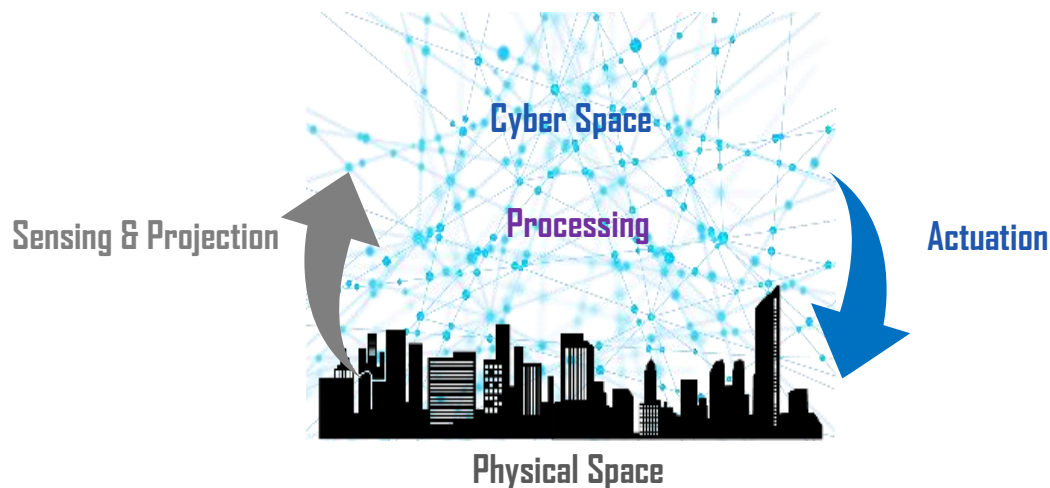


Figure 1.1: Realization of a “cyber physical system” that measures events (big data) in physical (real) space, projects them into cyber space, finds solutions (optimal solutions), and actuates the physical space event.

society in the future.

### 1.1.2 Covid-19 Pandemic

In response to the global pandemic of the new coronavirus (SARS-CoV-2), governments around the world have responded by enforcing lockdowns and other measures to minimize direct human-to-human contact and reduce infections. With the exception of essential workers, many people are being encouraged or compelled to work from home.



Figure 1.2: Spatially dispersed individuals will be connected by an advanced nerve network (Beyond 5G/6G) to collaborate with others, robots and avatars through cyberspace. It becomes possible to continue to create value at all times.

Telecommuting enables individuals to connect through cyber space, enabling them to continue their economic activities to some extent. However, the inadequacy of current information and communication technology (ICT) has become clear.

The advantages of conducting economic activities through cyber space are that they are not constrained by actual space and time; this is a new style of activity.

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

Communication networks have extremely high value as a fundamental infrastructure of society, and their security is attracting considerable attention.

There is an accelerating trend toward the dominance of next-generation mobile communications systems, both economically and in terms of security.

Against this background, interest in Beyond 5G/6G has increased significantly compared to the previous generation changes, and there is much discussion about how to proceed with research and development.

White Papers have been published by various organizations, forums have been established, and investment in R&D is beginning (see

[“Reference: Various White Paper Consortiums, etc.”](#) at the end of this chapter).

## 1.2 Purpose and Positioning of the White Paper

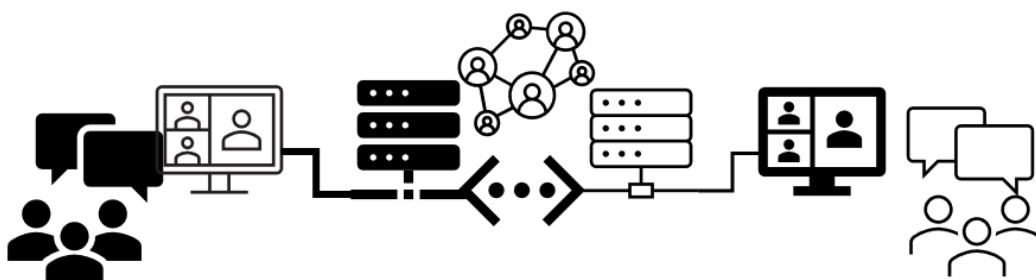
This White Paper is the result of NICT’s study, as a group of experts in information and communications technologies, on the realization of the Beyond 5G/6G world.

We created three scenarios, Cybernetic Avatar Society, City on the Moon, and Transcending Space and Time, based on an image of social life in the years from 2030 to 2035, and attempted to identify the necessary technologies by backcasting from the future society depicted in these scenarios.

Scenarios and use cases (Chapter 3), key technologies, requirements for realizing them, and the R&D roadmap (Chapter 4), and the deployment strategy (Chapter 6) are summarized. It goes without saying that in order to develop, implement and utilize the future technologies necessary to realize the depicted social lives, it is necessary to engage in discussions with not only NICT but also various stakeholders to set specific goals and carry out activities to achieve those goals.



In the future, we intend to use this White Paper as a basis for further discussions with many people. We plan to revise this White Paper as necessary to reflect the progress of these discussions.



## References: Various White Paper Consortiums, etc.

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

- Beyond 5G Promotion Strategy Council, Ministry of Internal Affairs and Communications

[https://www.soumu.go.jp/menu\\_news/s-news/01kiban09\\_02000364.html](https://www.soumu.go.jp/menu_news/s-news/01kiban09_02000364.html)

- NTT's IOWN initiative

<https://www.rd.ntt/iown/>

- DoCoMo's "DoCoMo 6G White Paper"

[https://www.nttdocomo.co.jp/corporate/technology/whitepaper\\_6g/](https://www.nttdocomo.co.jp/corporate/technology/whitepaper_6g/)

- KDDI's "Beyond 5G/6G White Paper"

[https://www.kddi-research.jp/tech/whitepaper\\_b5g\\_6g/](https://www.kddi-research.jp/tech/whitepaper_b5g_6g/)

- NEC's "Beyond 5G Vision White Paper"

[https://jpn.nec.com/nsp/5g/beyond5g/pdf/NEC\\_B5G\\_WhitePaper\\_1.0.pdf](https://jpn.nec.com/nsp/5g/beyond5g/pdf/NEC_B5G_WhitePaper_1.0.pdf)

- Samsung's "The Next Hyper – Connected Experience for All"

[https://cdn.codeground.org/nsr/downloads/researchareas/20201201\\_6G\\_Vision\\_web.pdf](https://cdn.codeground.org/nsr/downloads/researchareas/20201201_6G_Vision_web.pdf)

- University of Oulu's "6G channel"

<https://www.6gchannel.com/>

<https://www.6gchannel.com/portfolio-posts/6g-white-paper-validation-trials/>

### (2) Consortiums, etc.

- Beyond 5G Promotion Consortium

<https://b5g.jp>

- NEXT G ALLIANCE

<https://nextgalliance.org/>

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

### 2.1 Information and Communication Networks and the Nature of Society

Innovations in information and communication networks are expected to bring about the following:

- (1) Inlusiveness: A society where everyone can play an active role by eliminating various barriers and differences such as urban and rural areas, borders, ages, and the presence or absence of disabilities
- (2) Sustainability: A society that is free from social loss, convenient and sustainably growing
- (3) Reliability: A society that is resilient and vibrant, centered on human, in which safety and security are ensured and the bonds of trust will not be shaken even in the event of unforeseen circumstances, that is, Society 5.0

It is thought that CPSs will be used in various aspects of social activities, such as monitoring the real world through information and communication networks, aggregating the results as big data, analyzing the big data in cyber space and improving the real world based on the results using various actuators. There are high expectations that this system will realize a strong and vibrant society centered on humans.

### 2.2 Migration of Information and Communication Networks

The use of various infrastructure and resources that support social activities is expected to change dramatically from centralized to decentralized, and from monopolistic to sharing. Several examples of such use have already been presented, and this is what is called a shared economy. Examples include car sharing in transportation, co-working in the working environment, and crowdfunding in finance. The nature of information and communication networks is likely to change significantly in line with this trend.

Software-defined networks (SDN), i.e., network virtualization, will become increasingly common, and along with the development of white

boxes for hardware, artificial intelligence (AI) technology will be applied to control more complex networks. Network virtualization and white-box hardware will spread to terminals.

Terrestrial communication networks, including mobile communication systems, and non-terrestrial networks (NTN) in the aerospace field, which were previously separate networks, are expected to be integrated from both sides, with new components such as high-altitude platform stations (HAPS), drones, and flying cars involved.

The development of radio resources in the millimeter-wave and terahertz bands will necessitate making full use of radio waves.

### 2.3 Integration of Cyber Space and Physical Space in Beyond 5G/6G

Figure 2.1 shows an outline of solving social issues through the integrated use of physical space and cyber space in Beyond 5G/6G. Beyond 5G/6G provides highly controlled space and time in both physical space and cyber space, making it possible to do things that could not have been achieved in physical space alone. This integration of physical space and cyber space is realized by managing and controlling information through the control plane. In addition, enabling applications across integrated physical and cyber space requires fundamental services and functions, which are referred to as “enablers.” The combination of enablers realizes a wide range of applications. The Beyond 5G/6G applications provided in this way are expected to solve increasing social issues in the future.

Next, based on Figure 2.2, which is a more detailed version of Figure 2.1, we describe the functional architecture of Beyond 5G/6G.

In mobile communication systems up to 5G, frequency has been an important resource to be managed, but space and time have not been sufficiently recognized as resources that should be actively managed. However, space and time are essential resources for advanced applications. Based on the recognition that space and time are important resources for Beyond 5G/6G, we believe that it is necessary to make effective use of these resources by actively making predictions in cyber space and optimally controlling physical space based on these predictions. In this White Paper, we follow this concept and assume the

functional architecture of the Beyond 5G/6G as shown in Figure 2.2.

The social issues that Beyond 5G/6G aims to solve cover a wide range of fields, as represented by the Sustainable Development Goals (SDGs) and Society 5.0. At this time, by expanding the space we handle from physical to cyber, we will be able to solve many new social issues if we can open up the limits of space and time, the body, the brain, and other areas that were conventionally considered difficult to overcome.

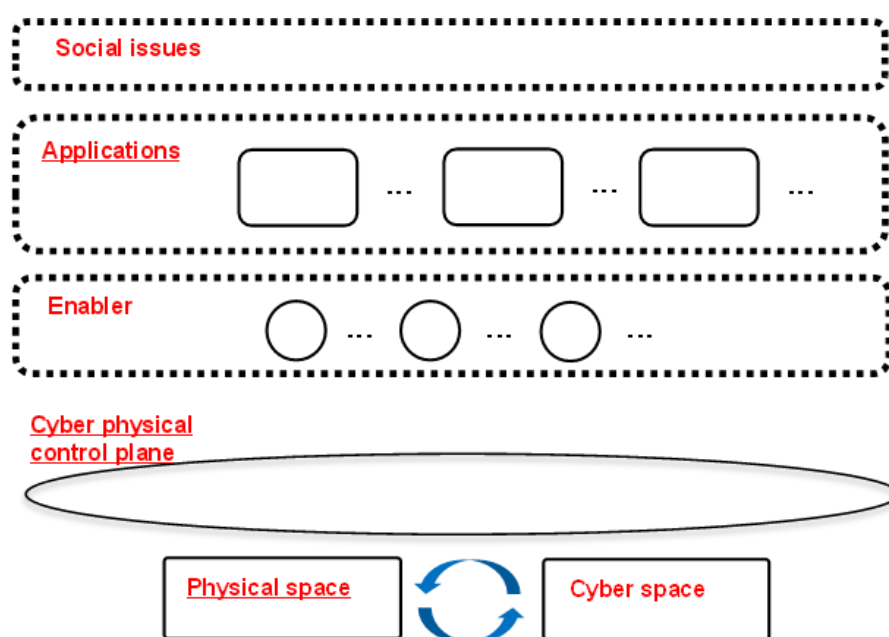


Figure 2.1: Integration of physical and cyber space in Beyond 5G/6G and solving social issues.

A wide range of applications do solve social issues. As examples of such applications, this White Paper presents three scenarios in Chapter 3: The Cybernetic Avatar Society, City on the Moon, and Transcending Space and Time. Applications are implemented with enablers as fundamental services and functions that span physical and cyber space. Enablers are building blocks for application-enabling features such as e-commerce, next-generation avatars, and space communications. Enablers are CPS-ready to handle both physical and cyber space.

Physical space and cyber space are managed by a cyber-physical control plane, which enables the utilization of resources including space and time, as well as the monitoring, sharing and optimization of the movement of people and things, the radio wave environment, and the

status of networks. By providing sensing results from physical space to cyber space and by actuating from cyber space to physical space, advanced control of space-time resources is made possible in both spaces.

In the physical space, not only the conventional mobile system for smartphones operated by mobile operators but also Local 5G, next-generation wireless LANs, private wireless systems for dedicated purposes and non-terrestrial wireless systems such as HAPS and satellites are integrated. Next-generation optical networks and data centers are integrated with these systems, and by flexibly combining the resources of each other, the optimal communication environment that meets applications' needs and intentions is provided.

In cyber space, a space corresponding to physical space is defined. In addition to realistic reproduction of physical space, subspaces

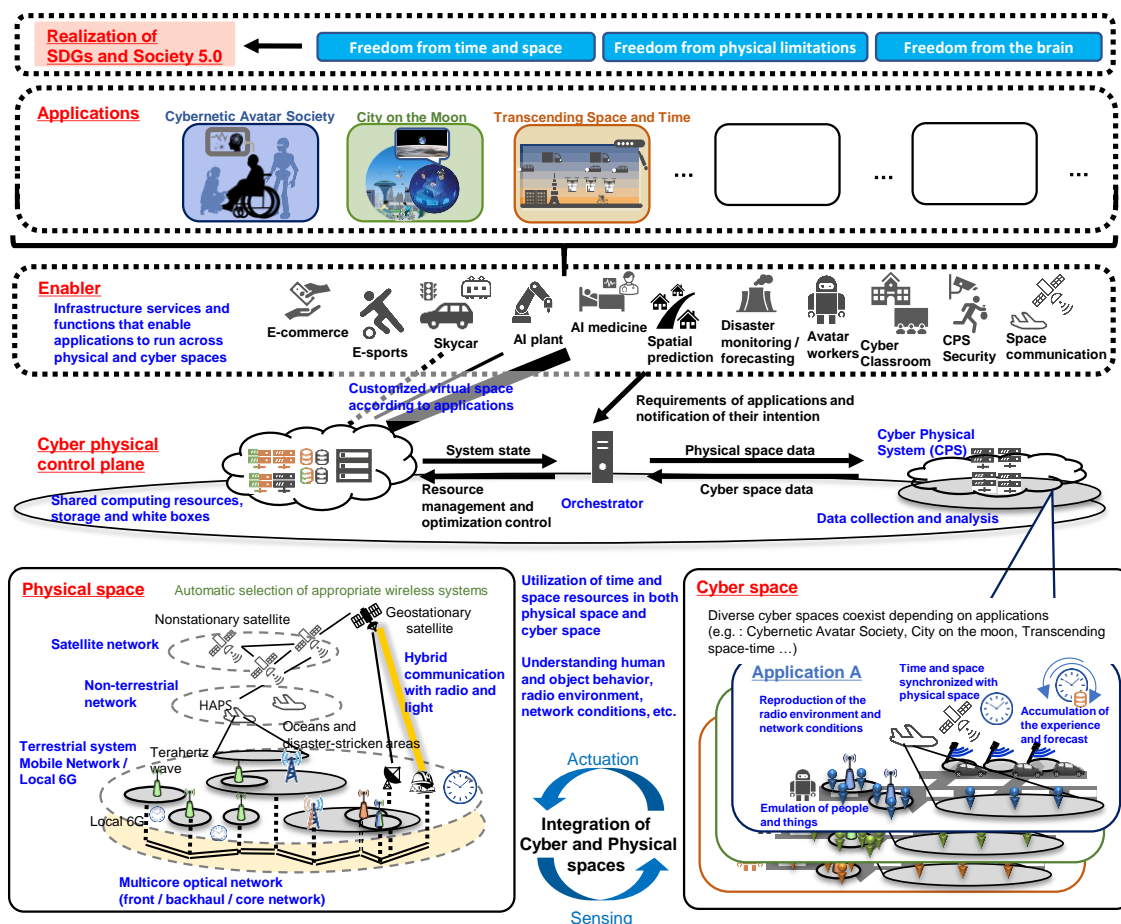


Figure 2.2: Overview of the functional structure of Beyond 5G/6G to achieve the SDGs and realize Society 5.0.



corresponding to various application scenarios are superimposed and reproduced, and optimal control of physical space is performed based on the prediction. In the cyber space, it is possible to perform verification on a time axis different from the actual one or on a scenario that is difficult to demonstrate in reality.

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

## 3.1 Scenario 1 – Cybernetic Avatar Society

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

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

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



Figure 3.1: Telepresence meeting.

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

Remotely participate in large-scale training event for simulating natural disasters (UC1-3: Telepresence). Using global core network technology, experts from various countries gathered in XR space to discuss matters further (UC1-1: Promotion of Mutual Understanding), and our products were operated



Figure 3.2: Telepresence event.

simultaneously in each country using time synchronization technology. We were very pleased to be able to verify the effectiveness of our products in the event of a disaster.

- 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 from a manufacturing plant in Thailand that the production line had been shut down. We attempted to remotely control the manufacturing equipment by hopping on a local avatar robot (UC1-3: Telepresence) and 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.

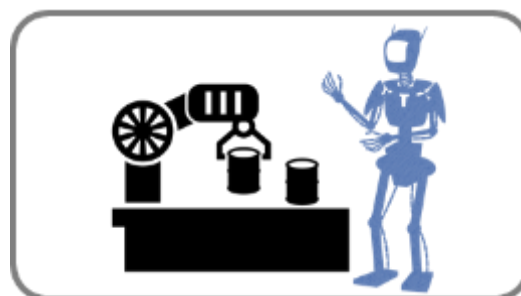


Figure 3.3: Remote response to emergency problem.

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

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



Figure 3.4: Remote assistance.

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

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

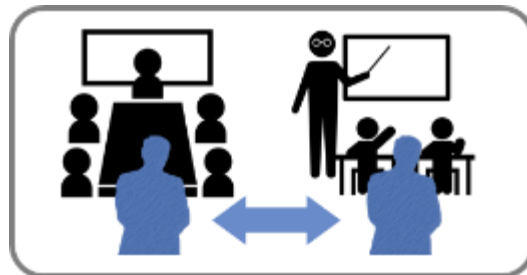


Figure 3.5: Company meeting and class visit.

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

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



Figure 3.6: XR Mount Fuji climbing.

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

Our products are popular in Europe and the Middle East, and today we had a remote meeting with a client in Turkey. I didn't know anything about the Turkish language, culture, and customs, so I was worried if I would be able to communicate with them, but thanks to the simultaneous



Figure 3.7: Remote negotiation across languages, cultures and customs.

interpretation system that takes into account each other's cultures, we will be able to sign a new contract with the client (UC1-1: Promoting Mutual Understanding).

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

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

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

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

What kind of system? Why do we need it?

It is difficult for a wide range of people with different cultures and values to truly understand each other just through daily verbal exchanges. However, this system analyzes the context, non-verbal information, and brain information to convey the true meaning of the other person in an easy-to-understand manner. Even in remote conversations with people from overseas using real avatars, the system will translate and interpret the concepts that the words convey, taking into account differences in culture and customs, thus deepening mutual understanding among people with diverse



Figure 3.8: Mutual understanding promotion system (UC1-1).

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 (see Chapter 4):

(T7) Brain information reading, visualization, and BMI technology

(T7) Real 3D avatar, multisensory communication and XR technology

(T7) AI analysis and dialogue technology using linguistic and extra-linguistic information

(T7) Multilingual simultaneous interpretation, paraphrasing, and summarization technologies

(T2) Integrated communication system configuration technology that coordinates the environment and requirements

(T6) Human-centric security technology

(\* technology not covered by NICT)

XR hardware technology such as head-mounted display (HMD)

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

What kind of system? Why do we need it?

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



Figure 3.9: Mind and body support avatar (UC1-2).

Usage:

- Elderly and physically challenged people use avatars.
- Caregivers can remotely control avatars to support care-receivers.

Required key technologies (see Chapter 4):

(T7) Intuition measurement, communication and assurance technology

(T7) Real 3D avatar, multisensory communication and XR technology

(T7) AI analysis and dialogue technology based on linguistic and extra-linguistic information

(T7) Multilingual simultaneous interpretation, paraphrasing, and summarization technologies

(T2) Integrated communication system configuration technology that coordinates the environment and requirements

(T6) Human-centric security technology

(\* technology not covered by NICT)

Hardware technologies such as home care robot and HMD

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

What kind of system? Why do we need it?

It 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. Your avatar is secure, and guaranteed not to be fake. It also allows multiple operators to switch



Figure 3.10: Working style revolution with telepresence (UC1-3).

between avatars that are specific to each task.

Usage:

- Environmental sensing information is also collected and transmitted.
- Multiple avatars are switched by multiple operators.

Required key technologies (see Chapter 4):

(T7) Intuition measurement, communication and assurance technology

(T7) Real 3D avatar, multisensory communication and XR technology

(T7) AI analysis and dialogue technology based on linguistic and extra-linguistic information

(T7) Multilingual simultaneous interpretation, paraphrasing, and summarization technologies

(T2) Integrated communication system configuration technology that coordinates the environment and requirements

(T6) Human-centric security technology

(\* technology not covered by NICT)

Hardware technologies such as remote-control robots and HMDs



### 3.2 Scenario 2 – City on the Moon

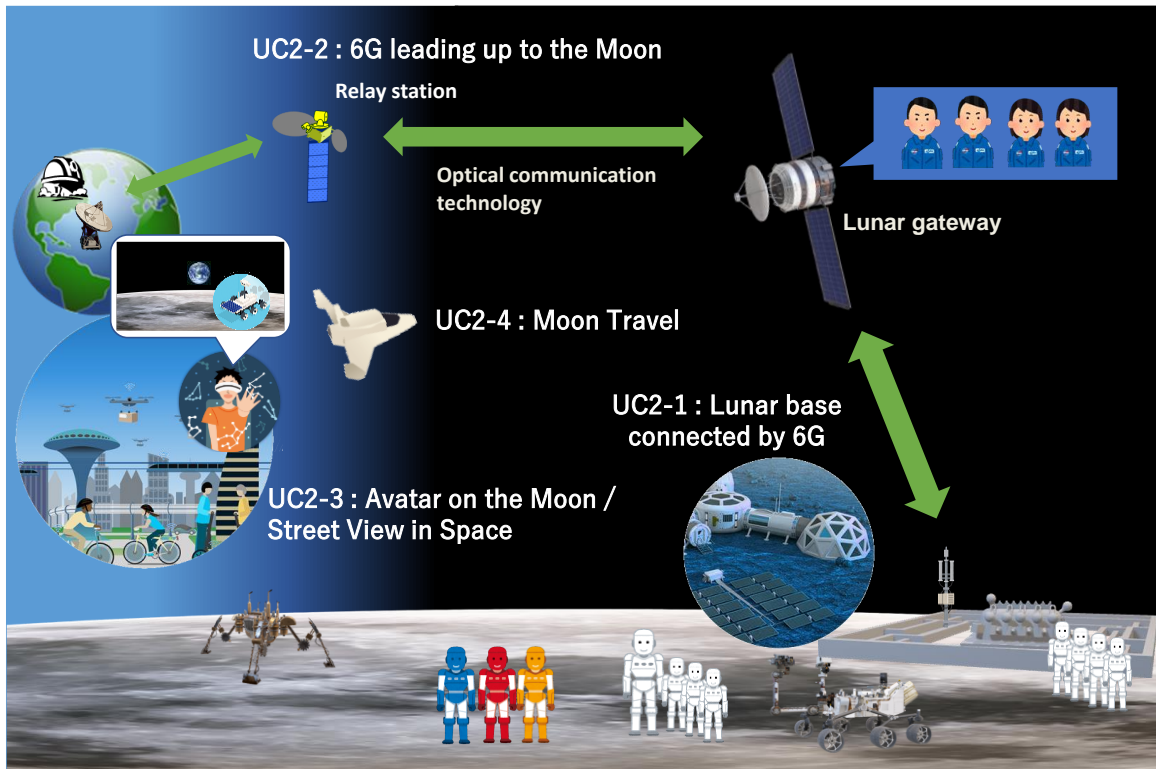


Figure 3.11: Image of Scenario – City on the Moon.

#### 3.2.1 People Cultivating the Moon At the Lunar Gateway:

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:

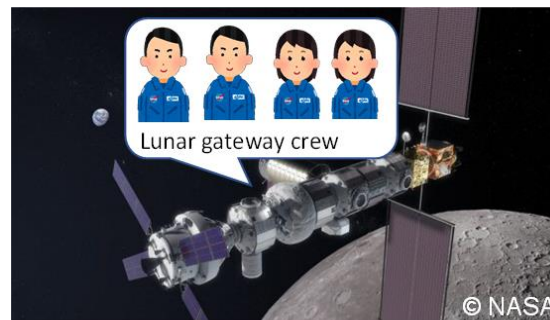


Figure 3.12: Future lunar gateway.

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

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

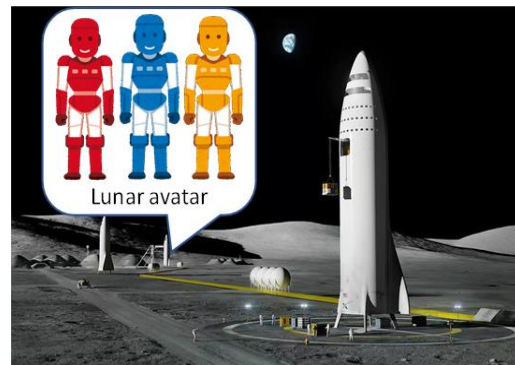


Figure 3.13: Image of lunar settlement and lunar base development.\*

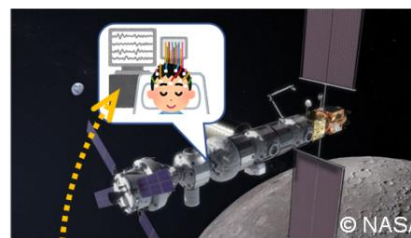
\* Space-X Base  $\alpha$ : <https://www.theverge.com/2017/9/28/16382716/spacex-elon-musk-moon-base-alpha-mars-colonization-interplanetary-transport-system>

From the Lunar Gateway to the Surface:

If you look at the horizon, you can clearly see the boundary between the black space and the gray-brown ground. This scene appears when you plug into an avatar machine on the Moon. 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, feed back the results, and optimize the exploration route.

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

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



Remote control from the moon

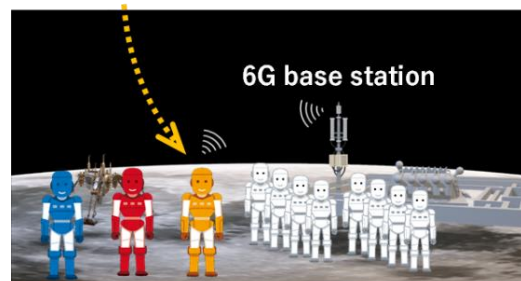


Figure 3.14: Remote work with lunar avatars.

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

### From Earth to the Moon

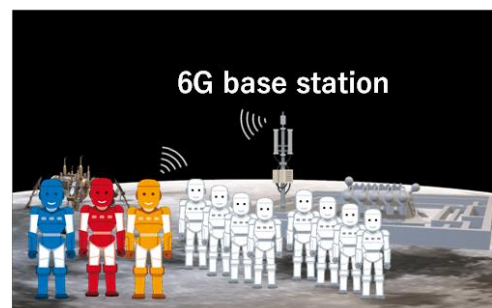
As I look at the horizon, I can clearly see the boundary between the black universe and the gray-brown ground. It is a familiar sight that appears when I plug into an avatar machine on the lunar surface. I head to the construction area with four avatar machines and meet up with three other avatar machines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

It is the 6G network that connects myself 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 6G base stations instead.

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



**Remote control of lunar avatars from the earth**



**Figure 3.15: Remote work with lunar avatars.**

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

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

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

Someone must be enjoying a Moon trip on Earth.

On Earth:

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

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

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

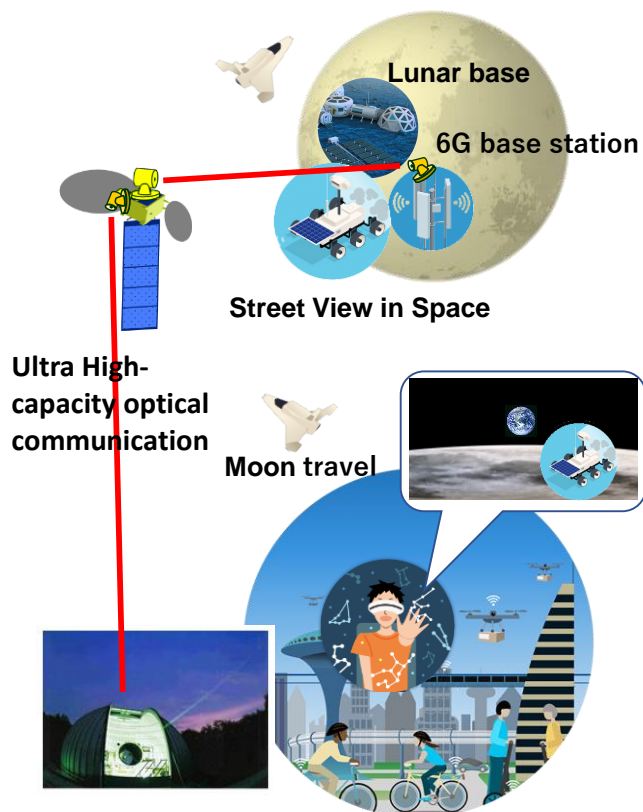


Figure 3.16: Accessing Street View in space from Earth.

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

#### UC2-1: Lunar Base Connected by 6G

What kind of system? Why do we need it?

The same 6G terminal as on the ground is connected at the lunar base, enabling positioning and location. The environment is severer than on the ground, and requires higher reliability and security for human life.

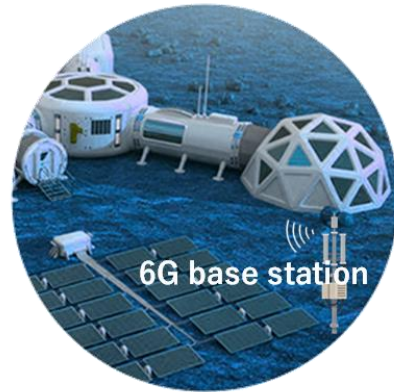


Figure 3.17: Lunar base connected by 6G (UC2-1).

Usage:

- Can be used in harsh environments on the Moon.
- Can be maintained remotely.

Required key technologies (see Chapter 4):

- (T3) Design and allocation of frequency utilization considering propagation on the lunar surface
- (T1) Wireless optical communications and terahertz technology used due to the lack of air
- (T2) Ultra-massive connectivity technology for communication of vital data, etc.
- (T4) Requires communication equipment that is resistant to radiation on the Moon
- (T5) An atomic clock built into the local 6G base station enables positioning on the lunar surface using radio waves
- (T4) Providing communication services in cooperation with a private mobile operator
- (T6) Security needs to be higher than on the ground
- (T4) 6G base station with software defined radio (SDR) installed on lunar surface (lunar surface radio with variable frequency and modulation)
- (T1) Fiber laying (multi-core fiber, laid during construction, buried in regolith)
- (T4) Minerals, fuels, buried resources, and transmission of financial information (encryption, security, time synchronization required)

(T4) Avoiding the effects of meteorites (tracking of debris and disrupting their orbits by laser irradiation)

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

What kind of system? Why do we need it?

A system used for communication between lunar avatars and users on Earth. High-speed communication is possible from Earth to the lunar base, and the same 6G terminal as on Earth is connected.

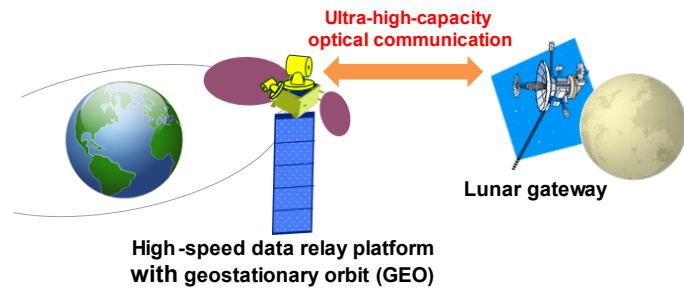


Figure 3.18: 6G leading up to the Moon (UC2-2).

Usage:

- Communication via the lunar gateway is required.
- Target data transmission speed is 5 Gbps or higher.
- Earth-Moon delay must be taken into consideration.

Required key technologies (see Chapter 4):

(T4) Earth-Moon ultra-high-capacity optical communication

(T4) 24/365 communication

(T4) Data relay station in geostationary orbit

(T4) Providing communication services in cooperation with private satellite operators

(T4) Security must be taken into account, with multiple routing choices for security and reliability

(T4) Adaptive optics for onboard satellites

(T4) Large aperture optical antenna technology for onboard satellites

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

What kind of system? Why do we need it?

A user on the ground performs an activity on the Moon by plugging in an avatar on the lunar surface. Enables real-time work to be performed at lunar plants, construction sites, and lunar laboratories (material evaluation, charge behavior in materials) while on the ground. It can also provide entertainment services (for a fee) such as games and education, and reduce the language barrier on the Moon by communicating in multiple languages in

areas such as mineral resource development and ownership, and space medicine (remote surgery by avatars), etc. In addition, real-time images of the universe can be enjoyed from the ground via webcams mounted on satellites.

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 (see Chapter 4):

(T1) Ultra-high-capacity wireless communication

(T7) Multilingual translation

(T2, T7) Low latency, brain tricks, gravity compensation

(T2) Local processing by AI and low latency control in edge computing, etc.

(T7) Leisure, gaming, VR/XR technology

(T6) Security considerations (specific to medical services)

(T4) It is necessary to ensure the reliability and the tolerance of the materials in a space environment because the degradation process is different from that on the ground.



Figure 3.19: Street View in space (UC2-3).

## UC2-4: Moon Travel

What kind of system? Why do we need it?

This is a system for high-capacity communication with Earth and the lunar base during an actual trip to the Moon in the future. This system will provide safe and secure travel that allows us to contact our grandparents on Earth without problems even during long trips. We are entering an era in which people can enjoy space travel even for leisure, and can send photos taken during their trip to Earth via SNS.

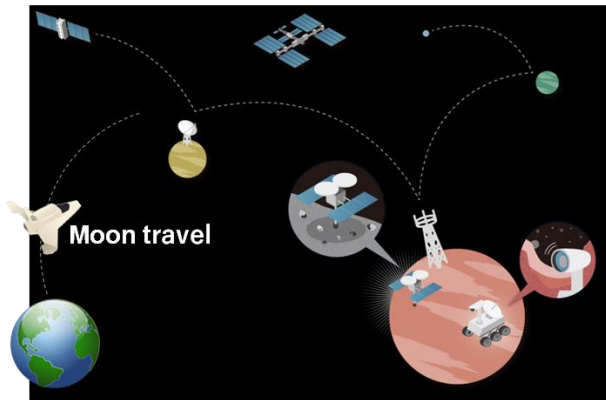


Figure 3.20: Moon travel (UC2-4).

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 (see Chapter 4):

- (T4) Importance of space weather (large impact on the human body and equipment)
- (T1) Ultra-high-capacity wireless communication
- (T2, T7) Long-distance teleconferencing
- (T2) Low latency
- (T6) Security considerations



### 3.3 Scenario 3 – Transcending Space and Time

#### 3.3.1 Creative and Active Lifestyles



##### **Father and daughter:**

My youngest daughter is very lively and I can't take my eyes off her even at the park. While watching my daughter, I call up my floating information terminal to have a meeting with my colleagues at work. It is a little cold outside. "Daddy, look! Hmm... POFF!" A pebble crashes into a pile of sand. I notice my wife's camera drone near my daughter. My wife can't stop watching her 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 of 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 stores only when his customers ask him to (UC1-3). Today he celebrated his 77<sup>th</sup> 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 cycling 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 skycar’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 when I do, I am filled with a sense of freedom. After leaving 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 from 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, in parts the mountain has collapsed, 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 relief supplies from my backpack. I heard 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?



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. The only noise is the sound of my grandfather tuning up a bicycle (UC3-3). 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 have taken after my father.

I get on my 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 is no car 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 skycar casts a shadow on my path. I pedal harder, trying not to let it pull away from me. When I notice the rain cloud radar alert and try to return home (UC3-2), a ray of light flicks across the sky toward the mountain where a large landslide has occurred (UC3-1).

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

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

What kind of system? Why do we need it?

Skycar is 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

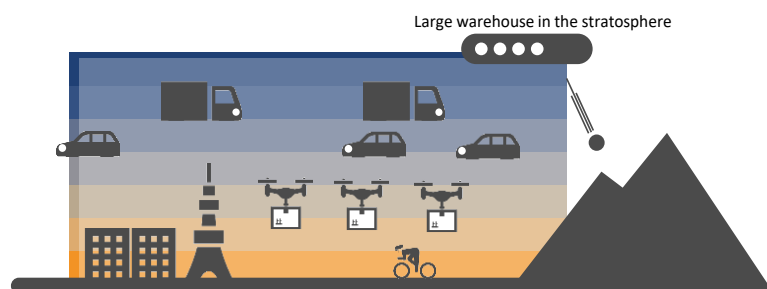


Figure 3.21: Vertical flow of people, things, and information.

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 skycar.

Usage:

Building invisible but solid "roads" in space means developing highly accurate space-time synchronization technology and spatial and frequency multiplexing of positioning base stations. Of course, it is also important to improve the accuracy of various sensors and the sophistication of cyber security in order to ensure the safety of vehicles traveling in the sky.

Required key technologies:

- (T5) Space-time synchronization technology
- (T6) Encryption and security technologies, resilience
- (T1) Ultra-high-speed and high-capacity wireless communication
- (T2) Ultra-low latency network
- (T2.1) Edge computing
- (T7.6) Passenger skycar
- (T7.7) Drone

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

What kind of system? Why do we need it?

Flood control is a difficult problem to solve amid population decline. In some cases, on-the-spot human judgment alone may not provide the optimal solution. A high-density precipitation sensor network that can provide accurate and wide-ranging information is needed to help speed up and improve the efficiency of evacuation of residents. In addition, by parallelizing irrigation channels and sluice gates and connecting them via a network, it will be possible to carry out smart drainage from the town. Thinning work is also important to strengthen the flood control function of forests. By synchronously controlling

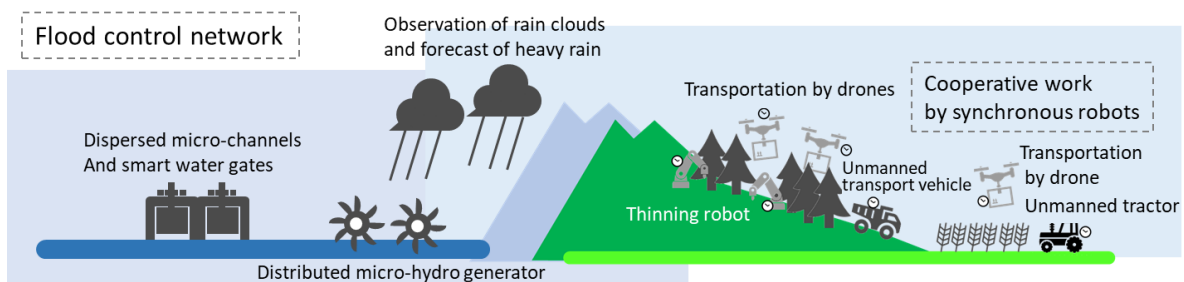


Figure 3.22: Resilient village forest (Satoyama) (UC3-2).

multiple unmanned robots and efficiently carrying out thinning operations, forests can be kept in good condition. This cooperative work of robots can also be deployed to agriculture as well as to the maintenance and management of “Satoyama.”

#### Usage:

By creating a large-scale network for flood forecasting, evacuation of residents, dam discharge, and control of sluice gates in various irrigation channels, which have not been sufficiently coordinated, we can plan cities that are resilient against floods without the need for human resources. By synchronizing and cooperating with a large number of unmanned robots, it will be possible to continuously preserve forests through thinning, maintain “Satoyama,” and improve the efficiency of farming.

#### Required key technologies:

- (T5) Robot group coordination by space-time synchronization
- (T6) Encryption and security technology
- (T6) Strengthened resilience
- (T1) Ultra-high-speed and high-capacity wireless communication
- (T2) Ultra-low delay network and high-speed image processing
- \*(Remote) sensor network

### UC3-3: Omni-Cloud Gateway

What kind of system? Why do we need it?

Until now, the cloud has been the place to go for connectivity, but as edge computing advances, we are entering an era of the omni-cloud, where we are surrounded by

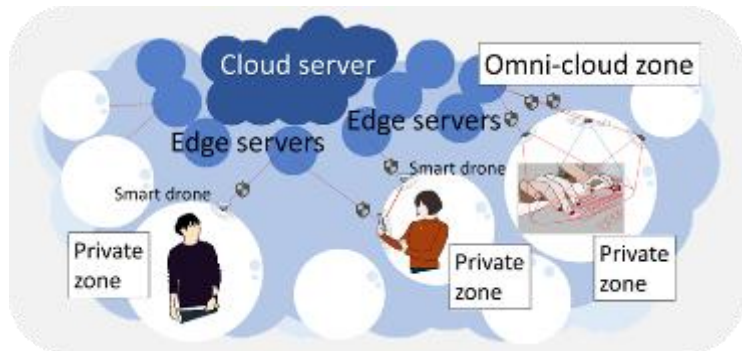


Figure 3.23: Omni-cloud gateway (UC3-3).

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 usage.

Required key technologies:

- (T5) Ultra-stable clock and high-precision synchronization
- (T6) Privacy protection and security technology
- (T1) Ultra-high-speed and high-capacity wireless communication
- (T2) Ultra-low delay network, high-speed image processing
- (T7.7) Micro-drones

\*High-accuracy inertial sensor

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

## 4.1 Technologies Enabling Use Cases

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

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

<b>T1. Ultra-High Speed &amp; High-Capacity Wireless Communication</b>		<b>T5. Time-Space Synchronization</b>	
T1.1	Terahertz wave	T5.1	Wireless time-space synchronization
T1.2	All-optical network (high-capacity optical fiber communication)	T5.2	Atomic clock chips
T1.3	All-optical network (optical and radio convergence technology)	T5.3	Generating & Sharing technology for reference time
<b>T2. Ultra-Low Latency and Ultra-Massive Connectivity</b>		<b>T6. Ultra-Security and Reliability</b>	
T2.1	Edge computing technology	T6.1	Emerging security technologies
T2.2	Adaptive wireless network construction techniques	T6.2	Cyber security technologies based on real attack data
T2.3	Adaptive wireless network application technologies	T6.3	Quantum cryptography
T2.4	Technologies for autonomous localization, tracking, and reservation of radio emission space	T6.4	Electromagnetic compatibility
T2.5	Ultra-multi-connected autonomous M2M network construction technology using ubiquitous social resources	T6.5	Resilient ICT
T2.6	Advanced radio emulation	<b>T7. Ultra-Reality and Innovative Applications</b>	
<b>T3. Wired / Wireless communication and Network Control Technology</b>		T7.1	Brain information reading, visualization, and BMI technologies
T3.1	Network control technologies (network operation automation, in-network computing)	T7.2	Intuition measurement, communication, and assurance technologies
T3.2	Frequency allocation and sharing management	T7.3	Real 3D avatars, sensory communication, and XR technology
T3.3	Self-operated wireless system management (Local B5G/6G)	T7.4	AI analysis and dialogue technology using linguistic and extra-linguistic information
<b>T4. Multi-Layers in Wireless Systems-NTN</b>		T7.5	Simultaneous interpretation, paraphrasing, and summarization technologies for multiple languages
T4.1	Satellite and non-terrestrial communication platforms	T7.6	Automated driving
T4.2	Optical satellite communications	T7.7	Drones
T4.3	Maritime communications		
T4.4	Underwater and submarine communications		
T4.5	Integrated network control		



## 4.2 Outline of Technology

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

#### T1.1 Terahertz wave

- ① Technology: The word “terahertz” generally means an intermediate frequency band between radio and light waves (approximately 100 GHz to 10 THz), which has not been fully employed in telecommunications due to technical difficulties.

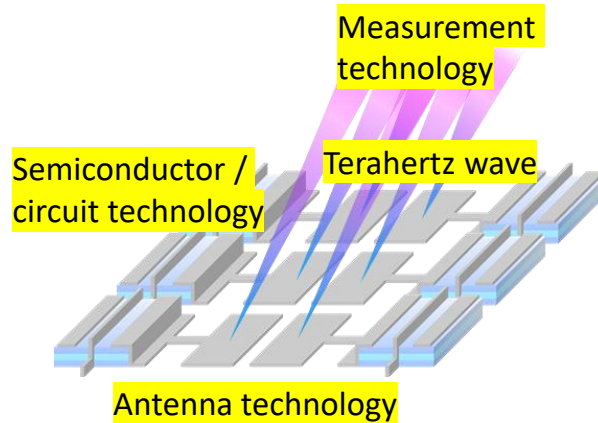


Figure 4.1 Key technologies for handling terahertz.

- 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 higher speed and capacity are anticipated. The wireless transmission of high-definition video such as 4K and 8K has already been demonstrated. In addition, terahertz waves are expected to be robust against radio interference when used for wireless communications due to their unique (short-range and ultra-wideband) characteristics.
- ③ Background: Technologies for handling terahertz waves are not yet mature. However, the development of fundamental technologies for 300 GHz band wireless communications including terahertz signal generation, modulation, and demodulation using both semiconductors and photonics devices are rapidly progressing [1] [2].
- ④ Requirements: The foundations of terahertz wireless communications call for various peripheral technologies related to semiconductor devices, electronic circuits, and antennas, enabling low-noise signal generation and high-speed measurement such as A/D conversion of terahertz waves themselves. Flexible approaches from both radio-wave and optical domains also need to be taken. In addition, practical techniques to reduce power consumption as well

as device size are required, particularly for consumer applications.

[1] NICT Press Release: Terahertz wireless makes big strides in paving the way to technological singularity, February 19, 2019

<https://www.nict.go.jp/en/press/2019/02/19-1.html>

[2] NICT Press Release: Successful 300 GHz terahertz wireless communication using ultra-small antenna, January 13, 2021

<https://www.nict.go.jp/press/2021/01/13-1.html>

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

- ① Technology: This technology concerns optical fiber, which is a thin glass fiber. It is possible to transmit a large amount of data at high speed to another country thousands of kilometers away. It is widely used for home and corporate networks, mobile phone networks, submarine cables connecting Japan and overseas, and so on.
- ② Purpose: As the number of people who work remotely at home or enjoy movies and anime through video streaming services increases, more data is transmitted and received over networks, causing data congestion. For this reason, high-capacity fiber-optic communications are needed to ensure smooth data transmission.
- ③ Background: Current optical fiber communication systems provide transmission capacity of up to 10 Tbps per optical fiber [1].
- ④ Requirements: In order to support the ever-increasing volume of data in the future, basic networks in the 2030s will require a transmission capacity of at least 100 Tbps per optical fiber, followed by a transmission capacity of at least 1 Pbps.

[1] Report of Study Group on Future Network Infrastructure (Ministry of Internal Affairs and Communications)

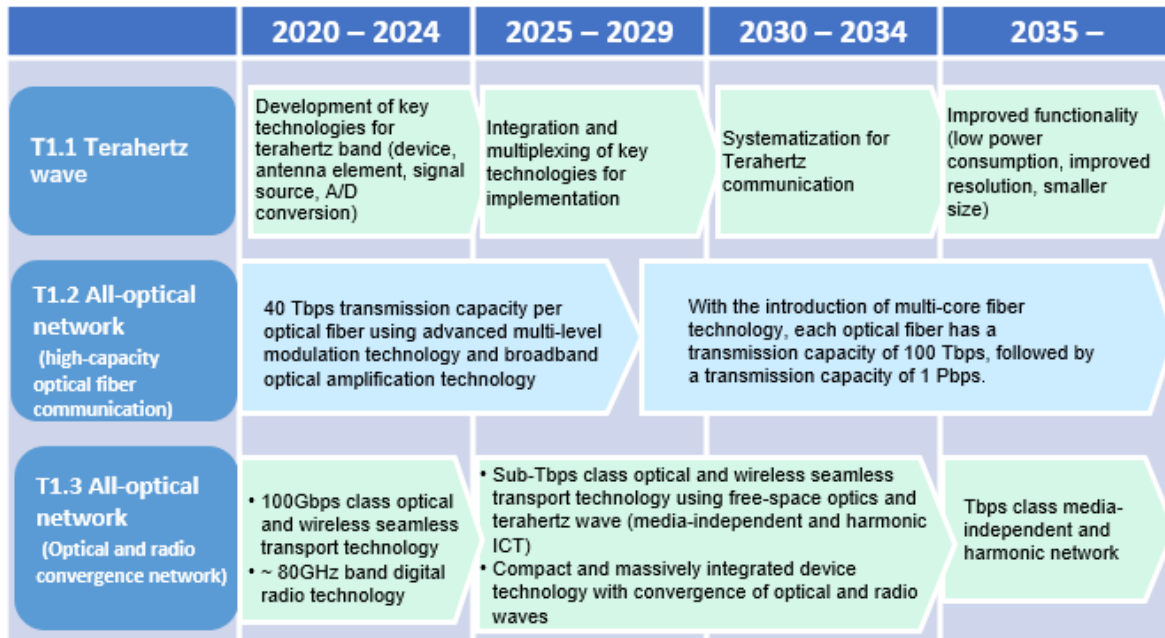
#### T1.3 All-optical network (optical and radio convergence technology)

- ① Technology: This technology is used to distribute large amounts of data generated in wireless sections such as IoT devices, mobile terminals and so on, to optical fiber networks, and large amounts of data processed in data centers and edge servers to wireless sections via optical fiber networks.
- ② Purpose: In daily life, people often move around such as when

exercising and shopping, but expect the quality of communications not to drop. To realize a sophisticated cyber-physical society in the future, it is necessary to utilize high-availability, high-flexibility and high-capacity communications while successfully converging wireless with optical fiber communications.

- ③ Background: The ITU-T SG 13 FG-NET-2030 Network 2030 Vision White Paper discusses the need for Tbps class high-capacity communication as a holographic society.
- ④ Requirements: A communication system is needed that enables high-capacity communication from 100 Gbps to Tbps, which is equivalent to 10 to 100 times the capacity of 5G, with low latency between optical fiber communication sections and wireless communication sections in an area for dedicated moderate range communication (DMRC) of several tens of kilometers. Additionally, there is a need for a massively integrated device technology for the convergence of optical and radio waves, to support the construction of this system.

Table 4.2: Roadmap of ultra-high-speed and high-capacity wireless communications



#### 4.2.2 Ultra-Low Latency and Ultra-Massive Connectivity

##### T2.1 Edge computing technology

- ① Technology: This technology uses devices embedded in the city and computers in the network to provide ICT services with ultra-low latency and high reliability.
- ② Purpose: For example, if a computer that is running a process to avoid a vehicle accident at a corner is actually located in the cloud far away via the network, it will not be able to respond in time. In addition, communication may be delayed by network congestion. Furthermore, even when it is convenient, people do not want to leak sensitive information including bio-information to external networks or the cloud. Therefore, security is also essential.
- ③ Background: The European Telecommunications Standards Institute (ETSI) is conducting standardization for edge computing by multi-access edge computing (MEC) as well as regulation of 5G provision. “Network Vision 2030” presented by the Ministry of Internal Affairs and Communications states the need for ultra-low latency and high-

capacity communications using edge computing. The White Paper of 5G Americas proposes the future direction of edge computing architecture including collaboration with information-centric networking.

- ④ Requirements: Ultra-low latency response, trade-off solution of information integrity, reliability, and security, and scalability to realize network computing in which a large number of devices connect to and interact with the network are required.

### T2.2 Adaptive wireless network construction techniques

- ① Technology: This technology controls modulation, transmission timing, relay routes, etc. in order to realize high-level actions by wireless devices cooperating according to situations and requirements.

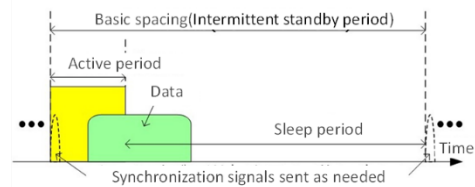


Figure 4.3: Intermittent waiting action for saving power.

- ② Purpose: This technology is indispensable for various wireless systems including IoT and mono-based systems, and satisfies the following requirements: 1) Adjusts high-speed transmission and robustness in response to the communication environment, and makes the communication efficient. 2) Enables power-saving operation and low-latency transmission while avoiding collision and congestion by controlling transmission timing. 3) By exchanging control information between wireless devices and establishing relay routes autonomously and dispersively, the accessible area is extended.
- ③ Background: There are standards such as IEEE 802.15.4 (physical layer and MAC layer) and IEEE 802.15.10 (L2R) that have been standardized with the leadership of NICT. In addition, Wi-SUN, the world's first certification referring to these standards, has been established; NICT is one of the founding members.
- ④ Requirements: In order to realize a large number of wireless communication devices, it is essential to satisfy the requirements of machines rather than humans, such as operation for 10 years or more without battery replacement, and to be able to perform autonomous

distributed operation.



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

### T2.3 Adaptive wireless network application technologies

- ① Technology: This technology handles session management, time synchronization, and the application interface in order to realize the advanced action of multiple wireless devices cooperating according to the situation and requirements.
- ② Purpose: This technology is indispensable for various wireless systems including IoT and mono-based systems, and satisfies the following requirements: 1) Optimizes information exchange by prioritizing session management and traffic coordination. 2) Realizes communication between wireless devices via wide-area backbone networks, etc., and compensates for time synchronization between wireless devices according to the assumed service. 3) Visualizes the connections among wireless devices used for communication, and handles the application interface that allows the operator to set up a huge number of wireless devices appropriately and efficiently.
- ③ Background: Standards such as ECHONET LITE (session layer or higher) exist [1].
- ④ Requirements: It is necessary to establish an appropriate user interface in addition to time synchronization of the application to guarantee the upper-layer operation.

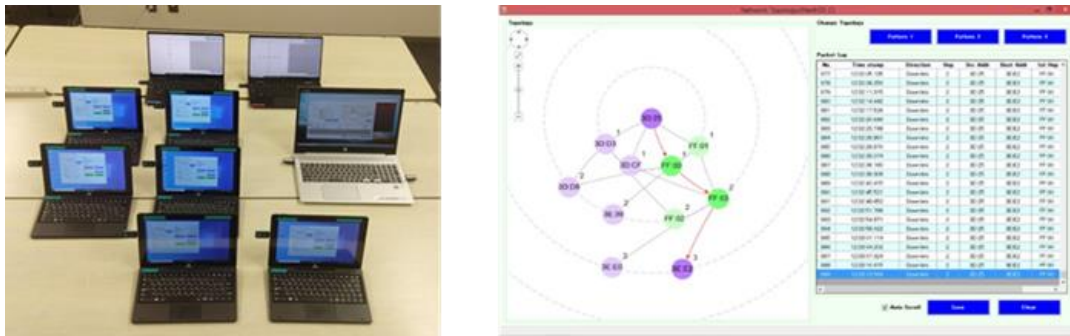


Figure 4.5: App interface for visualizing radio device operation (left: radio devices, right: connection status).

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

## T2.4 Technologies for autonomous localization, tracking, and reservation of radio wave emission 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 cyber space, 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, and has become a core technology as massive MIMO technology [1] in 5G wireless communication systems.
- ④ Requirements: It is necessary to reduce the effective isotropic radiated power (EIRP) of radio waves in an unplanned space to a level where information cannot be restored even by an ultra-high-sensitivity

receiver, and to automatically track objects as they move (walking-speed level). It is also necessary to accurately predict the arrival time of devices at future destinations and the radio wave propagation environment at such destinations, so that the optimal radio wave emission space can be reserved with microsecond accuracy.

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

## T2.5 Ultra-multi-connected autonomous M2M network construction technology using ubiquitous social resources

- 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 Requirements: It is necessary: 1) to be able to autonomously discover, secure, and manage ultra-multi-hopping relay devices related to propagation paths and frequencies suitable for information propagation in accordance with environmental conditions, etc., and to have an application programming interface (API) and appropriate user interface for that purpose, 2) to be able to secure and manage the necessary resources to ensure a certain level of time synchronization



and reliability, and 3) to be able to autonomously eliminate information whose value has already disappeared or information that violates discipline.

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

## T2.6 Advanced radio emulation

- ① Technology: This technology enables new technology evaluation and large-scale system verification to be conducted in a short time and at low cost by simulating the radio wave propagation between wireless devices based on the assumed scenario of users in a virtual space with high accuracy.
- ② Purpose: It is difficult, both financially and physically, to conduct field tests of new technologies for effectively using frequencies and tests of 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: One of the representative initiatives overseas is the SC2 project of the Defense Advanced Research Projects Agency (DARPA) [1]. It held a spectrum sharing technology contest with multiple scenarios tailored to the real world.
- ④ Requirements: Quasi real-time emulation to set mobile routes during running scenarios, large-scale system verification capability of 10,000 units, radio wave emission pattern emulation of beamforming, and 400 MHz band signal processing assuming Beyond 5G/6G.

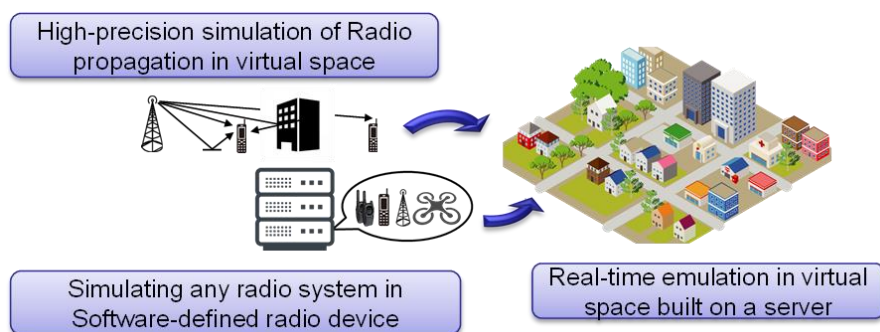
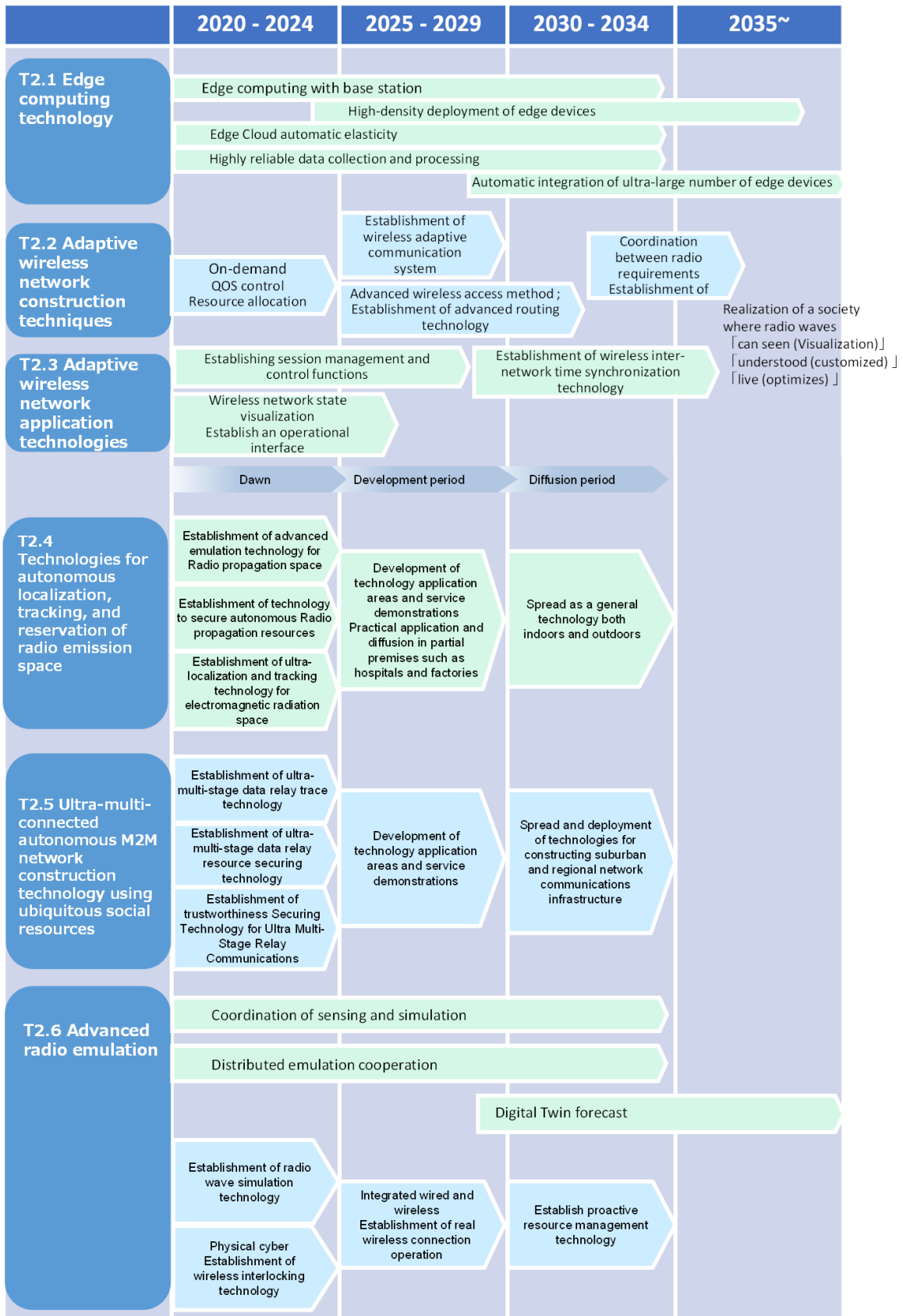


Figure 4.6: Advanced radio wave emulation.

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

Table 4.3: Roadmap for ultra-low latency and ultra-massive connectivity



### 4.2.3 Wired/Wireless Communication and Network Control

#### T3.1 Network control technologies (network operation automation, in-network computing)

- ① Technology: This networking technology ensures high sustainability for diverse service requirements in the future. These include: 1) technologies for fully automating network operations utilizing network telemetry and AI/machine-learning-based advanced data analysis mechanisms, and 2) ultra-low latency and highly reliable in-network computing technologies applying information-centric networking and edge networking.
- ② Purpose: In order to realize a safe, secure, and convenient society in the 6G era, the above technologies are essential to resolve future social issues such as a decrease in the working-age population, to satisfy the application requirements of the 6G era, and to select and agilely provide truly necessary, valid, and reliable information from a huge amount of information.
- ③ Background: The new network for 6G “Network 2030” advocated by ITU-T is a globally competitive research field [1]. In the EU, the “6 Genesis” project led by the University of Oulu in Finland is under way [2], while in Japan, NTT DoCoMo and NEC published White Papers on Beyond 5G and 6G in 2020 [3,4]. In the US, 5G Americas proposed to integrate edge computing and information-centric networking technologies as a future direction in the White Paper “5G at the Edge” [5].
- ④ Requirements: Technologies for automating network operations by utilizing open source frameworks are needed to minimize human operations. In addition, advanced mechanisms are required to guarantee application quality (ultra-low latency, high-speed processing, fault tolerance, etc.) and reliability of information.

[1] [https://www.itu.int/en/ITU-T/focusgroups/net2030/Documents/White\\_Paper.pdf](https://www.itu.int/en/ITU-T/focusgroups/net2030/Documents/White_Paper.pdf)

[2] <https://www.oulu.fi/6gflagship/>

[3]

[https://www.nttdocomo.co.jp/binary/pdf/corporate/technology/white\\_paper\\_6g/DOCOMO\\_6G\\_White\\_PaperJP\\_20210203.pdf](https://www.nttdocomo.co.jp/binary/pdf/corporate/technology/white_paper_6g/DOCOMO_6G_White_PaperJP_20210203.pdf)

[4]

[https://jpn.nec.com/nsp/5g/beyond5g/pdf/NEC\\_B5G\\_WhitePaper\\_1.0.pdf](https://jpn.nec.com/nsp/5g/beyond5g/pdf/NEC_B5G_WhitePaper_1.0.pdf)

[5] <https://www.5gamericas.org/wp-content/uploads/2019/10/5G-Americas-EDGE-White-Paper-FINAL.pdf>

### 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 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 necessary frequencies by spectrum sharing [2].
- ④ Requirements: It is necessary to develop software (broker/middleware) that automatically acquires the spectrum resources required for users, visualize spectrum operation, and allocate resources by calculating radio interference with simulators utilizing dynamic database, block chain, and digital twin technologies.

[1] [https://www.soumu.go.jp/main\\_content/000711788.pdf](https://www.soumu.go.jp/main_content/000711788.pdf)

[2] <https://www.6gworld.com/videos/spectrum-sharing-in-6g-6gsymposium/>

### T3.3 Self-operated wireless system management (Local B5G/6G)

- ① Technology: Local 5G is a unique Japanese system for using advanced 5G technology for private wireless systems. The functions are expected to be customized according to the needs of the location and region.
- ② Purpose: The system offers both stability and confidentiality, and is

expected to be used for industrial and regional applications such as factory automation systems and disaster prevention/mitigation 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 Requirements: Even at present, it is necessary to coordinate with other local 5G operators in the vicinity, but in the future, coordination with the public network and remote Local 5G is expected. It is important to utilize other technologies such as CPSs in order to create a system that maintains customizability and confidentiality while avoiding interference.

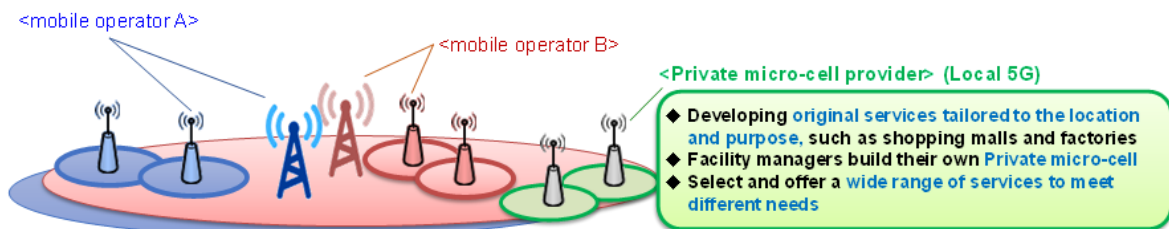
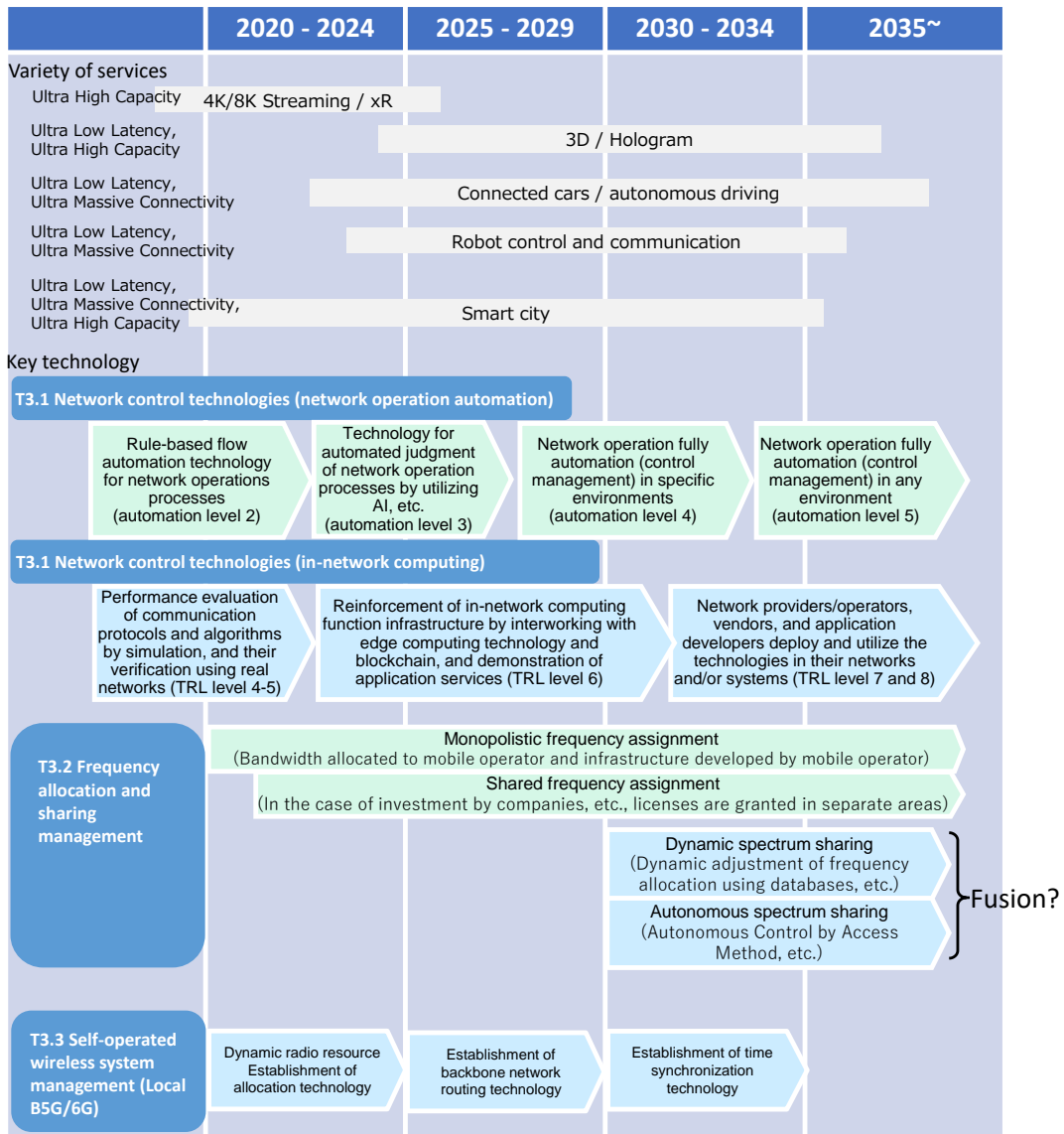


Figure 4.7: Private wireless system management (Local 5G).

[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](https://www.soumu.go.jp/main_content/000722596.pdf)

Table 4.4: Roadmap for wired and wireless communication and network control



## 4.2.4 Multi-Layering of Wireless Systems – NTN

### T4.1 Satellite and non-terrestrial communication platforms

- 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.

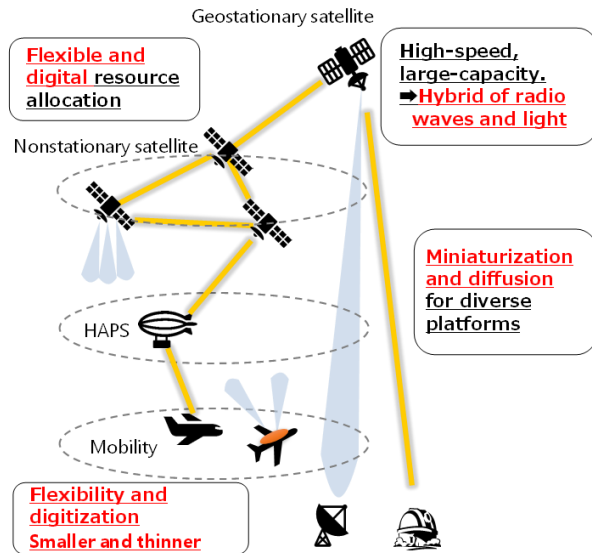


Figure 4.8: Satellite and non-terrestrial communication platforms and their requirements.

- ③ Background: As satellite communications have increased in capacity (High-Throughput Satellites: HTS) with shorter delay (low-Earth-orbit satellites) [1], HAPS have been actively developed [2]. Non-terrestrial networks (NTN) are being standardized by 3GPP.
- ④ Requirements: For practical application, wireless communication systems on each platform are required to be high-speed, high-capacity, flexible, compact, and low-cost in order to seamlessly connect with heterogeneous systems.

[1] [Rep. ITU-R M.2460-0](#)

[2] <https://hapsalliance.org/>

### T4.2 Optical satellite communications

- ① Technology: This technology provides high-capacity wireless communication using light (laser) in space, aiming for ultra-high speed, low latency and broadband communication.

② Purpose: While the amount of data generated by earth observation satellites is increasing, there is a limit to high-speed communication in the radio frequency band. High-speed optical wireless technology is powerful for large-capacity image transfer and long-distance data communications.

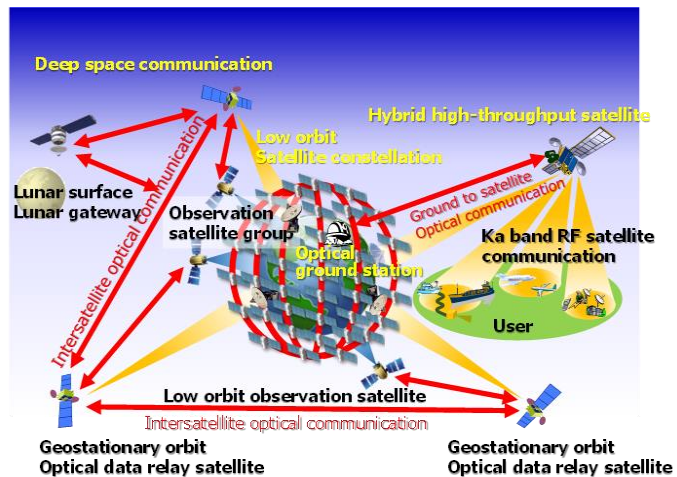


Figure 4.9: Use of optical satellite communications.

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.

④ Requirements: In optical communications, the beam is sharp, so optical communication devices and capture/tracking devices with capture/tracking/directional functions are required. For practical application, communication speeds of 10–50 Gbps class, which is an order of magnitude higher than the present level, and communication technology connecting multiple different networks are also required.

[1] <https://www.satnavi.jaxa.jp/project/lucas/>

[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>

#### T4.3 Maritime communications

- ① Technology: This technology provides M2M data transmission and high-speed, high-capacity networks to ships on the ocean.
- ② Purpose: The sharing of high-speed and high-capacity data over the ocean and land is effective for automated navigation, efficient use of



marine resources, maritime security, and onboard broadband.

- ③ Background: Several tens of Mbps are provided in the global service, but the size of the communication equipment and cost are obstacles due to restrictions on installation locations [1].



Figure 4.10: Image of maritime communications.

- ④ Requirements: A high-speed, low-cost, small-sized broadband communication system is needed across the globe, including the Arctic region, with a view to future unmanned operations.

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

#### T4.4 Underwater and submarine communications

- ① Technology: This technology provides communication under the sea where it is difficult to use radio waves. Conventional communication using sound waves has problems of slow communication speed and large propagation delay. 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].
- ④ Requirements: 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.

[1] <https://www.trimatiz.com/jp/consortium/alan.html>

#### T4.5 Integrated network control

- 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 interruption of communication 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, 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 Japan, a subcommittee of the Space ICT Promotion Forum [3] is studying new use cases for collaboration between satellites and Beyond 5G/6G.
- ④ Requirements: Standardization of each platform and development of infrastructure for integrated network systems (such as satellite-ground resource management functions) are required.

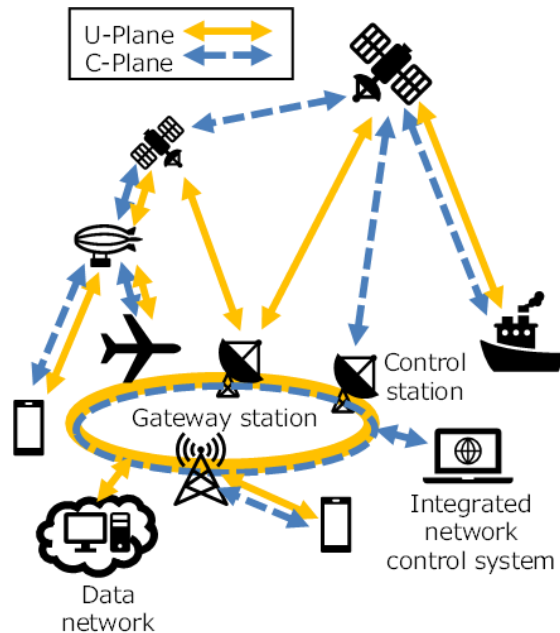
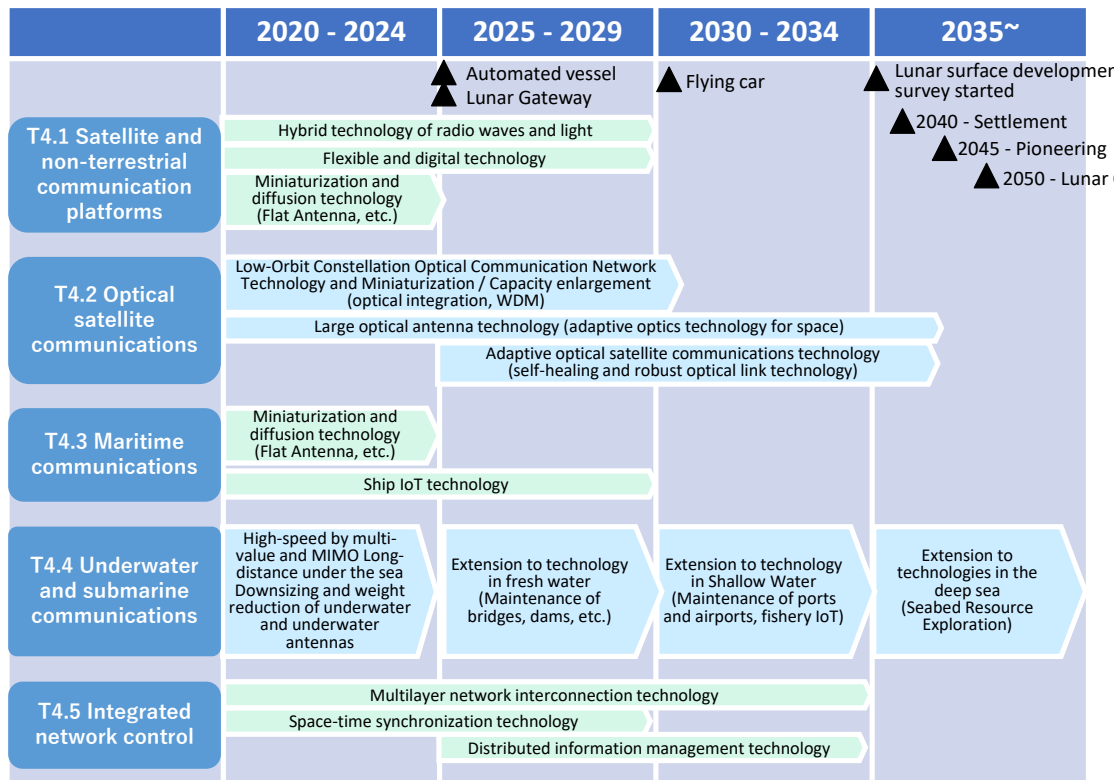


Figure 4.11: Image of the integrated network architecture.

Table 4.5: Roadmap of multi-layering of wireless systems with non-terrestrial network (NTN)



[1] <https://artes.esa.int/projects/satis5-0>

[2] <https://www.sat5g-project.eu/>

[3] <https://spif.nict.go.jp/>

#### 4.2.5 Space-Time Synchronization

##### T5.1 Wireless space-time synchronization

- ① **Technology:** This technology provides time synchronization and mutual positioning by wireless technology for remote devices to work cooperatively. High-precision space-time synchronization can be 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 create shapes rapidly by linking multiple robots. In addition, cost-effective, easy-to-use and



Figure 4.12: Space-time synchronized 3D printer.

robust space-time synchronization technology is essential for the diversification of computing resources.

- ③ Background: The 5G Technical Specification (3GPP TS v. 18) requires time synchronization with a low delay of less than 1 ms and jitter of less than 1 microsecond from end to end for multi-robot collaboration. As a positioning technology, GNSS (GPS, etc.), beacons, Wi-Fi/Bluetooth technology, etc. are combined to measure the position, and the position measurement accuracy of 20 cm is required at the highest service level (see the 3GPP document mentioned above).

- ④ Requirements:

Case 1) Inventory in warehouse/indoor robot coordination:

- Time synchronization accuracy 1 microsecond, communication delay (end to end) < 1 millisecond, position measurement accuracy 1 cm

Case 2) Vertical traffic control:

- Time synchronization accuracy 1 microsecond, communication delay (end to end) < 1 millisecond, position measurement accuracy 5 m

## 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. This is because traditional clocks vary depending on the environment in which they are used. By stabilizing the clock to the atomic frequency standard, you can synchronize and control the clocks of all devices in

a single synchronization.

- ② Purpose: The age of cloud computing and the age of real-time processing of huge amounts of computation by multiple computers will come. By synchronizing and tuning the clock, it is 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 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, we need a scenario for further miniaturization and low-power-consumption expansion.
- ④ Requirements:

Edge computing size < 5 cc, power consumption < several mW

Personal device size < 1 cc, power consumption < several hundred mW

[1] R. Lutwak et al., The MAC-a Miniature Atomic Clock, in Proc. IFCS2005, p. 752.

[2] H. Zhang et al., ULPAC: A Miniaturized Ultralow-Power Atomic Clock, IEEE JSSC, 54(11), 2019, p. 3135.

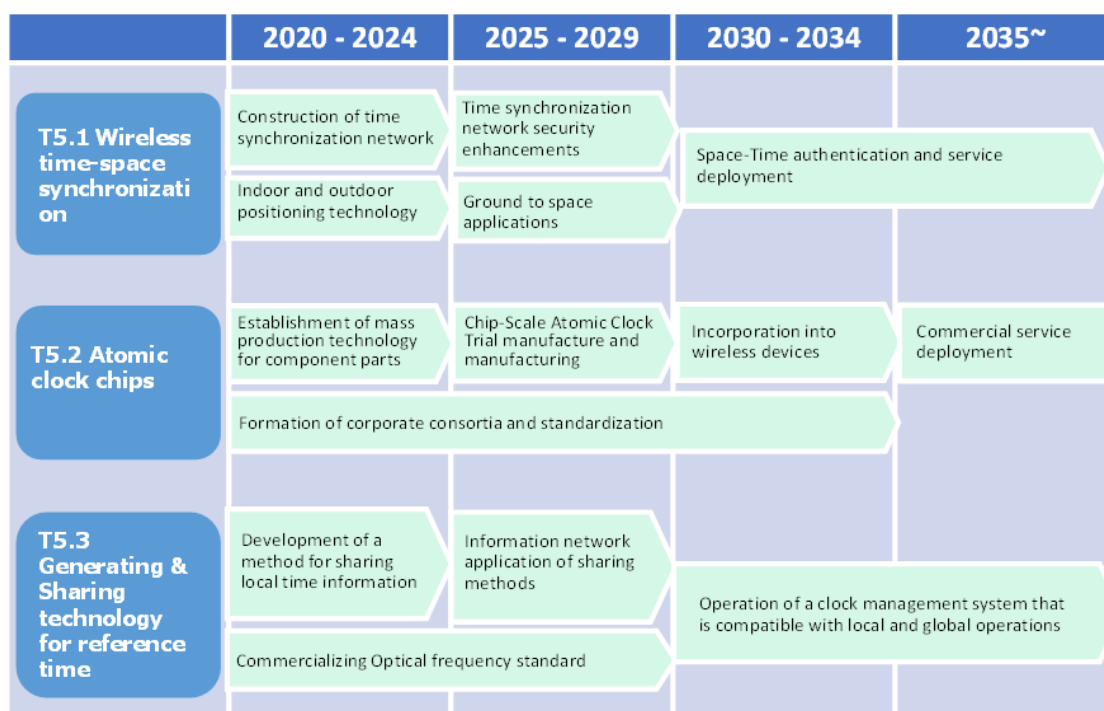
### T5.3 Generating & sharing technology for reference time

- ① Technology: This technology creates and shares a highly disaster-resistant virtual standard time by using a large number of clocks in a local network, and 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 Requirements: High-speed and highly-efficient data exchange in local networks requires relative time accuracy at the picosecond level. Data exchange based on universal timestamps requires absolute time accuracy at the microsecond level.

Table 4.6: Roadmap for space-time synchronization



#### 4.2.6 Ultra-Security and Reliability

##### T6.1 Emerging security technologies

- ① Technologies: 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 the real space will be sent to the cyber space 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 twin). 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 under way in the Cross-miniature Strategic Innovation Promotion Program (SIP) project.
- ④ Requirements: Hardware (sensors, drones, satellites, etc.) security technology (anti-tamper technology, hardware trojan detection technology, measurement and control security technology, etc.). Security technologies for real data processing software and clouds (vulnerability detection, data-protection technologies, adversarial attack resistant AI technologies, DoS attack protection technologies, etc.). Beyond 5G/6G infrastructure security technology, and security technologies for new technologies and services (automated driving, unmanned delivery, XR, satellite and HAPS communications, etc.) are required.

#### T6.2 Cyber security technologies based on real attack data

- ① Technology: This technology provides large-scale attack observation and visualization to respond to increasingly diverse and sophisticated cyber-attacks, and cross-analyzes large-scale aggregated information to derive countermeasures.
- ② Purpose: In a society where Beyond 5G/6G has been realized, a huge number of devices will be connected to each other with ultra-high speed, low latency and large capacity. In other words, as the number of devices subject to attack increases and 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 Requirements: Technology to observe diverse cyber-attacks including indiscriminate attacks and targeted attacks, visualization technology to grasp the situation from observed information, and technology to analyze vast amounts of observation data in real time using AI technology and derive automated countermeasures.

### T6.3 Quantum cryptography

- ① Technology: This technology is an encryption method that uses a shared secret key to encrypt and transmit data using the properties of quantum mechanics. It is possible to attain information theoretic security that cannot be deciphered in principle 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 cyber space. Quantum cryptography can protect national secrets and security, and 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 of quantum communications using ultra-small satellites. In addition, Japanese companies have begun to commercialize quantum cryptography devices.
- ④ Requirements: Quantum key distribution (QKD) to share private keys,



QKD networking, QKD using artificial satellites, as well as the establishment of 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 compatibility

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

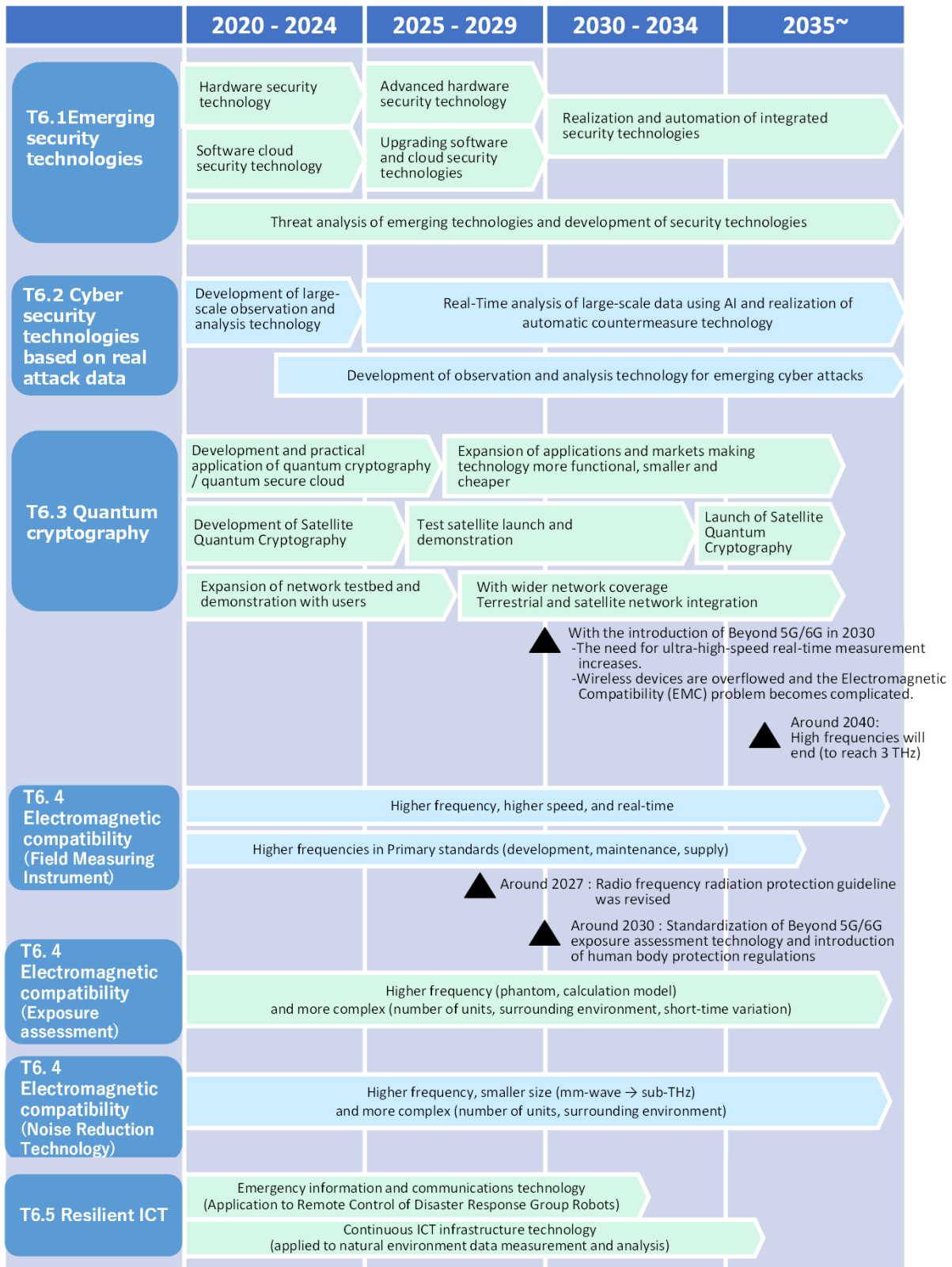
methods, and evaluation methods.

#### T6.5 Resilient ICT

- ① Technology: This technology provides temporary and continuous use of communication infrastructure (network, data observation and analysis, etc.) even when the environment changes rapidly due to various failures and disasters.
- ② Purpose: An emergency network infrastructure is required in order to carry out recovery work by sending in a group of robots where human entry has become difficult due to a disaster. At the same time, network infrastructure that continuously supports the observation and analysis of natural environmental data and the distribution of local information is necessary to ensure security and safety at any time and anywhere.
- ③ Background: ITU-T Technical Report [1] describes resilience as one of the requirements for future networks. In addition, the 6th Basic Plan for Science, Technology and Innovation states that in order to reduce risks due to sudden changes such as natural disasters, the Government will focus on strengthening resilience by using cutting-edge ICT in such areas as observation and prediction of natural disasters and emergency response.
- ④ Requirements: As an emergency information-sharing platform, we aim to realize the communication requirements (end-to-end (E2E) delay of 0.1 ms or less) required for remote control of a robot group at the space ratio and time ratio of 99.99% or more, and as a continuous information-sharing platform, we aim to realize an area coverage ratio and availability of 99.99% or more.

[1] FG NET-2030 Sub-G1, [Representative use cases and key network requirements for Network 2030](#), Jan. 2020.

Table 4.7: Roadmap for ultra-security and reliability



#### 4.2.7 Ultra-Reality and Innovative Applications

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

- ① Technology: This technology controls various devices and provides non-verbal communication (emotion, intelligibility, skill) by reading and analyzing brain information with 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 sensor, miniaturization, decoding, and wireless communication technologies, and further advancement of each basic technology is expected.
- ④ Requirements: Wireless communication of brain information requires ultra-high-speed broadband communication, ultra-low latency, ultra-large number of simultaneous connections, ultra-low power consumption, ultra-security/reliability, and expandability.

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

- ① Technology: This technology measures the discomfort felt during work in cyber space such as teleconferencing and remote control from biosignals including brain information to maintain the intuition of users.
- ② Purpose: In cyber space 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 cyber space 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 less load on the brain will become possible.

- ④ Requirements: In order to maintain intuition, including at the unconscious level, it is necessary to construct a brain model that estimates intuition from biological signals such as brain information, and to perform dynamic delay and jitter control based on biological signal feedback in wired and wireless integrated networks.

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

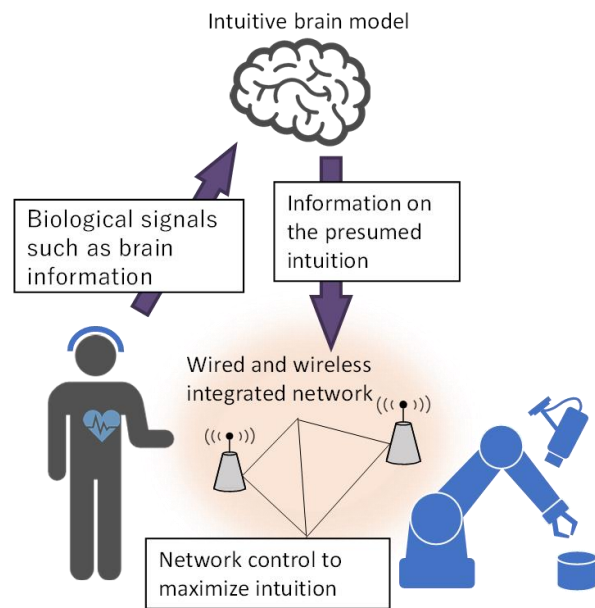


Figure 4.13: Intuition measurement, communication and assurance technologies. .

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

- ① Technology: This technology provides an ultra-reality communication that enables real and natural remote XR interaction by instantaneously creating a 3D model of the body and environment and transmitting and reproducing it along with multisensory information (visual, auditory, tactile, olfactory, etc.).

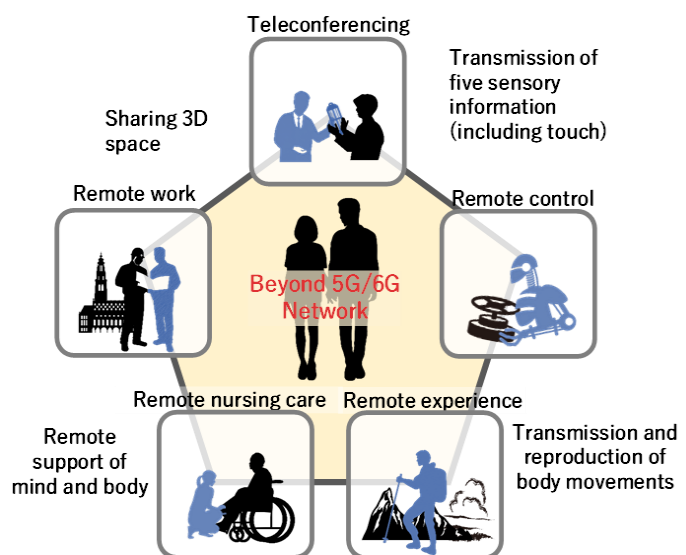


Figure 4.14: Ultra-reality communication transcending space, time and physical barriers.

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.

- ④ Background: In the post-Covid-19 society, there is 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.
- ⑤ Requirements: Ultra-reality communication technologies such as 3D avatars, multisensory communications, and XR that guarantee the quality of experience (QoE) equivalent to the real world are required for various tasks performed remotely by humans.

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

- ① Technology: This technology analyzes and organizes large amounts of information and knowledge on the Internet, and helps users to 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 being used by ordinary households and the accuracy of machine reading technologies is now exceeding that of humans, there exists no technology that covers all aspects of dialogue and no methodology that can expand and refine the user's perception of the world through dialogue.
- ④ Requirements: When individual users request analysis of a large amount of data on the Internet, in order to avoid third parties obtaining the results of the analysis, 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 Simultaneous interpretation, paraphrasing, and summarization technologies for multiple languages

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



Figure 4.15: Secure remote simultaneous interpretation.

Source: Global Communication Plan 2025  
(Ministry of Internal Affairs and Communications, March 31, 2020)

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

## T7.6 Automated driving

- ① Technology: This technology automates the movement of vehicles (mobility) in various fields such as cars and trucks used for the transportation of people and goods, industry and agriculture, robots that compensate for the labor shortage at medical sites, and wheelchairs that help the movement of the disabled and the elderly.
- ② Purpose: We will be able to realize a vibrant and bright society by

creating a safe and secure traffic environment free from accidents, eliminating labor shortages and declining productivity due to the aging population and low birth rate, and encouraging the participation and independence of the disabled and the elderly who are worried about mobility.

- ③ Background: Efforts to realize autonomous driving are being made in various fields of transportation, communication and industry.
- ④ Requirements: The creation of ultra-precise environmental maps of space, obstacle avoidance and collision prevention, remote monitoring for emergency measures, and distributed sensor technology such as roadside infrastructure are essential. In order to realize these technologies, cooperation between vehicles and networks, and establishment of high-capacity information communication (over several tens of Gbps) and real-time communication (delay of 1 ms or less) are required.

#### T7.7 Drones

- ① Technology: This technology is based on an unmanned aircraft that can fly through the sky freely, from inside to outside of the area of visual observation, by 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 improve 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 eco-system 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 Law and the Radio Law 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 standardization of communications and airframe safety technologies.

- ④ Requirements: Highly-reliable and low-cost wireless communications supporting safe flight operations of drones, spectrum sharing and frequency-expansion technologies for this, and collaboration and integration with terrestrial, space and HAPS networks are required.

Table 4.8: Roadmap for ultra-reality and innovative applications

	2020 - 2024	2025 - 2029	2030 - 2034	2035~
<b>T7.1 Brain information reading, visualization, and BMI technologies</b>	Estimating visual information based on brain activity	Early models of artificial brains	Emotion and intelligibility are estimated from brain waves, etc.	Conversation / motor intention Low / non-invasive extraction of brain information
<b>T7.2 Intuition measurement, communication, and assurance technologies</b>	Knowledge of reduced remote work efficiency due to communication delay	Measurement technology for discomfort and development of intuitive indicators	Dynamic delay / jitter control based on intuitive metrics	Network that guarantees unconscious intuition
<b>T7.3 Real 3D avatars, multisensory communication, and XR technology</b>	Remote VR conference using CG avatar	Remote XR conference using real 3D avatars	Acquisition / transmission / XR reproduction of five sensory information including tactile sense	XR remote work using multisensory information / nursing care, etc.
<b>T7.4 AI analysis and dialogue technology based on verbal and non-verbal information</b>	Realization of Dialogue Using Web Information	Dialogue technology using a virtual personality with the purpose and policy of dialogue	Technology for engaging in dialogue while reasoning at a level that can be referred to by experts, including multiple linguistic information	Dialogue technology that reduces dependence on external search services and ensures privacy
<b>T7.5 Simultaneous interpretation, paraphrasing, and summarization technologies for multiple languages</b>	Translation for everyday life and business	Simultaneous interpretation that supplements the context, the speaker's intention, etc.	Simultaneous interpretation for severe negotiations	Simultaneous interpretation of autonomous growth
<b>T7.6 automatic operation</b>	Self-driving car (Conditional self-driving vehicle)	Fully autonomous vehicle (Fully autonomous outdoor driving)	All equipment Fully automatic operation (Self-driving for all indoor and outdoor)	Intelligent Fully automatic operation (Intelligent Autonomous Driving) To a humanoid robot (HUMAN MOBILITY)
<b>T7.7 Drone</b>	Demonstration of multimulti-hop technology (in some special areas) Research on application of inter-airframe communication technology to safe flight	Expansion of practical application areas of communication technology (mountains, oceans, urban areas, etc.) Long-distance and large-capacity communications (in response to the increase in the number of drone flights and the expansion of active areas) Sophistication of spectrum sharing	Collaboration with satellites and HAPS Expansion of frequency Expanding to Flying Cars	Realization of three dimensional networks in space - HAPS - sky - ground / sea / sea

### 4.3 R&D Roadmap

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

Table 4.9: R&D Roadmap

	2020 - 2024	2025 - 2029	2030 - 2034	2035~
Science and Technology Basic Plan	Sixth Science and Technology Basic Plan			
Evolution of mobile communication systems	Early 5G (Non Stand Alone)	Enhanced 5G (Stand Alone)		Beyond 5G
B5G Promotion Strategy	Phase of phase		Acceleration phase of efforts	
Scenario		▲ Real-3D Avatar Remote XR Simultaneous Interpretation Conference ▲ Lunar Gateway ▲ Promotion of the Lunar Gateway / ARTEMIS Program	▲ Support for the elderly based on language / non-language / brain information analysis ▲ Experimental demonstration ▲ Automatic driving support using edge servers	▲ Intuitive remote work by transmitting multisensory info including touch ▲ Survey and development of moon ▲ Infrastructure conservation and environmental monitoring with the sensor network
Ultra-high-speed and high-capacity wireless communications (4-2.1)	Basic technology development THz wireless elemental technology, 100 Gbps class optical wireless connection, 40 Tbps optical fiber	Development of advanced technologies and practical systems THz wireless system, sub-Tbps class optical and wireless connection, 100 Tbps optical fiber		Media harmonic network 1 Pbs class transmission, Tbps class network
Ultra-low Latency and Ultra Massive Connectivity (4-2.2)	Establishment of basic radio system Resource allocation and QoS control technology Edge processing applied session construction technology	Verification, demonstration and standardization of advanced functions Adaptive wireless network construction technology, adaptive wireless access and routing control technology Advanced edge cloud technology and wireless inter-network time synchronization technology		Social development and business development Establishing coordination among service requirements Edge device deployment
Wired and Wireless Communication / Network Control (4-2.3)	Establishment of basic technology and applied technology research Operation Automation Technology, In-Network Computing Technology Local B5G, wireless control, etc.	Technology expansion, collaboration and service demonstration Enhancement of operation automation and in-network computing function infrastructure Development of local B5G networks efficient frequency allocation, etc.		Practical application and social development Operation Full-Automation, advanced in-network computing Introduction of local B5G technologies, spectrum sharing, etc.
Multi-Layering of Wireless Systems - NTN (4-2.4)	Establishment of basic technology and applied research Radio wave / optical hybrid, flexible / digital, compact / large capacity Expansion of air, LEO, GEO, moon, sea and water areas		Technology expansion, collaboration and advancement Network interconnection, distributed information management, large optical antennas, and adaptive optical communications Expanding into deep space, shallow sea, and deep sea	
Space and time Synchronization (4-2.5)	Establishment of basic technology Synchronous network modeling Chip-Scale Atomic Clock mass production technology	Preparation for implementation and deployment Synchronous network security enhancement Chip-Scale Atomic Clock prototype	Practical application and service development Space-Time authentication service incorporated into Chip-Scale Atomic Clock radios	
Ultra-security and Reliability (4-2.6)	Establishment and advancement of basic technologies New quantum cryptography communication system Network control management technology		Practical application of wide-area quantum cryptographic networks Integration of satellite and terrestrial quantum cryptography networks	
Ultra-Reality and Innovative Applications (4-2.7)	Establishment of basic technology Remote VR technology (CG avatar) for estimating sensory information from brain activity	Sophistication of technology An early model of an artificial brain Remote XR technology (real 3D avatar)	Technology development for practical application Dialogue technology including advanced reasoning Severe simultaneous negotiation interpreter	Social development Intuitive XR technology using multisensory Self-growing simultaneous interpretation
R&D Open Platform (5-1)	Building platforms and promoting R&D		Advancement of platforms and promotion of research and development	
Standardization (6-1)	ITU-R Technology trend survey Vision recommendation	Technical performance requirements - standardization	ITU-R Technology trend survey Vision recommendation	Technical performance requirements - standardization
R&D Projects (6-2)	Beyond 5G R&D Promotion Project			

## Chapter 5: R&D Open Platform

In response to the recommendations of the Beyond 5G Promotion Strategy Council, the Beyond 5G Promotion Strategy - Roadmap to 6G - was announced in June 2020. This describes the R&D open platform as follows.

Among the core technologies of Beyond 5G, it is appropriate for the relevant ministries and agencies to cooperate and intensively promote research and development of strategically important key technologies that Japan should focus on for a limited period of time. In order to effectively promote R&D of cutting-edge key technologies, we will collaborate with R&D platforms such as SINET and the supercomputer “Fugaku,” as well as funding programs for young researchers. NICT will also build the Beyond 5G R&D platform and other locations, and provide various players in Japan and overseas with advanced R&D environments including testbeds such as radio wave environment emulators. We will promote joint R&D utilizing these environments.

Beyond 5G/6G requires innovative R&D not only in collaboration with diverse players from industry, academia, and government, but also in an internationally coordinated system.

Accordingly, NICT, which specializes in R&D in the information and communications field, will develop new Beyond 5G/6G by sharing research facilities and equipment, which will be needed to realize ultra-high speed, ultra-high capacity, ultra-low latency, ultra-massive connectivity, low power consumption, etc., which will be the core of Beyond 5G/6G technology. In addition, NICT will build a system to promote open R&D by combining the wisdom of industry, academia, and government in organic coordination with existing R&D infrastructure (cybersecurity, data utilization, quantum networking, brain information communication, etc.).

## Chapter 6: Deployment Strategies

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

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

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

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

The Ministry of Internal Affairs and Communications established the Beyond 5G Promotion Consortium in December 2020, which is planning to publish a Beyond 5G White Paper. It is also planning to make a proposal for the 38th WP5D in June 2021.

NICT plans to incorporate its technology seeds into its Future Technology Trends and the vision until 2023, positioning them as Beyond 5G/6G technology, and contributing to standardization for early commercialization.

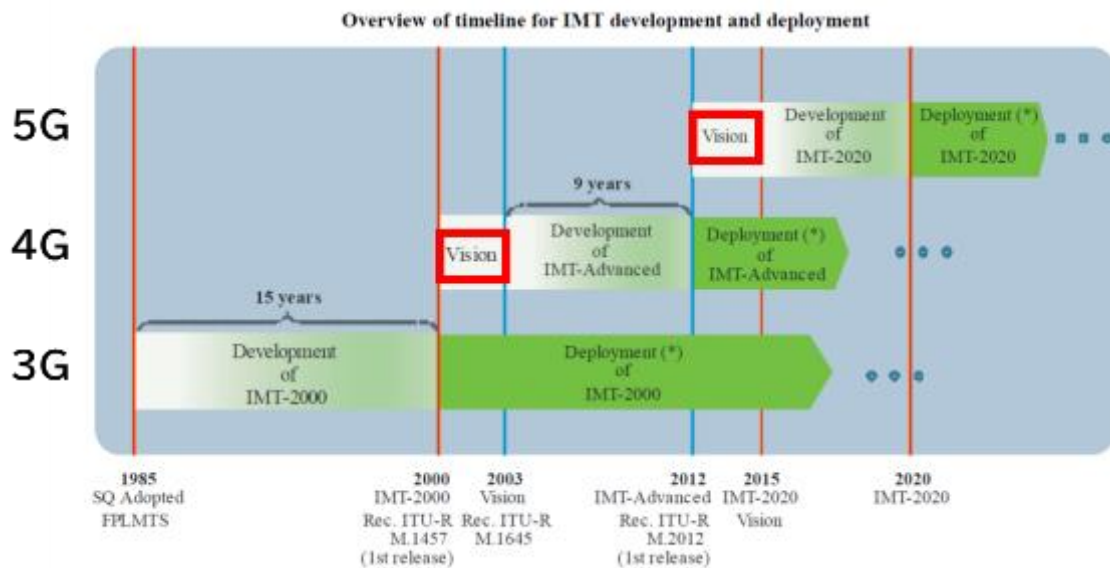


Figure 6.1: Processes in 3G, 4G and 5G (ref. ITU-R Recommendation M. 2083 Figure 1 - The red frame of Vision and 3G, 4G, 5G on the left side were added by NICT).

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

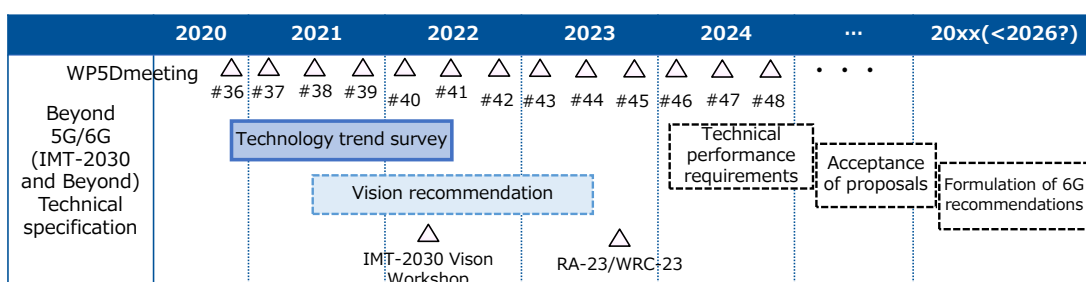


Figure 6.2: Agreed standardization process at the 34th WP5D.

Figure 6.3: (Removed in English version)

## 6.2 National Project for Beyond 5G/6G Research and Development

In the “Beyond 5G Promotion Strategy - Roadmap to 6G -” announced by the Ministry of Internal Affairs and Communications in June 2020, activities up to the introduction of Beyond 5G/6G around 2030 are described in two phases: the “Proactive Action Phase” and the “Acceleration Phase.” As part of the Proactive Action Phase, the Beyond 5G R&D Promotion Program is strongly supported by the government, in accordance with the R&D policy published in January 28, 2021 by the Ministry of Internal Affairs and Communications, in order to focus on strengthening R&D capabilities for technologies that are advanced in Japan and technologies that are indispensable for Japan to have.

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

- Beyond 5G Function Realization Program
- Beyond 5G International Joint R&D Program
- Beyond 5G Seeds Creation Program

Of these programs, the Beyond 5G Function Realization Program, which conducts R&D on core technologies that are necessary and strategically important for the realization of Beyond 5G/6G, will call for individual R&D themes in sequence using the following two schemes from the R&D Themes Candidate List (1st edition) (Figure 6.4) of the Beyond 5G Function Realization Program shown in the R&D Policy. We expect this list to be updated in the future.

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

In the Beyond 5G Function Realization Program, we plan to gradually establish key technologies from around 2025 and reflect them in international standards for 3GPP, etc.

## Key Features for Beyond 5G

2

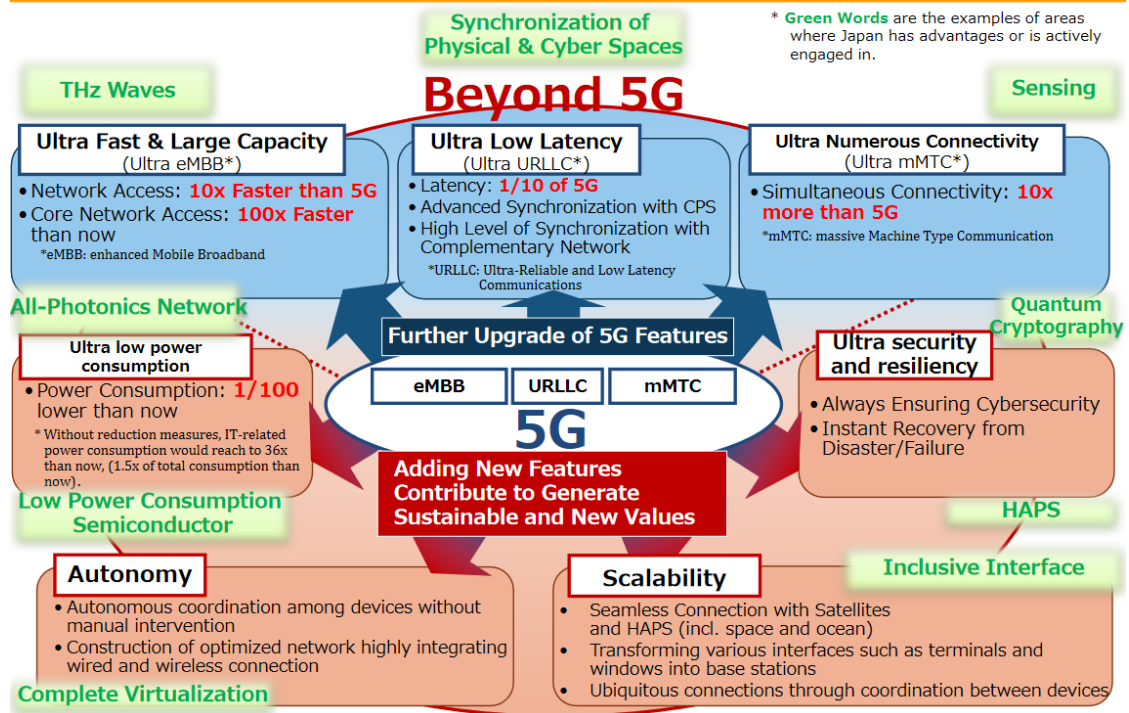


Figure 6.4: R&D Policy of Beyond 5G R&D Promotion Program, January 28, 2021.

( [https://www.soumu.go.jp/main\\_sosiki/joho\\_tsusin/eng/presentation/pdf/Beyond\\_5G\\_Promotion\\_Strategy.pdf](https://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/presentation/pdf/Beyond_5G_Promotion_Strategy.pdf) )



## Chapter 7: Conclusion

In this White Paper, we assumed three scenarios based on the views of social life around 2030 to 2035. By backcasting from the future society described in these scenarios, we summarized Beyond 5G/6G concepts, use cases, and essential technologies. A roadmap for R&D was also presented. The White Paper also discusses the open platforms and deployment strategies required for the R&D, and outlined its overall picture.

In order to develop, implement and utilize the necessary future technologies in order to realize the depicted social life and world view, it is necessary to take into account technological evolution not only in the information and communications field but also in a wide variety of fields, and to discuss with various stakeholders in order to achieve the goals. We will continue to discuss and revise this White Paper.

## Acknowledgment

The NICT Open Summit 2020 was held for two days, January 20–21, 2021, to present this White Paper. and discuss with the following experts. 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.

Prof. NAKAO Akihiro (University of Tokyo)

Prof. Andreas DENGEL (Deutsches Forschungszentrum für Künstliche Intelligenz)

Prof. Matti LATVA-AHO (University of Oulu)

Dr. Onur ALTINTAS (Toyota Motor North America R&D)

Dr. WAKIKAWA Ryuji (SoftBank Corp.)

Dr. KONISHI Satoshi (KDDI Research/KDDI CORPORATION)

Prof. SAMPEI Seiichi (Osaka University)

Dr. NAKAMURA Takehiro (NTT DOCOMO)

Dr. MATSUI Yasunori (Sony Corporation)

Authors (in alphabetical order)

ABE Yuma, ANDO Hiroshi, ASAEDA Hitoshi, CALLAN Daniel, DOI Miwako, EGUCHI Tomoyuki, FUJII Katsumi, FUJITA Satoshi, FUJIWARA Mikio, FURUKAWA Hideaki, FURUSAWA Kentaro, FUSE Tetsuharu, HACHISU Hidekazu, HAGIHARA Yuichiro, HAMADA Rira, HANADO Yuko, HARA Motoaki, HARA Shinsuke, HARAI Hiroaki, HASHIMOTO Yasuhiro, HIROTA Yusuke, HOSAKO Iwao, HOSOKAWA Mizuhiko, IBUKA Kazuo, ICHIKAWA Ryuichi, IDO Tetsuya, IIDA Ryu, IMAI Koji, INOUE Daisuke, IRIMAJIRI Yoshihisa, ISHIJIMA Hiroshi, ISHIZU Kentaro, ISOGAI Mitsuho, ITOH Hiroshi, JOACHIMCZAK Michal, KAN Tomoshige, KANNO Atsushi, KASAMA Takahiro, KASAMATSU Akifumi, KAWAMURA Seiji, KAWASAKI Hikaru, KOJIMA Fumihide, KOJIMA Syoichiro, KOMADA Genki, KOTAKE Hideaki, LIU Juan, MATSUDA Takashi, MATSUMOTO Atsushi, MATSUMURA Takeshi, MATSUZONO Kazuhisa, MIURA Amane, MIURA Ryu, MIYAZAWA Takaya, MIZUNO Maya, MOROHASHI Isao, MURAKAMI Homare, NAKAGAWA Takuya, NAKAZAWA Tadateru, NARUSE Yasushi, NEZU Hiromi, NISHINAGA Nozomu, OH Jonghoon, OKURA Takuya, OODO Masayuki, OTAKE Kiyonori, PYO Chang-Woo, SAITO Yuki, SAKAGUCHI Jun, SASAKI Masahide, SATOH Kohei, SAWADA Kaori, SEKINE Norihiko, SHIGA Nobuyasu, SHOJI Yozo, SUGA Ryotaro, SUGIBAYASHI Kiyoshi, SUMITA Eiichiro, SUZUKI Takafumi, SUZUKI Yoichi, TAKEOKA Masahiro, TAKIZAWA Kenichi, TEMMA Katsuhiko, TERANISHI Yuuichi, TERUI Toshifumi, TORISAWA Kentaro, TOYOSHIMA Morio, TSUJI Hiroyuki, UCHIMOTO Kiyotaka, WAKE Kanako, WATANABE Hiroki, WATANABE Issei, YAMAGUCHI Shingo, YAMAMOTO Naokatsu, YAMAMOTO Shuntaro, YASUDA Satoshi, YOKOTA Yusuke, YOSHIDA Maki, YOSHIDA Yuki, YOSHIMURA Naoko

## Update History

Release 0.9: April 30, 2021

The English text (version 0.9) was translated from the Japanese text (version 1.0) by White Paper staff using TexTra, a machine translation system developed by NICT.

<https://mt-auto-minhon-mlt.ucri.jgn-x.jp/>

Release 1.0: August 31, 2021

English expressions were refined based on the English version 0.9.



Beyond 5G/6G White Paper

Published August 2021

ISBN978-4-904020-20-3

National Institute of Information and Communications Technology

-----  
4-2-1 Nukuikitamachi, Koganei, Tokyo 184-8795, JAPAN

E-mail [nict-idi-wp@ml.nict.go.jp](mailto:nict-idi-wp@ml.nict.go.jp)

URL <https://www2.nict.go.jp/idi/>

Unauthorized copying and replication of the contents of this paper are prohibited.

-----



ISBN978-4-904020-20-3

