NICT National Institute of Information and Communications Technology

Beyond 5G/6G White Paper

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Beyond 5G / 6G White Paper

(English version 0.9)

National Institute of Information and
Communications Technology (NICT)
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Executive Summary

Beyond 5 G / 6 G, 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 optical networks. In cyberspace, a variety of spaces coexist depending on application, and information processing is carried out based on accumulated past data and future forecasts.

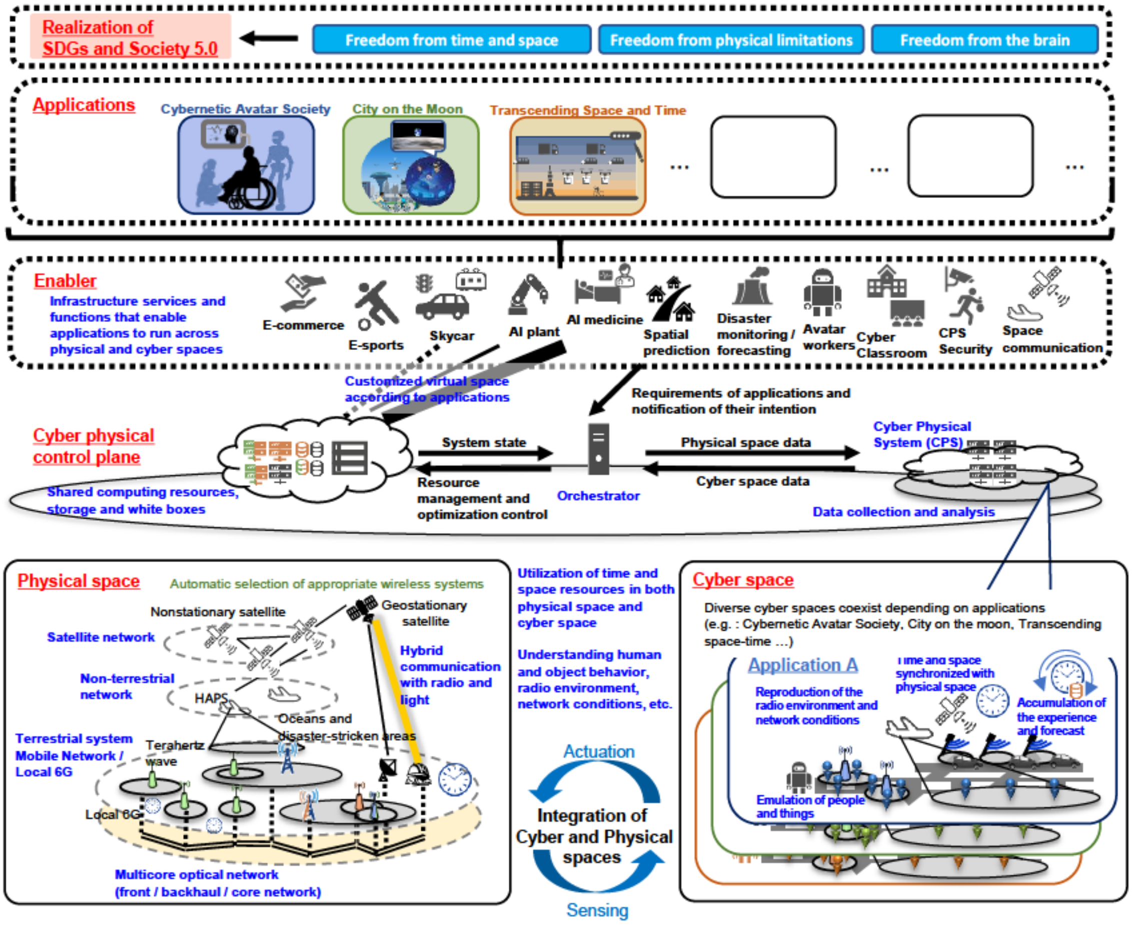


Figure A: Overview of Functional Configurations of Beyond 5G/6G to achieve SDGs and realize Society 5.0 (Figure 2.2 in the text).

In the Beyond 5G/6G era, time and space will be highly controlled in both physical space and cyberspace, and the integration of two spaces will make it possible to do things that have not been possible in the physical space alone. The combination of enablers (Platform services / Basic functions) that can be implemented across the integrated physical and cyberspace 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 the images of the three scenarios: "Cybernetic Avatar Society," which depicts a society in which avatars are highly 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 limitation of space and time is transcended. The roadmap for each scenario is shown in Table C. The second half of the white paper summarizes the elemental technologies and requirements to realize the use cases, the R&D roadmap (Chapter 4), and the deployment strategy

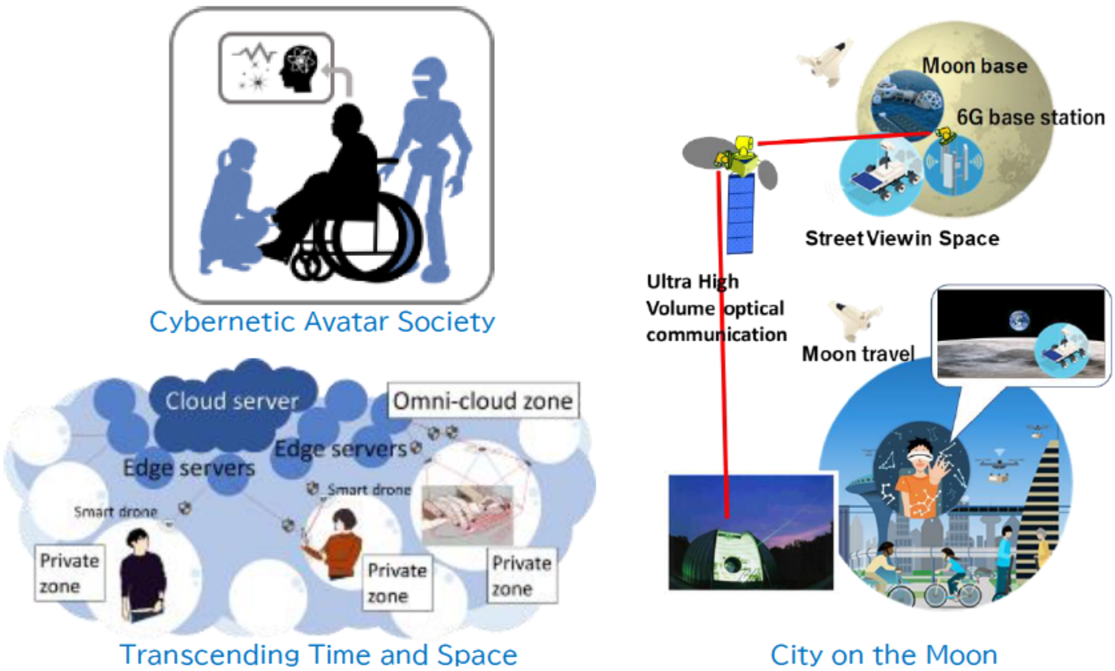


Figure B: Three Scenarios of Beyond 5G/6G that envision Social Life around 2030-2035
(Figures 3.9, 3.16 and 3.23 in the text).

(Chapter 6).

This document is 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 to discuss with many people based on this document, and revise this white paper as needed according to the progress of the discussion.

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
Scenario: City on the Moon (3-2)	▲ Lunar Gateway ▲ Promotion of the Lunar Gateway / ARTEMIS Program		▲ Experimental demonstration	▲ Survey and development of moon
Scenario: 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

At present (March 2021), the social implementation of the fifth-generation mobile communication system (5G) is going into full swing from around 2020, and there are great 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, as in the Internet of Things (IoT).

The Cyber Physical Systems (CPSs), in which people interact with each other, people with things, and things with things through cyberspace, have become significant in various aspects of social life.

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

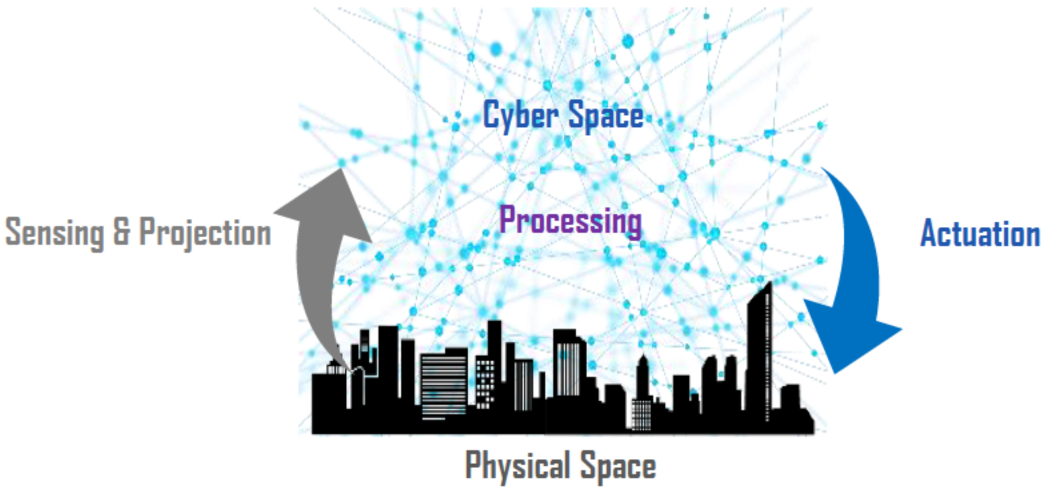


Figure 1.1: Realization of a "cyber physical system" that measures physical (real)-space events (big data), projects them into cyber space, finds solutions (optimal solutions), and actuates the physical space event.

1.1.2 COVID-19 pandemic

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.

In response to the global pandemic of the new coronavirus (SARS-CoV-2), the governments around the world are responding by lockdown and other measures to reduce direct human to human contact as much as possible in order to control infection.

With the exception of essential workers, many people are encouraged / forced to work from home.

Telecommuting enables individuals to connect through cyberspace, enabling them to continue their economic activities to some extent. However, it also recognizes the inadequacy of current information and communication technology (ICT).

The advantages of economic activities through cyberspace are that they are not constrained by realistic time and space, and this is recognized as a new way of activities.

1.1.3 R&D competition for next-generation mobile communication systems

As a fundamental infrastructure of society, the value of communication networks is extremely high, and they are attracting considerable attention from the viewpoint of security.

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

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

White papers have been published by various organizations, forums have been established, and R&D investments are beginning (see "Reference : Various White Paper Consortiums, etc." at the end of this chapter).

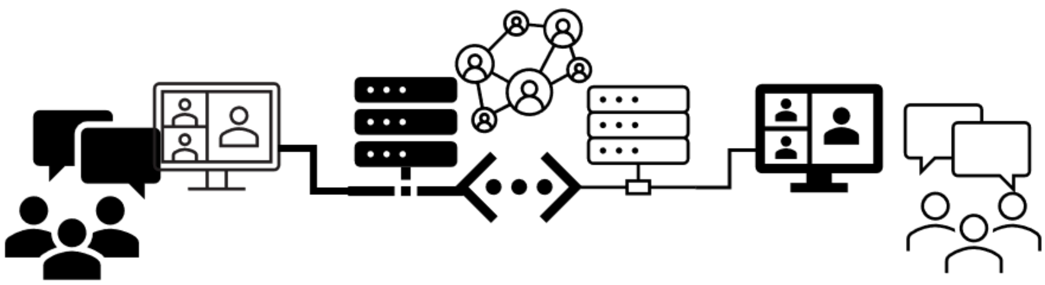
1.2 Purpose and Positioning of the White Paper

This white paper is the results 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 Time and Space," based on the 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), elemental technologies and requirements for realizing them, R&D roadmap (Chapter 4) and 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 the NICT but also various stakeholders to set specific goals and carry out activities to achieve those goals.

In the future, we hope 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

○ NTT's IOWN initiative
https://www.rd.ntt/iown/

● DoCoMo's "DoCoMo 6G White Paper"
https://www.nttdocomo.co.jp/corporate/technology/whitepaper_6g/

● KDDI's "Beyond 5G/6G White Paper"
https://www.kddi-research.jp/tech/whitepaper_b5g_6g/

● NEC's "Beyond 5G John White Paper"
https://jpn.nec.com/nsp/5g/beyond5g/pdf/NEC_B5G_WhitePaper_1.0.pdf

● Samsung's "The Next Hyper---- Connected Experience for All"
https://cdn.codeground.org/nsr/downloads/researchareas/20201201_6G_Vision_web.pdf

○ Oulu University's "6G channel"
https://www.6gchannel.com/
https://www.6gchannel.com/portfolio-posts/6g-white-paper-validation-trials/

(2) Consortium, etc.

● Beyond 5G Promotion Consortium
https://b5g.jp

● NEXT G ALLIANCE
https://nextgalliance.org/

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

2.1 Information and Communication Networks and Nature of Society

Through innovations in information and communication networks

(1) (Inclusiveness) 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 tough and vibrant centered on human, in which safety and security will be ensured and the bonds of trust will not be shaken even in the event of unforeseen circumstances, that is Society 5.0

are expected to be realized.

It is thought that CPS 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 driving the real world based on the results using various actuators. There are great expectations that this system will realize a strong and vibrant society centered on human.

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. 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.

SDN (Software-Defined Network), i.e., network virtualization, will be promoted more than ever before, 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 require us to make 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 the solution of social issues through the integrated use of physical space and cyber space in Beyond 5G / 6G. Beyond 5G / 6G provides highly controlled time and space 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 management and control of 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. It is expected that the Beyond 5G / 6G applications provided in this way will solve increasing social issues in the future.

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

In mobile communication systems up to 5G, frequency has been an important resource to be managed, but time and space have not been sufficiently recognized as resources that should be actively managed. However, time and space are essential resources for advanced applications. Based on the recognition that time and space are important resources for Beyond 5G / 6G, we believe that it is necessary to make effective use of these resources by actively carrying out predictions in cyber space and optimal control of 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 the 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 time and space, the body, the brain, and other areas that were considered difficult to overcome under conventional wisdom.

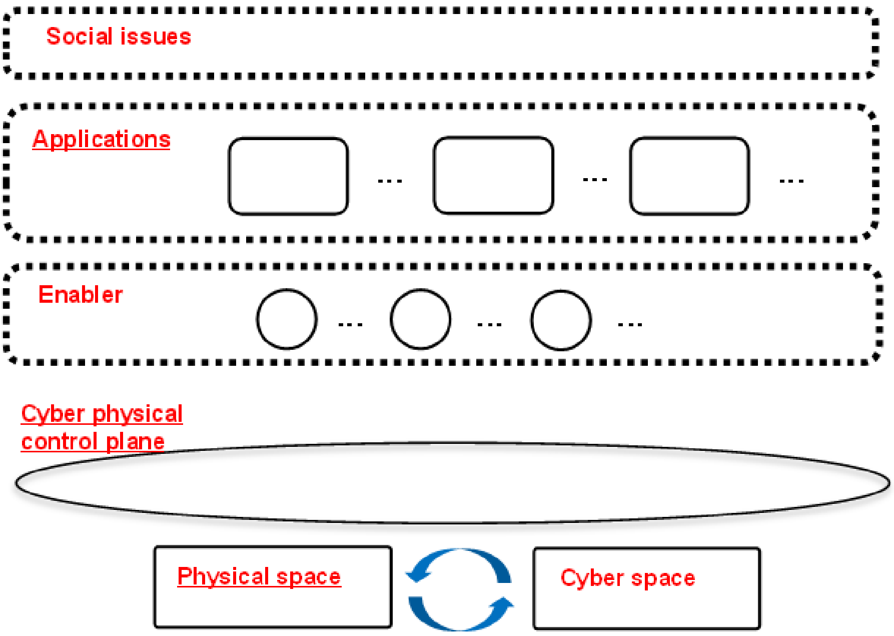


Figure 2.1: Integration of physical and cyber space in Beyond 5G / 6G and solving social issues.

A wide range of applications do solve social issues. As an example of the applications, this white paper presents three scenarios in Chapter 3 : The Cybernetic Avatar Society, City on the Moon, and Transcending Space-Time. Applications are implemented with enablers as f fundamental services / 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 time and space, the monitoring, sharing and optimization of the movement of people and things, the radio wave environment, 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 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

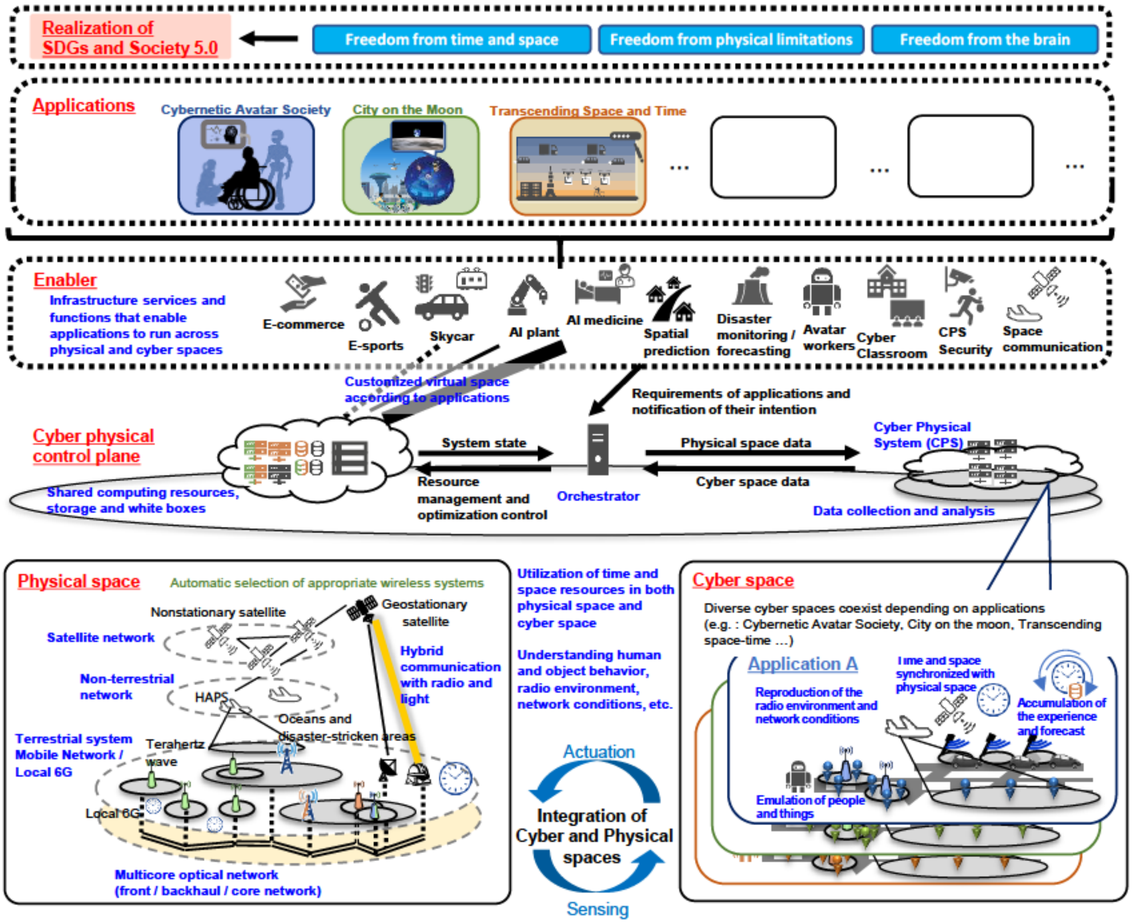


Figure 2.2: Overview of the functional structure of Beyond 5G/6G to achieve SDGs and Society 5.0.

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 the 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 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 the president's go-ahead right away.

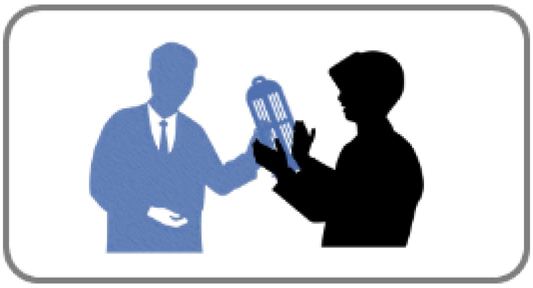


Figure 3.1: Telepresence meeting.

- 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 deepen discussions (UC1-1: Promotion of Mutual Understanding), and our products ware operated simultaneously in each country using time synchronization technology. We are very pleased that we were able to verify the effectiveness of our products in the event of a disaster.

Figure 3.2: Telepresence event.

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

A sudden notice 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 discomfort of delay.

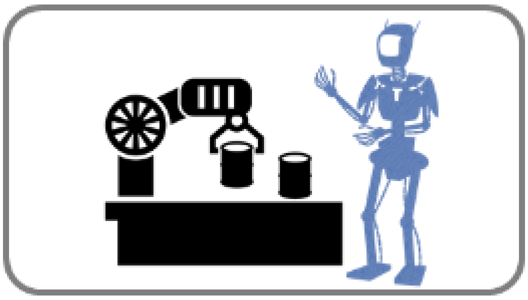


Figure 3.3: Remote response to emergency problem.

- 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 was deteriorating, using 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 son's class visit 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 is set to autonomous alter-ego mode, the AR was used to check the status of the meeting (UC1-3: Telepresence). In 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.

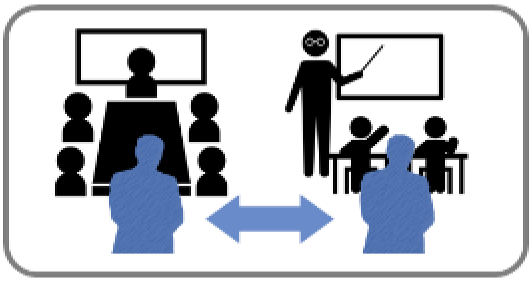


Figure 3.5: Company meeting and Class visit.

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

Petit- XR Mt. Fuji climbing for a refresh (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 an actual mountain-climbing while viewing the beautiful sea of clouds in a live performance, which refresh 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 Turkish language, culture, and customs, so I was worried if I would be able to communicate with each other, but thanks to the

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

simultaneous interpretation system that takes into account each other's cultures, we will be able to conclude 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 county's birth is declining 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 fifteen 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 going to be a test of human wisdom on how to use these technologies.

3.1.2 Use Case Examples 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 mean, taking into account on differences in culture and customs, thus deepening mutual understanding among people with

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

diverse cultures.

[Usage]

- Conceptual translation is carried out by detecting the inconsistent situations in human-to-human conversation.
- Operation is performed using voice, BMI (Brain-machine Interface), multiple sensors, etc.

See Chapter 4 “Key Technologies”

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

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

(T7) AI analytics and dialogue technology based on verbal and non-verbal information

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

(T2) Integrated communication system configuration technology that coordinates 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 soft robot) reads verbal, non-verbal and brain information of elderly and physical challenged and assist 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 and assist the caregiver’s personal care while using the simultaneous

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

interpretation system.

[Usage]

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

[Required elemental technology] * See Chapter 4

(T7) Intuitive measurement, communication and assurance technology

(T7) Real 3D Avatar, Multisensory Communication and XR Technology

(T7) AI analytics and dialogue technology based on verbal and non-verbal information

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

(T2) Integrated communication system configuration technology that coordinates 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 you need it?]

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. It can be instantly moved to overseas manufacturing plants and farms, and remote work can be done intuitively with multisensory information. You can also take care of your parents who are far away while you work. Your avatar is

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

guaranteed not to be fake, and it is secure. It also allows multiple operators to switch 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 elemental technology] ＊See Chapter 4

(T7) Intuitive measurement, communication and assurance technology

(T7) Real 3D Avatar, multisensory Communication and XR Technology

(T7) AI analytics and dialogue technology based on verbal and non-verbal information

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

(T2) Integrated communication system configuration technology that coordinates 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

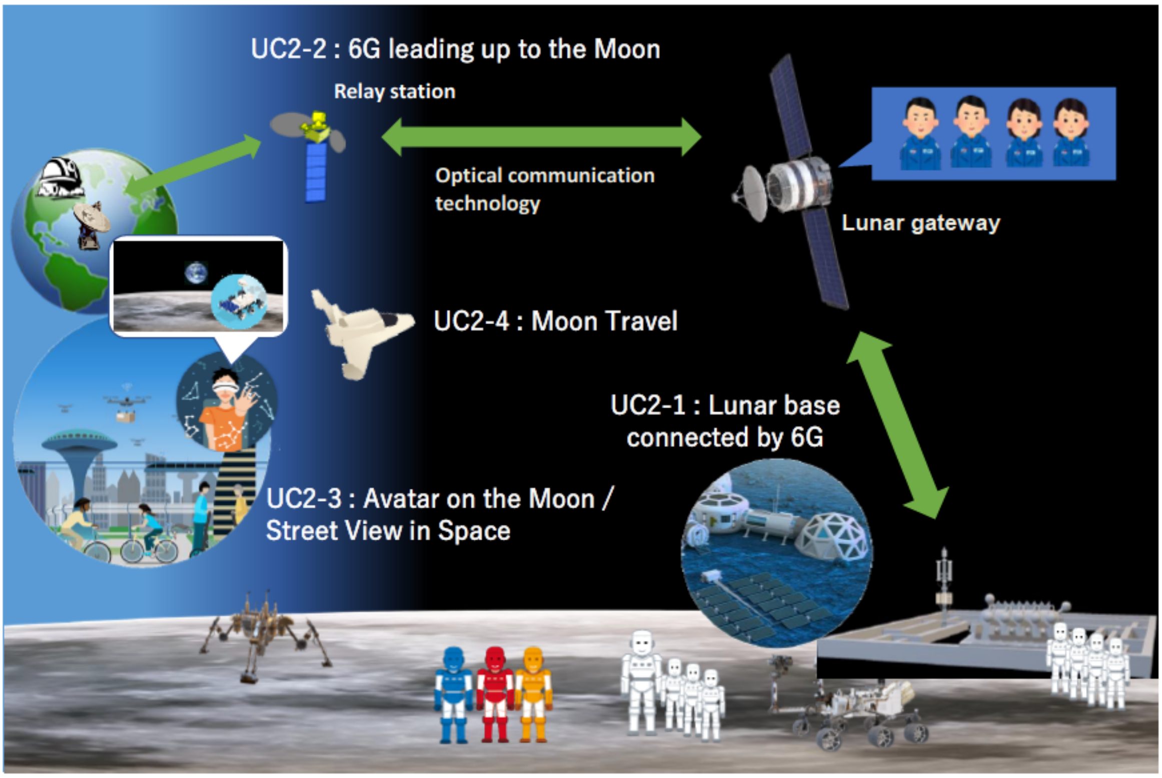


Figure 3.11: Image of Scenario - City on the Moon.

3.2.1 People cultivating the Moon

<at Lunar Gateway>

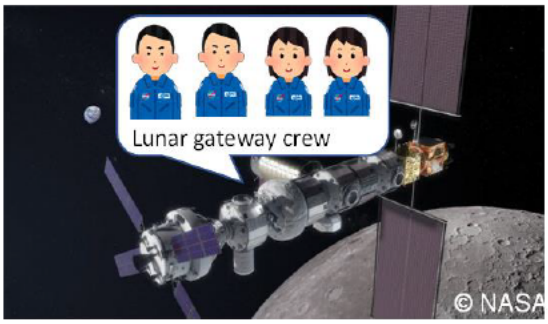


Figure 3.12: Future Lunar gateway.

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

"Today's range is 70 percent larger than the routine exploration range, but aren't we overworking?"

My boss answers with a strong breath.

"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 moved to their own pods and started connecting to the lunar avatar machine (UC2-1, UC2-3). I pour the remaining lemon tea into the exhaust duct and slide into my pod.

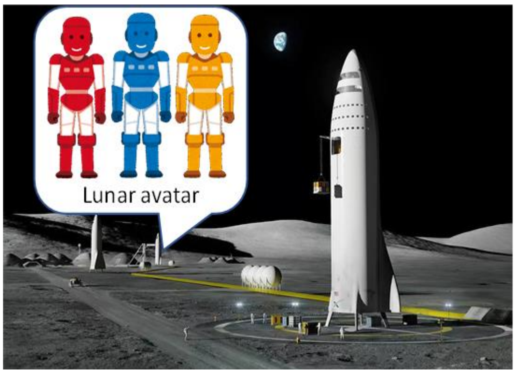


Figure 3.13: Image of Lunar Settlement and Lunar Base Development＊

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

<From Lunar Gateway to Surface>

If you look at the horizon, you can clearly see the boundary between the black space and the gray-brown ground. A scene that 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, feedback the results, and optimize the exploration route.

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

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

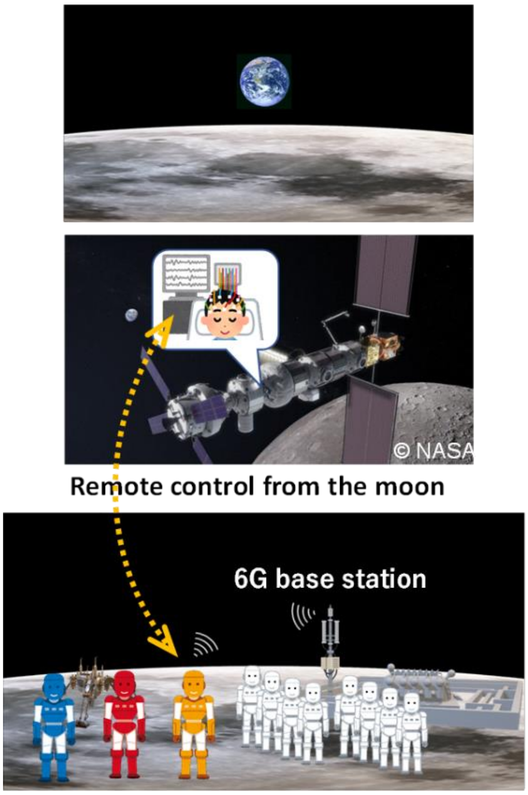


Figure 3.14: Remote work with lunar avatars.

vibrations of multiple large impact drivers is transmitted to the grip arm of the lunar surface avatar and transmitted to my bare hand on the lunar gateway (UC2-1, UC2-3). It makes me feel a little ticklish when I thought that these vibrations had been converted into radio waves before they reached me.

<From the 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 other three 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 make the connection between myself on the Earth and this body (the avatar machine on the Moon). When I arrive at the site, I first check the communication status with the Earth (UC2-1, UC2-2). After checking the communication status, 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 supply 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, but with the high-precision positioning system of 6G base stations.

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 is built on the lunar surface, and the influence of

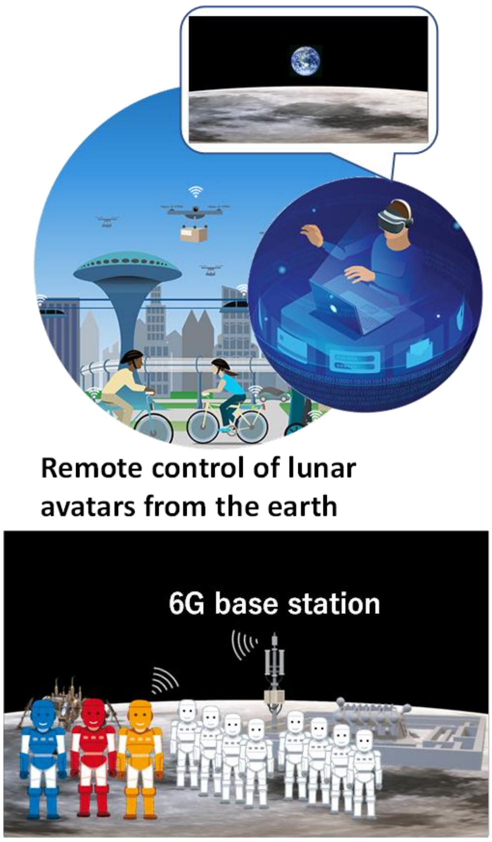


Figure 3.15: Remote work with lunar avatars.

communication delay is sufficiently suppressed by utilizing brain information (UC2-1, UC2-3). As a result, humans and things can silently and safely cooperate on the Moon, far away from Earth.

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

A few moments before it switches to a vision on the Earth, a rover with a 3D camera passed over my sight (UC2-3).

Someone must be enjoying a Moon trip on Earth.

<On the Earth>

Slowly my consciousness returns from the lunar avatar machine to myself on the ground. I stare my palm in my pod on the 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 theater for broadcasting has been completed in B construction area. My nephew is going to the theater soon.

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

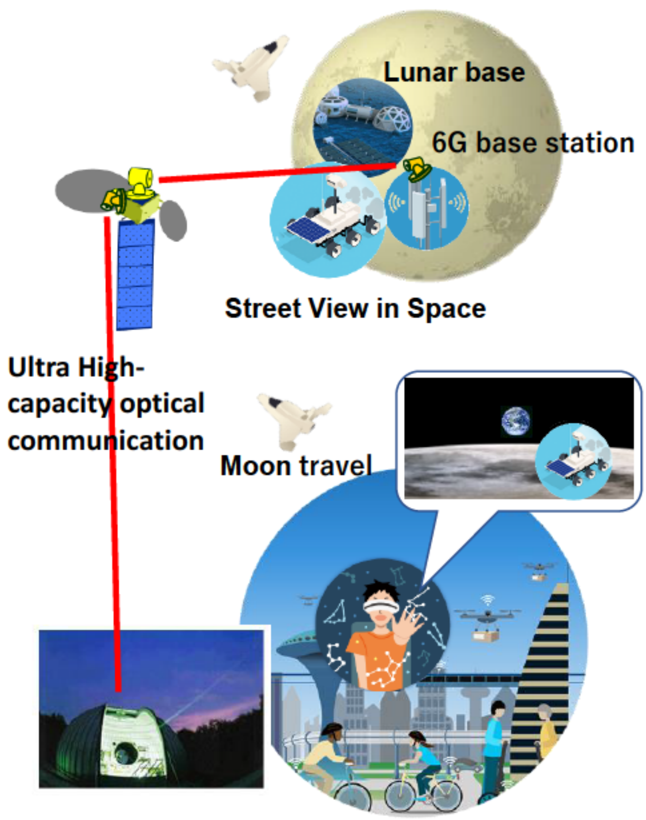


Figure 3.16: Street View in Space to access from the earth.

3.2.2 Use Case Examples 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 require higher reliability and security for human life.

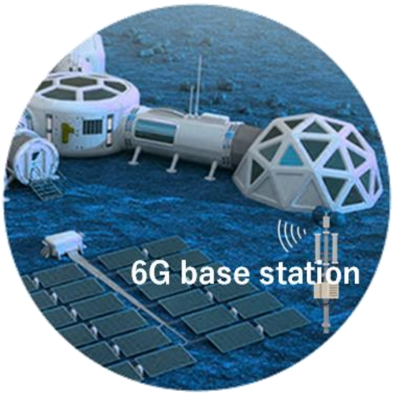


Figure 3.17: Lunar base connected by 6G (UC2-1).

[Conditions for use]

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

[Required elemental technology] ＊See Chapter 4

(T3) Design and allocation of frequency utilization considering propagation on the lunar surface

(T1) Wireless optical communications and terahertz technology are active 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 ground level

(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) Mineral, fuel, buried resources, and Transmission of financial information (encryption, security, time synchronization required)

(T4) Avoiding the effects of meteorites (tracking of debris and changing orbit by laser irradiation)

UC2-2: 6G leading up to the Moon

[What kind of system? Why do you need it?]

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

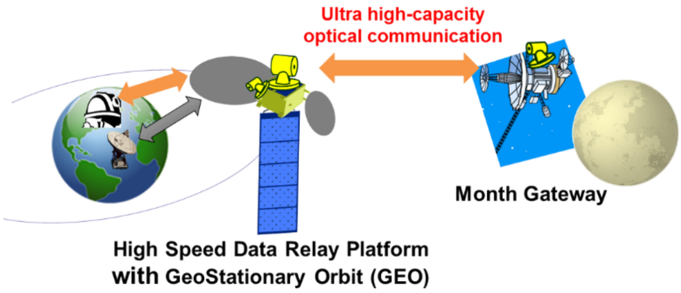


Figure 3.18: 6G leading up to the Moon (UC2-2).

[Conditions for use]

- Communication via the lunar gateway is required.
- Target data transmission speed is 5 Gbps or higher.
- Consider Earth-Moon delay.

[Required elemental technology] * See Chapter 4

(T4) Earth-Moon Ultra High Capacity Optical Communication

(T4) 24 hours, 365 days 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, and 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 a Moon activity by plugging in an avatar on the lunar surface. Enables real-time work at lunar plants, construction sites, and lunar laboratories (material evaluation, charge behavior in materials) while on the ground. It can also contribute to the entertainment (services with charge) such as games and the 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, enjoy real-time images of the universe while we are on the ground with a webcam on the satellites.

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

[Conditions for use]

- The conceptual translation is carried out by detecting the inconsistent situation of the human-to-human conversations.
- Operation is performed by voice, BMI, multiple sensors, etc.

[Required elemental technology] ＊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 delay 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 of the material system in the space resistant environment because the degradation process is different from the ground.

UC2-4: Moon Travel

[What kind of system? Why do we need it?]

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

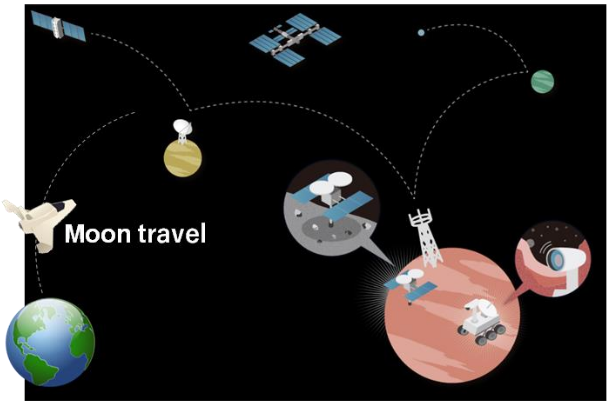


Figure 3.20: Moon Travel (UC2-4).

[Conditions for use]

- Communication lines can be used without any special skills.
- It is necessary to take measures to safely return to the spacecraft even if the communication for passengers is cut off during extravehicular activities.
- It is necessary to take measures against blackouts for when returning to the Earth.

[Required elemental technology] ＊See Chapter 4

(T4) Importance of Space Weather (large impact on human body and equipment)

(T1) ultra-high-capacity wireless communication

(T2, T7) Long-distance teleconferencing

(T2) Requires low latency

(T6) Security Considerations Required

3.3 Scenario 3 – Transcending Space and Time

3.3.1 Creative and Active lifestyle

<Father and daughter>

My youngest daughter is very active and I can't take my eyes off her even at the park. While looking at 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 crashed into a pile of sandbox. I noticed my wife's camera drone near my daughter. My wife can't seem to be keeping her eyes off her daughter. She is supposed to be on a business trip until today, but it looks like she is connected to the smart drone system to check it out (UC3-3). "She never trusts on me."

<First son>

The teacher's lesson through the glass monitor is enthusiastic. 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, and I stop dancing, and I check the 3D feedback images while changing the viewpoint. The dances of my friends are superimposed on the images of myself (UC1-3). "Hmmm, Well, looks like I have a talent in dance."

<Second son>

My brother seems to have started a dance lesson upstairs. The rattling noise is loud. It is my brother's turn to cook today, but I decided to take over. It's fun to be able to create new menus with Skill Learning Assist (apparently the teacher is an old lady in 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 while I'm in there. What's his favorite?"

<Grandfather and father>

My father is a local charismatic hairdresser. These days, he opens his stores only when his clients ask him to (UC1-3). Today was the celebration of my father's 77th birthday (It calls "Kiju" in Japanese). It was exciting just like a talent show, with regular customers and old staffs coming to celebrate. His hobby was cycling and fishing, and he got a suntan. “Stay well, granpa.”

<With Family>

After finishing the board game, the children began to breathe sleep. My wife also started to doze off, rocking her body back and forth like rowing a boat. Thank you for your business trip. My second son made Inarizushi (sushi wrapped in fried tofu), but I wonder where he knew my father’s favorite food. Seeing someone’s sleeping faces made me feel sleepy too. I switched to automatic navigation mode and stretch out myself. The gliding skycar’s interior is really quiet (UC3-1). 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 goes 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, I see a city with countless rivers branching and flowing emerges from the haze. As I look closely, I can see the river branches 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 will be 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, what is shining in the vast red pine forest is work drones. 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, a part of the mountain collapsed, and the spreading red pine forest has many lines of reddish-brown soil peeking out. 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 into battery. After a few minutes of safety checks, the staff took out relief supplies from my backpack. I heard a cheer from a distance.

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

3.3.3 What are full of 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. The physical keyboard is not there. 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 his bicycle (UC3-3). He is seventy-seven years old and still going strong. It’s about time for me to start teaching at a university abroad. 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 realized now that this is why he asked me the day before yesterday about his grandfather's favorite food. A long, slender finger with a casual look at my palm. 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 bit!” There is no reply. It must be a lecture time, I'm 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 realized the rain cloud radar alert and tried to return home (UC3-2), and a ray of light traced the sky toward the mountain where the large landslide had occurred (UC3-1).

3.3.4 Use Case Examples and Key Technologies Required for Implementation

UC3-1: Vertical flow of people, things, and information

[What kind of system? Why we you need it?]

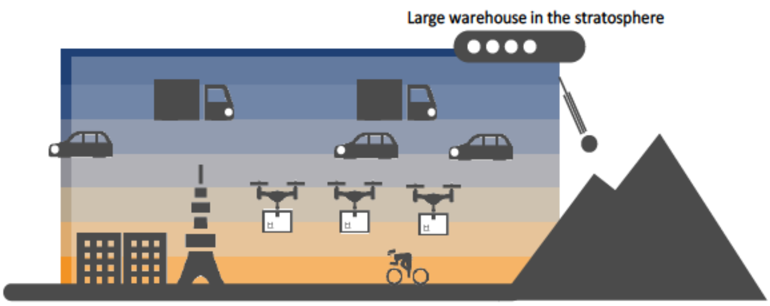


Figure 3.21: Vertical-passenger flow, logistics, and experiential

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 we try to move three dimensionally in space, we cannot rely on 2D maps, and three-dimensional navigation is essential. And if we're carrying people or heavy objects, the navigation must be extremely reliable. In addition to the conventional

Global Navigation Satellite System (GNSS), it is important to multiplex the positioning and navigation systems by assisting a large number of base stations that enable edge computing, and increasing the stability and accuracy of the clock and inertial sensor of skycar.

[Conditions for use]

Building invisible but solid "roads" in space means the development of highly accurate space-time synchronization technology and spatial and frequency multiplexing of positioning base stations. Of course, it is 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 elemental 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 poses a difficult problem to solve in facing of population decline. In some cases, on-the-spot human judgement alone may not be an optimal solution. A high-density precipitation sensor network that can provide accurate and wide-ranging information on help to 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 important to enhance the flood control function of the forests. By synchronously controlling

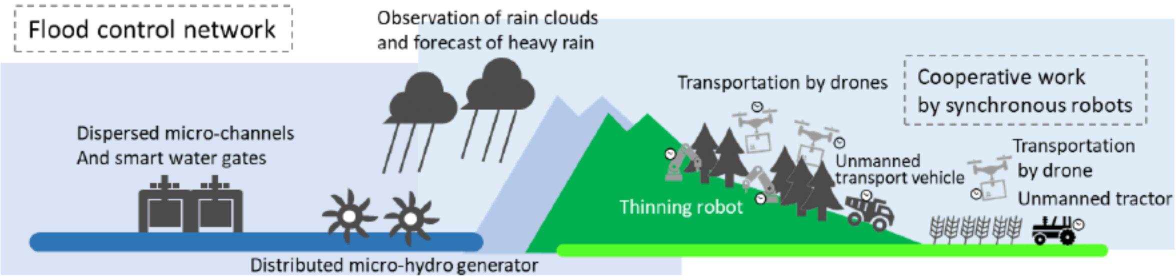


Figure 3.22: Resilient village forest (Satoyama) (UC3-2).

multiple unmanned robots and efficiently carrying out thinning operations, forests are maintained in ideal conditions. This cooperative work of robots can also be deployed to agriculture as well as to the maintenance and management of "Satoyama."

[Conditions for use]

By creating a large-scale network of flood forecasting, evacuation of residents, dam discharge, and control of sluice gates in various irrigation channels, which have not been sufficiently coordinated, we can propose city planning that is 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 and maintain "Satoyama" by improving the efficiency of farming.

[Required elemental technologies]

(T5) Robot Group Coordination by Space-Time Synchronization
(T6) Encryption and security technology
(T6) Strengthening 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 Gate Way

[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 the cloud resources. The omni-cloud provides us with computing resources, information resources, communications resources, and even power resources. What will be important is 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 your personal information.

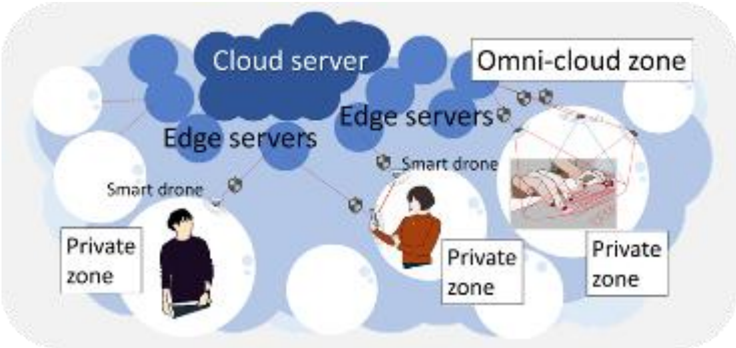


Figure 3.23: Omni Cloud Gate Way (UC3-3).

[Conditions for use]

High-precision positioning is realized with an ultra-high stable clock and the transmitted radio waves drones. By combining images among multiple drones whose posture is controlled by high-precision gyroscopes, the location of the user is also identified, and the service is provided by video and audio, etc. It will also be possible to reallocate resources more efficiently by redistributing security levels locally and dynamically according to usage.

[Required elemental technologies]

(T5) Ultra-High Stability 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 as summarized in Table 4.1 that support the use cases.

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

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

4.2 Outline of technology

4.2.1 Ultra High Speed & High Capacity Wireless Communications

T1.1 Terahertz wave

① Technology: The word "Terahertz" is generally specified as 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.

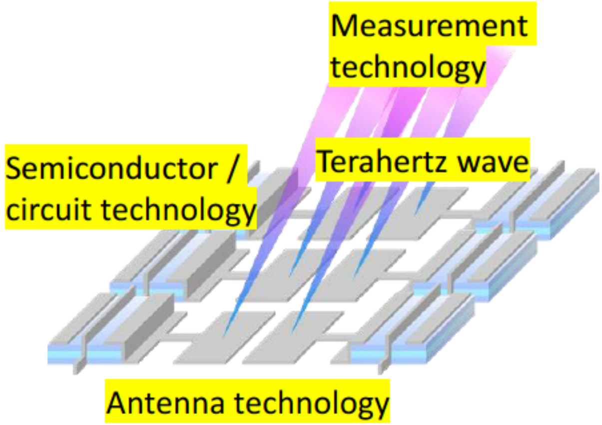


Figure 4.1 Element technologies for handling terahertz.

② Purpose: Since the frequencies of terahertz waves are an order of magnitude higher than that typically used for the conventional radio-wave communications, wireless communications with more than 10 times of improvements can be anticipated in terms of both speed and capacity. It has already been demonstrated that wireless transmission of high-definition video such as 4K and 8K is possible. In addition, terahertz waves are also expected to be robust against the radio interference when used for wireless communications due to their unique (short-range and ultra-wideband) characteristics.

③ Background: Technologies for handling terahertz waves have not yet been at maturity. 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 in progress [1] [2].

④ Requirements: The foundations of terahertz wireless communications call for various peripheral technologies related to semiconductor devices, electronic circuits, and antennas, which leads to 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 dimensions of the devices 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 is regarding the optical fiber, which is a thin glass fiber. It is possible to deliver a large amount of data at high speed to a foreign 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 transport.

③ Background: Current optical fiber communication systems provide up to 10 Tbps of transmission capacity per optical fiber [1].

④ Requirements: In order to support the ever-increasing volume of data for the future, basic networks in the 2030s requires 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.

Purpose : In daily life such as an exercise and a shopping, there are many cases where you move a little bit, however the quality of communication is expected not to be dropped even then. To open up realizing a future cyber-physical society in a high level, it is necessary to utilize high-availability, high-flexibility and high-capacity communications while successfully convergence of wireless with optical fiber communications.

② Background : ITU-T White Paper : ITU-T SG13FG-NETWORK 2030 Network 2030 Vision White Paper discusses the needs for Tbps class high-capacity communication as a holographic society.

⑤ Requirements : There is a need for a communication system that enables high-capacity communication from 100 Gbps to Tbps, which is equivalent to 10 to 100 times of 5G, with a low-latency between optical fiber communication sections and wireless communication sections in an area for a dedicated moderate range communication (DMRC) in several tens of kilometers. Additionally, there is a need for a massively integrated device technology for the convergence optical and radio waves, that support to construct this system.

Table 4.2: Roadmap of Ultra High Speed and High Capacity Wireless Communications

	2020 - 2024	2025 - 2029	2030 - 2034	2035~
T1.1 Terahertz wave	Development of Element Technology for Terahertz Band (Device, Antenna Element, Signal Source, A/D conversion)	Integration and multiplexing of elemental technologies for implementation	Terahertz communication Systematization for	Improved functionality (low-power-consumption, improved resolution, smaller size)
T1.2 All-optical network (high-capacity optical fiber communication)	40 Tbps transmission capacity per optical fiber using advanced multi-level modulation technology and broadband optical amplification technology		With the introduction of multi-core fiber technology, each optical fiber has a transmission capacity of 100 Tbps, followed by a transmission capacity of 1 Pbps.	
T1.3 All-optical network (Optical and radio convergence network)	• 100Gbps class optical and wireless seamless transport technology • ~ 80GHz band digital radio technology	• Sub-Tbps class optical and wireless seamless transport technology using free-space optics and terahertz wave (Media-independent and harmonic ICT) • Compact and Massively integrated device technology with convergence optical and radio waves		Tbps class media-independent and harmonic network

4.2.2 Ultra-Low Latency and Ultra-Massive Connectivity

T2.1 Edge computing technology

① Technology: This technology is to use devices embedded in the city and computers in the network to execute ICT services with ultra-low latency and high reliability.

② Purpose: For example, if a computer running a process to avoid an accident at a corner on a cloud far away via network, it will not be able to make it in time, and there is also a problem of communication being delayed by network congestion. And even when it's convenient, you do not want to leak sensitive information including bio-information to external networks or the cloud. Therefore, security is also highly required.

③ Background: European Telecommunications Standards Institute (ETSI) is conducting standardization for edge computing by MEC (Multi-Access Edge Computing) as well as regulation of 5G provision. Network Vision 2030 presented by the Ministry of Internal Affairs and Communications proposes the need for ultra-low latency and high-capacity communications using edge computing. In the white paper of 5G Americas advocates 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 is to control modulation, transmission timing, relay routes, etc. in order to realize high-level actions by wireless devices cooperating according to situations and requirements.

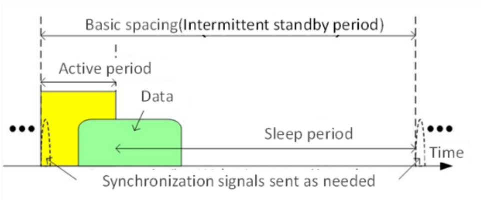


Figure 4.3: Intermittent waiting action for power saving.

② Purpose: This technology is indispensable for various wireless systems including IoT and mono-based systems, and satisfies the following requirements. 1) It adjusts high-speed transmission and robustness in response to the communication environment, and makes the communication efficient. 2) It 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, access 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 st andardized with leadership of NICT. In addition, Wi-SUN, the world' s first certification referring to these standards, has been establis hed, where NICT is a member of the founders.

④ Requirements: It is essential to be able to satisfy requirements from machine's point of view beyond the human category, such as operation for 10 years or more without battery replacement, and to be able to perform autonomous distributed operation to realize a large number of wireless communication devices.

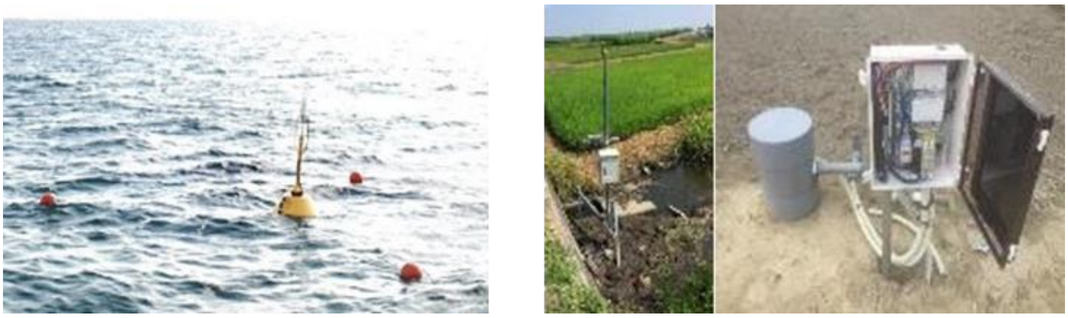


Figure 4.4: Demonstration of low-power operation
(left: fishery, right: farming)

T2.3 Adaptive wireless network application technologies

① Technology: This technology is to realize session management, time synchronization, and 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) Optimize information exchange by prioritizing session management and traffic coordination. 2) Realize communication between wireless devices via wide-area backbone networks, etc., and compensate for time synchronization between wireless devices according to the assumed service. 3) Visualize the connection of wireless devices that make up communication, and an 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 the time synchronization on the application to guarantee the upper layer operation.

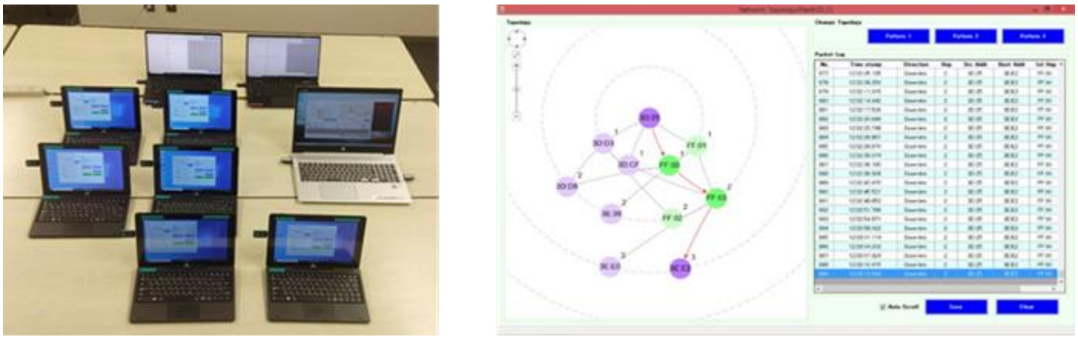


Figure 4.5: App interface for visualizing radio device operation (left : radio devices, right : connection status).

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

T2.4 Technologies for autonomous localization, tracking, and reservation of radio emission space

① Technology: Mobile devices that intend to transmit information using radio waves calculate the minimum necessary radio 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 is to share spectrum resource by predicting the future behavior of mobile devices and making precise reservations (schedules) for the time and space required to use radio wave resources.

② Purpose: By minimizing the physical radio wave emission space, it is possible to simultaneously increase the interference resistance (reliability) and security under the ultra-high-density inter-device communication environment. In addition, by integrating this technology with the technology for predicting the movement of devices in cyberspace, it will be possible to secure communication quality in preparation for future communication congestion.

③ Background: Electronic localization and tracking technology for radio 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 propagation environment at such destinations, so that the optimal radio 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 is to autonomously build M2M (Machine-to-Machine) networks of ultra-multi-hopping relay 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 system that automatically shares 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 even 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. (It can be said to be 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 operations with several hundred to one thousand units have been put into practical use, 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 API (Application Programming Interface) and appropriate user interface for that purpose, 2) to be able to secure and manage resources related to the above, to ensure a certain level of time synchronization and reliability, and 3) to be able to autonomously eliminate the information whose value has already disappeared or the 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 realizes the evaluation of new technology and large-scale system verification in a short time and at low cost by simulating the radio 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 that contribute to the effective use of frequencies and of large-scale systems with several thousand units. The use of 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 emission pattern emulation of beamforming, and 400 MHz band signal processing assuming Beyond 5G / 6G.

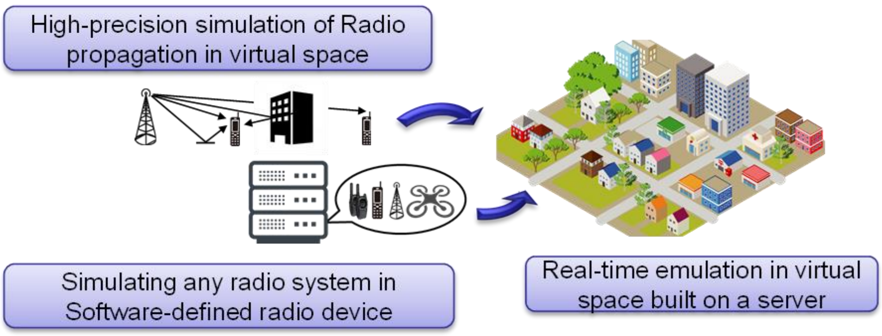
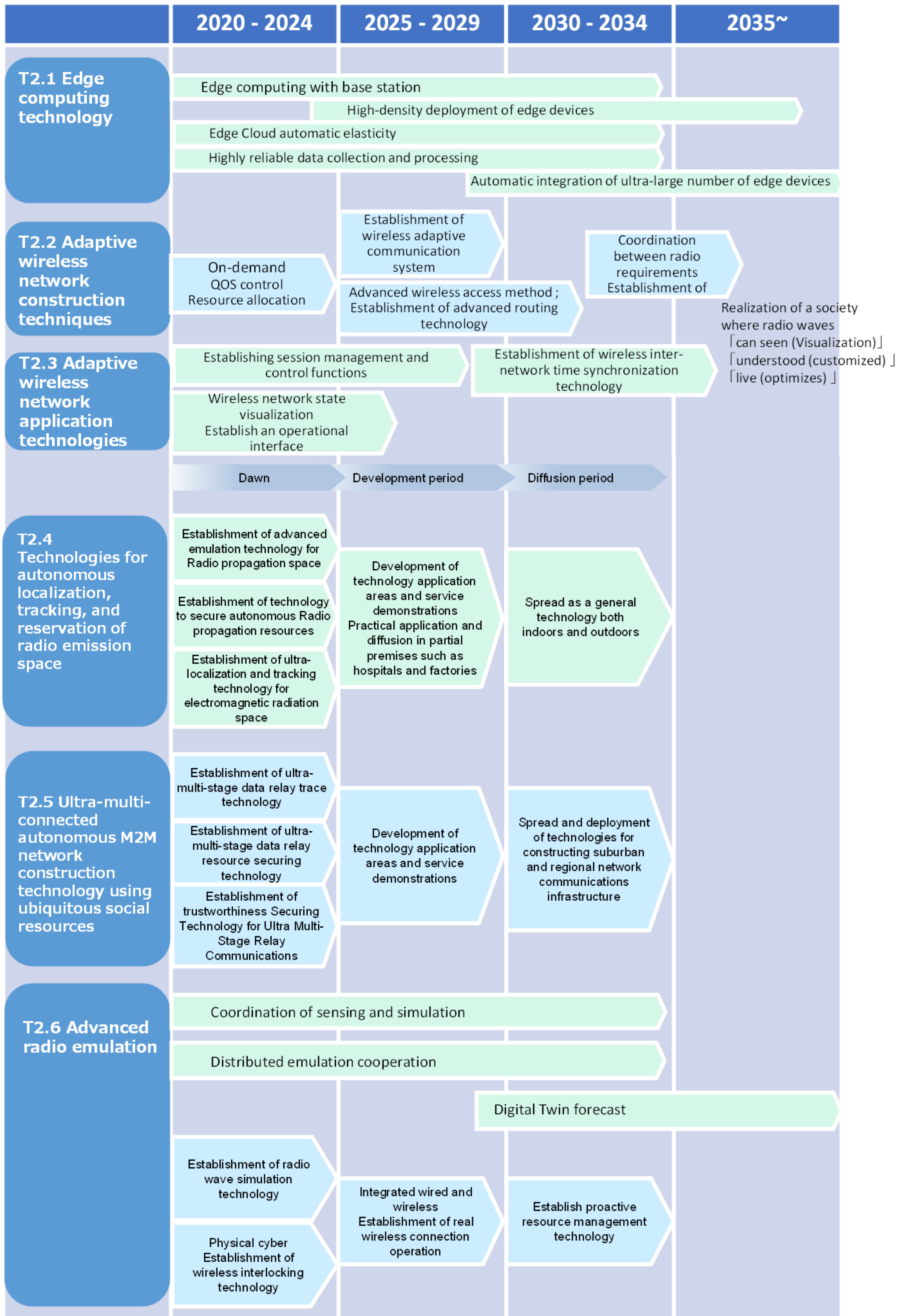


Figure 4.6: Advanced radio emulation

[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 is a networking technology to realize a high sustainability for diverse service requirements in the future. These include 1) network operation full-automation technologies 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 "Network2030" advocated by ITU-T is a competitive research field in the world [1]. In the EU, "6 Genesis" project led by University of Oulu in Finland is ongoing [2], while in Japan, NTT DoCoMo and NEC published white papers on Beyond 5G and 6G in 2020 [3,4]. In the USA, 5G Americas proposes to interwork edge computing and information-centric networking technologies as a future direction in the white paper "5G at the Edge"[5].

④ Requirements: We require network operation automation technologies reducing human operations as much as possible by utilizing open source frameworks, and also require advanced mechanisms 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

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

[3] https://www.nttdocomo.co.jp/binary/pdf/corporate/technology/whitepaper_6g/DOCOMO_6G_White_PaperJP_20210203.pdf

[4] 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 is to allocate frequencies to the mobile operators, as well as to enable 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 database and autonomous operation using new radio access methods in addition to the existing spectrum sharing methods there mobile operators occupant 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 realize software (broker / middleware) that automatically acquires the spectrum resource required for users, visualize spectrum operation, and allocate resources by calculating radio interferences with simulators utilizing dynamic database, block chain, and digital twin technologies.

[1] https://www.soumu.go.jp/main_content/000711788.pdf

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

T3.3 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 system. It is also expected the functions will be customized according to the needs of the location and region.

② Purpose: It has 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 its 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. In the future, coordination with the public network and remote Local 5G is expected. It is important to utilize other technologies such as CPS in order to create a system that maintains customizability and confidentiality while avoiding interference.

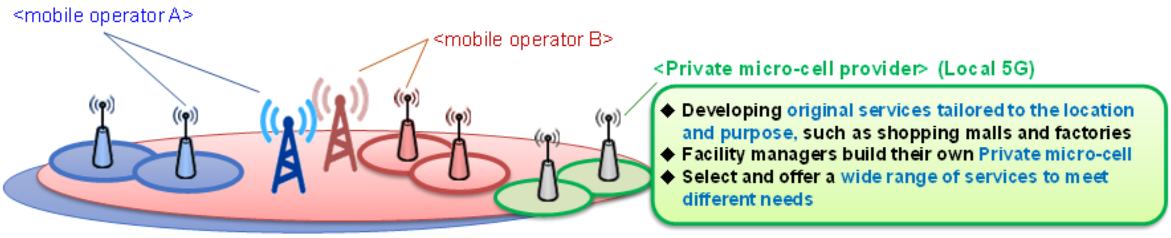
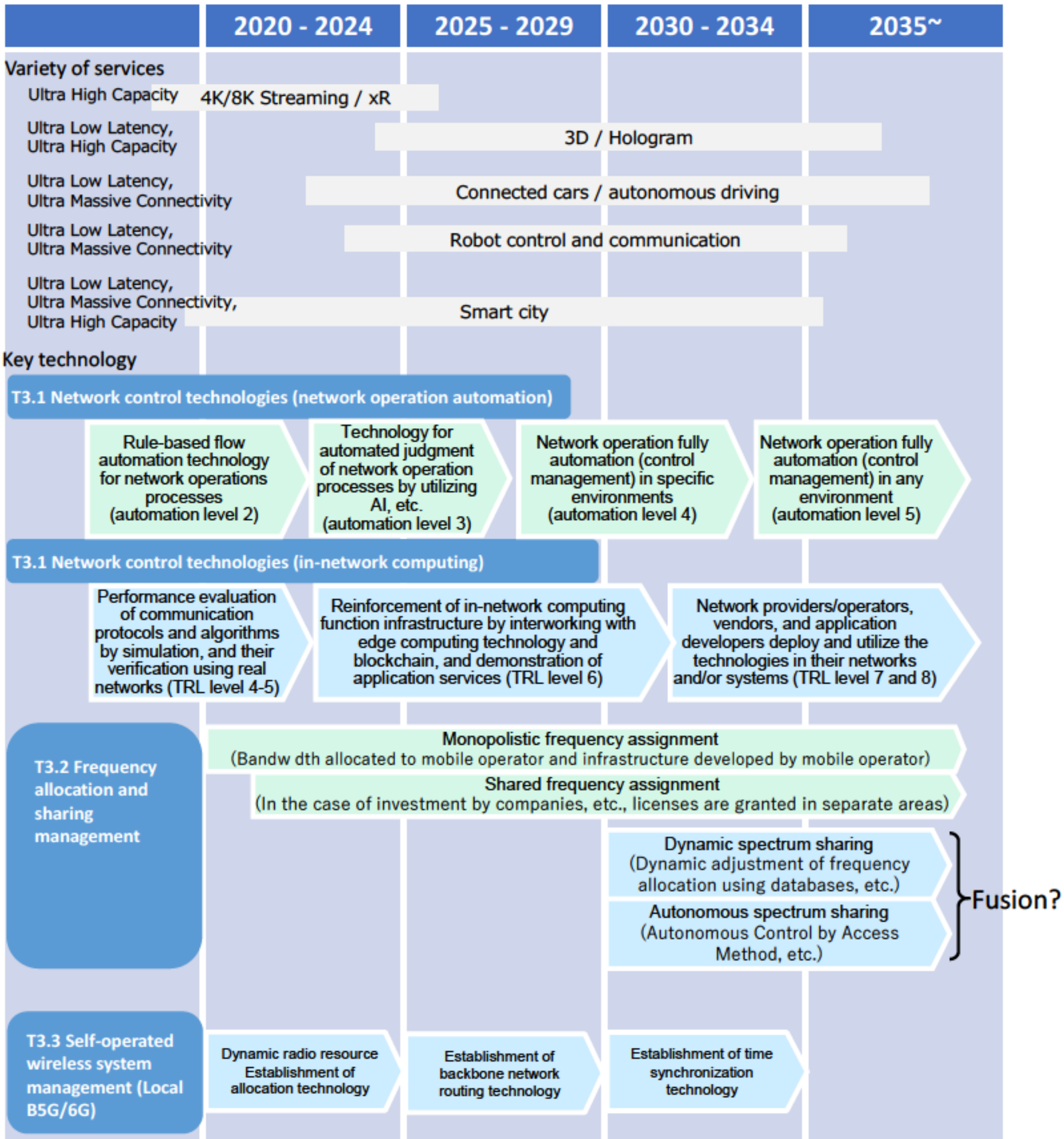


Figure 4.7: Private wireless system management (Local 5G).

[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

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 is for wireless communication system to seamlessly connect from the ground to mobility, high altitude platform (HAPS), satellite and deep space probe in three dimensions.

② Purpose: By making it possible to communicate to all areas, people will be able to have various communications in a future society where environment will be continuously changing.

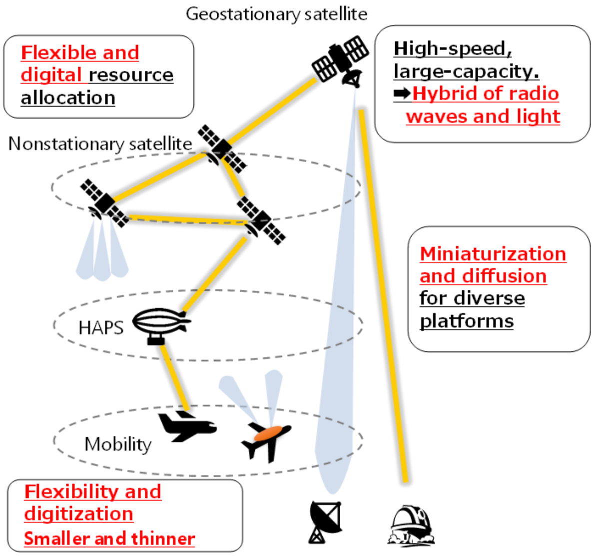


Figure 4.8: Satellite and Non-terrestrial communication platforms and their requirements.

③ Background: As satellite communications have increased in capacity (high-throughput satellites) and delay (low-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 is to realize high-capacity wireless communication technology 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.

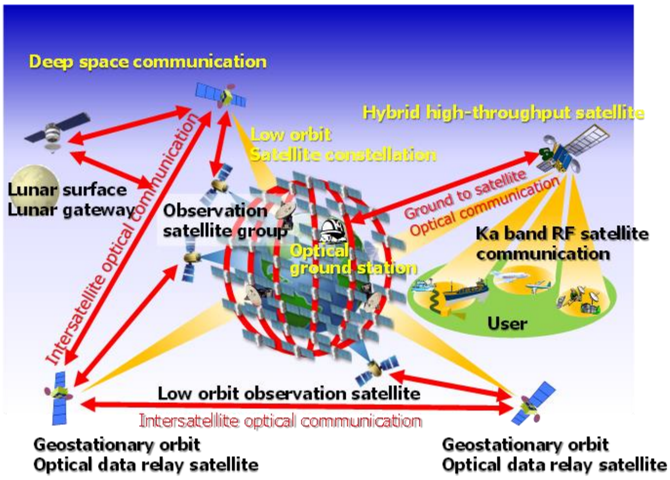


Figure 4.9: Use of optical satellite communications

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 speed of 10-50Gbps class, which is one digit 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 is to provide M2M data transmission and high-speed, high-capacity networks to ships in the ocean.

② Purpose: By sharing high-speed and high-capacity data over the ocean and land, it is effective for automated navigation, efficient and promoted 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 restriction of installation location [1].

④ Requirements: We need to realize a high-speed, low-cost, small-sized broadband communication system in the global area including the arctic region with a view to future unmanned operations.

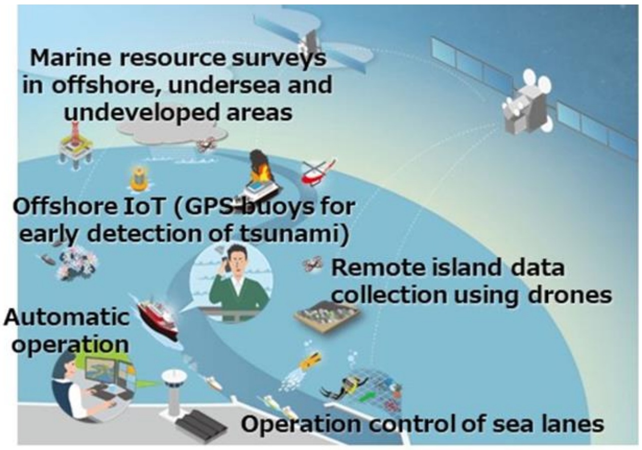


Figure 4.10: Image of maritime communications

[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 is to realize communication under the sea where radio utilization has been difficult. Conventional communication using sound waves has problems of slow communication speed and large propagation delay. However, using radio waves enables high-speed and low-delay communication.

② Purpose: For bridge maintenance, IoT of 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 water resistance.

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

T4.5 Integrated network control

① Technology: This technology is to link 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.

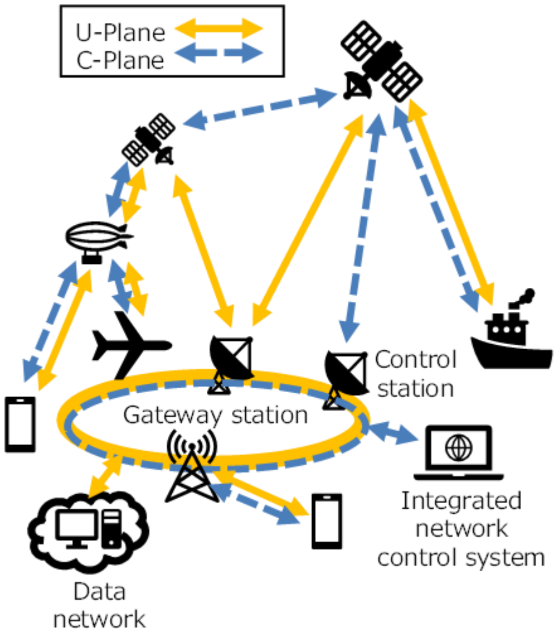


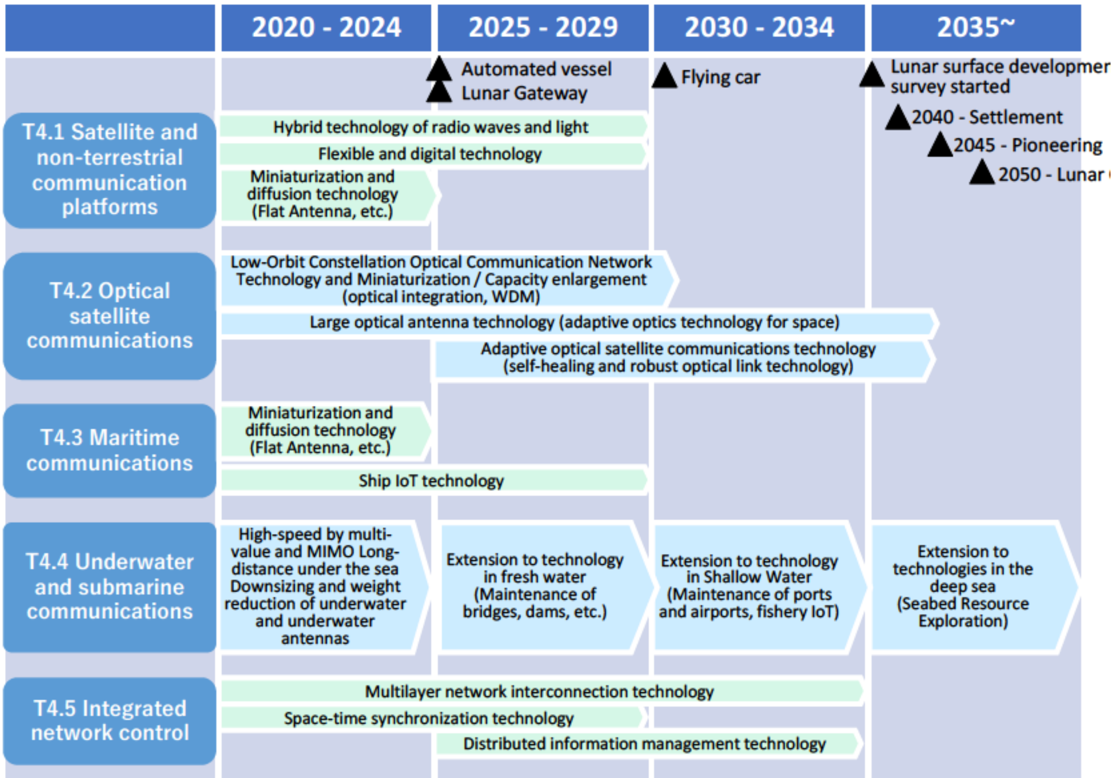
Figure 4.11 : Image of the integrated network architecture

② Purpose: It is possible to build a system that does not interrupt communication anywhere, such as aircraft, ships, remote islands, deserts, mountains, planets, etc., in response to user requests such as 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 inter-satellite resource management functions) are required.

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 and Time Synchronization

T5.1 Wireless time-space synchronization

① Technology: This technology is to realize 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 high-speed shapes by linking multiple robots. In addition, cost-effective, easy-to-use and robust space-time synchronization technology is essential for the diversification of computing resources.

Figure 4.12: Space-time synchronized 3D printer.

③ Background: The 5G Technical Specification (3GPP TS v. 18) requires time synchronization that achieves 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.), beacon, 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 (ref. 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 5m.

T5.2 Atomic clock chips

① Technology: This technology is to provide 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 in 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 amount of computation by multiple computers will come. Synchronizing and tuning the clock makes it possible to use an infinite number of machines as if you were 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 several centimeters square, the market other than dual-use is thin, 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, pp.752.

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

T5.3 Generating & Sharing technology for reference time

① Technology: This technology is to create and share a highly disaster-resistant virtual standard time by using a large number of clocks in a local network, and to realize 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 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 optical frequency standard with high accuracy is advancing in metrology research lab 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 high-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

	2020 - 2024	2025 - 2029	2030 - 2034	2035~
T5.1 Wireless time-space synchronization	Construction of time synchronization network	Time synchronization network security enhancements	Space-Time authentication and service deployment	
	Indoor and outdoor positioning technology	Ground to space applications		
T5.2 Atomic clock chips	Establishment of mass production technology for component parts	Chip-Scale Atomic Clock Trial manufacture and manufacturing	Incorporation into wireless devices	Commercial service deployment
	Formation of corporate consortia and standardization			
T5.3 Generating & Sharing technology for reference time	Development of a method for sharing local time information	Information network application of sharing methods	Operation of a clock management system that is compatible with local and global operations	
	Commercializing Optical frequency standard			

4.2.6 Ultra-Security and Reliability

T6.1 Emerging security technologies

① Technologies: This technology is to create Beyond 5G / 6G infrastructure and its 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 underway in the Cross-miniature Strategic Innovation Promotion Program (SIP) project.

④ Requirements: Hardware (sensors, drones, satellites, etc.) security technology (anti-tamper technology, hardware trojan detection technology, measurement and control security technology, etc.). Security technologies for real data processing software and clouds (vulnerability detection, data-protection technologies, adversarial examples resistant AI technologies, DoS attack protection technologies, etc.). Beyond 5G / 6G infrastructure security technology. 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 is to realize large-scale attack observation and visualization to respond to increasingly diverse and sophisticated cyber-attacks, and to cross-analyze large-scale aggregated information to derive countermeasures.

② Purpose: In a society where Beyond 5G / 6G has been realized, a huge amount 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 targeted for attack increases and an attacker takes over a large number of devices, a large-scale attack activity 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: CAIDA (Center for Applied Internet Data Analysis) in the U.S. and NICT have constructed one of the largest observation networks in the world for darknet monitoring indiscriminate attacks. While active R&D is being conducted around the world on the integration of cyber security and AI, there are technical challenges to automation, including countermeasures, and high interpretability of AI output.

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 realize an information-theoretical 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, it is assumed that more important information will go to cyberspace than now. Quantum cryptography can protect national secrets, including 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 advanced 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 is to maintain 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 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: It is necessary for safe and secure radio usage and EMC conservation.

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, frequency up to 300 GHz are assumed to be used. There is no limit that expects to use the terahertz band currently.

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 a diversified radio wave usage, and to accurately evaluate radio frequency radiation protection guideline from millimeter band to terahertz band in order to extend exposure 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 is to realize the 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 putting a group of robots into a place where human entry has become difficult due to the occurrence of a disaster. At the same time, the network infrastructure that continuously supports the observation and analysis of natural environmental data and the distribution of local information is necessary to deliver security and safety anytime 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 non-continuous changes such as natural disasters, the Government will focus on strengthening resilience through the use of 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 (E2E (End to End) 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 at 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

	2020 - 2024	2025 - 2029	2030 - 2034	2035~
T6.1Emerging security technologies	Hardware security technology	Advanced hardware security technology	Realization and automation of integrated security technologies	
	Software cloud security technology	Upgrading software and cloud security technologies		
	Threat analysis of emerging technologies and development of security technologies			
T6.2 Cyber security technologies based on real attack data	Development of large-scale observation and analysis technology	Real-Time analysis of large-scale data using AI and realization of automatic countermeasure technology		
	Development of observation and analysis technology for emerging cyber attacks			
T6.3 Quantum cryptography	Development and practical application of quantum cryptography / quantum secure cloud	Expansion of applications and markets making technology more functional, smaller and cheaper		
	Development of Satellite Quantum Cryptography	Test satellite launch and demonstration	Launch of Satellite Quantum Cryptography	
	Expansion of network testbed and demonstration with users	With wider network coverage Terrestrial and satellite network integration		
			▲ With the introduction of Beyond 5G/6G in 2030 -The need for ultra-high-speed real-time measurement increases. -Wireless devices are overflowed and the Electromagnetic Compatibility (EMC) problem becomes complicated.	
				▲ Around 2040: High frequencies will end (to reach 3 THz)
T6. 4 Electromagnetic compatibility (Field Measuring Instrument)	Higher frequency, higher speed, and real-time			
	Higher frequencies in Primary standards (development, maintenance, supply)			
		▲ Around 2027 : Radio frequency radiation protection guideline was revised		
			▲ Around 2030 : Standardization of Beyond 5G/6G exposure assessment technology and introduction of human body protection regulations	
T6. 4 Electromagnetic compatibility (Exposure assessment)	Higher frequency (phantom, calculation model) and more complex (number of units, surrounding environment, short-time variation)			
T6. 4 Electromagnetic compatibility (Noise Reduction Technology)	Higher frequency, smaller size (mm-wave → sub-THz) and more complex (number of units, surrounding environment)			
T6.5 Resilient ICT	Emergency information and communications technology (Application to Remote Control of Disaster Response Group Robots)			
	Continuous ICT infrastructure technology (applied to natural environment data measurement and analysis)			

4.2.7 Ultra-Reality and Innovative Applications

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

① Technology: This technology is to control various devices and provide 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 promote social participation by the elderly and disabled people.

③ Background: The social development of BMI systems using invasive and non-invasive methods are starting both in Japan and overseas, particularly for medical applications. However, both methods have issues in 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-high low-power-consumption, ultra-security / reliability, and expandability.

T7.2 Intuition measurement, communication, and assurance technologies

① Technology: This technology is to measure the discomfort felt during work in cyberspace such as teleconferencing and remote control from biosignals including brain information to guarantee the intuition of users.

② Purpose: In cyberspace work such as teleconferencing and remote control, which are rapidly spreading due to the COVID-19 pandemic, the workload on the brain is high unlike in physical space. Therefore, technology that enables intuitive work in cyberspace is necessary.

③ Background: Human-centric value creation is proposed for 5G / 6G [1], but if intuition can be dynamically controlled at the cognitive level of the brain, teleconferencing and teleworking with less load on the brain will become possible.

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

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

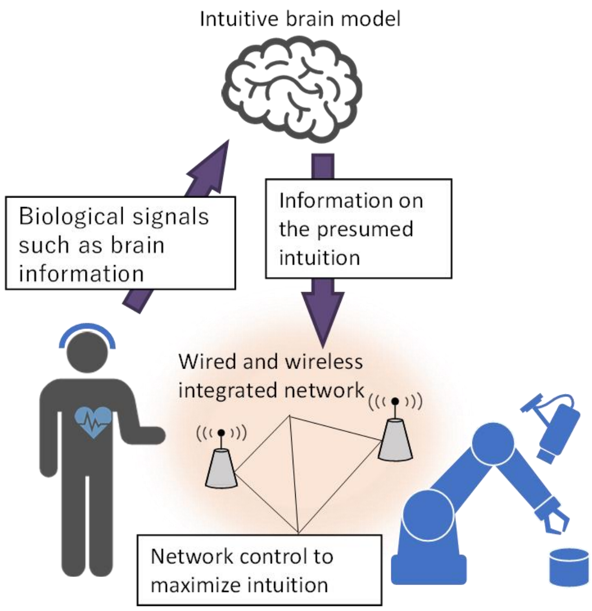


Figure 4.13: Intuitive measurement, communication and assurance

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

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

③ Purpose: By using ultra-reality communication technology, we will enable remote communication that

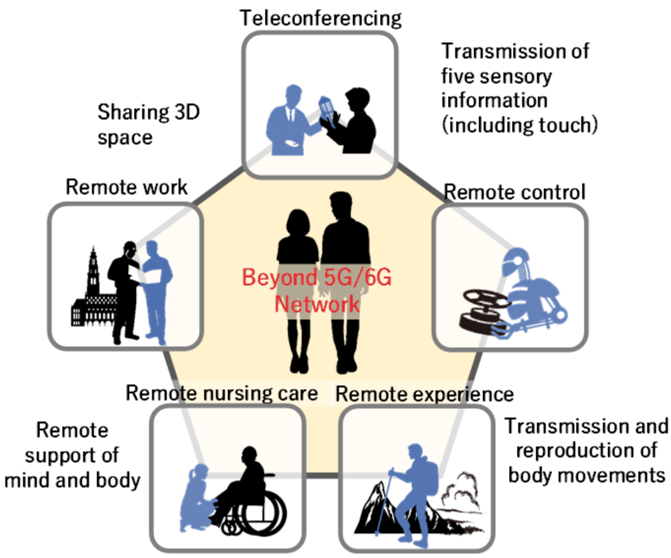


Figure 4.14 : Ultra-reality communication transcending space, time and physical barriers.

transcends space, time, and physical barriers, and contribute to the realization of a super-aged society in which we can dramatically improve labor productivity and realize the richness of our minds.

④ Background: In the post COVID-19 society, for various purposes such as remote medical care, nursing care, education and collaboration, there is a demand for the development and realization of avatars, multisensory communication and XR technologies.

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: The aim of this technology is to analyze and organize large amounts of information and knowledge on the Internet, and also to support users to help them expand and refine their world view, through various forms of multi-modal dialogues using linguistic and extra-linguistic information, based on the analysis results of the information and knowledge on the Internet.

② Purpose: In the midst of a serious shortage of human resources due to the aging of society and a declining birthrate, this technology is necessary to make the most of each individual's abilities. In particular, it is essential for elderly care, R&D, education, and other areas facing serious human resource shortages.

③ Background: Although AI speakers are increasingly used among ordinary households and the accuracy of machine reading comprehension 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 is to convert between different languages to establish communication between Japanese and foreigners with good time efficiency. To the extent necessary for that, the context and extra-linguistic information are also referred to and the 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 live without division 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 ' s dominance is secured with a public-based framework represented by translation banks [1].

Figure 4.15: Secure Remote Simultaneous Interpretation

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

④ Requirements: Hardware and networks that enable parallel execution of single-device learning and cloud-based learning with low latency will enable ultra-high-precision model learning tailored to individual users for the first time.

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

T7.6 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: Creation of ultra-precise environmental map 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 over the sky freely from inside to outside of the visual observation by an automatic control program. It is also known as a flying smartphone and a 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 it will develop into a flying car that will be the 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 our overall social activities, which is necessary for the realization of an eco-system through energy conservation and a new society resistant to virus infection.

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 invisible 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. R&D in Europe, the United States, China, South Korea, and other countries conduct 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 fusion 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~
T7.1 Brain information reading, visualization, and BMI technologies	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
T7.2 Intuition measurement, communication, and assurance technologies	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
T7.3 Real 3D avatars, multisensory communication, and XR technology	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.
T7.4 AI analysis and dialogue technology based on verbal and non-verbal information	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
T7.5 Simultaneous interpretation, paraphrasing, and summarization technologies for multiple languages	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
T7.6 automatic operation	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)
T7.7 Drone	Demonstration of multimultihop 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

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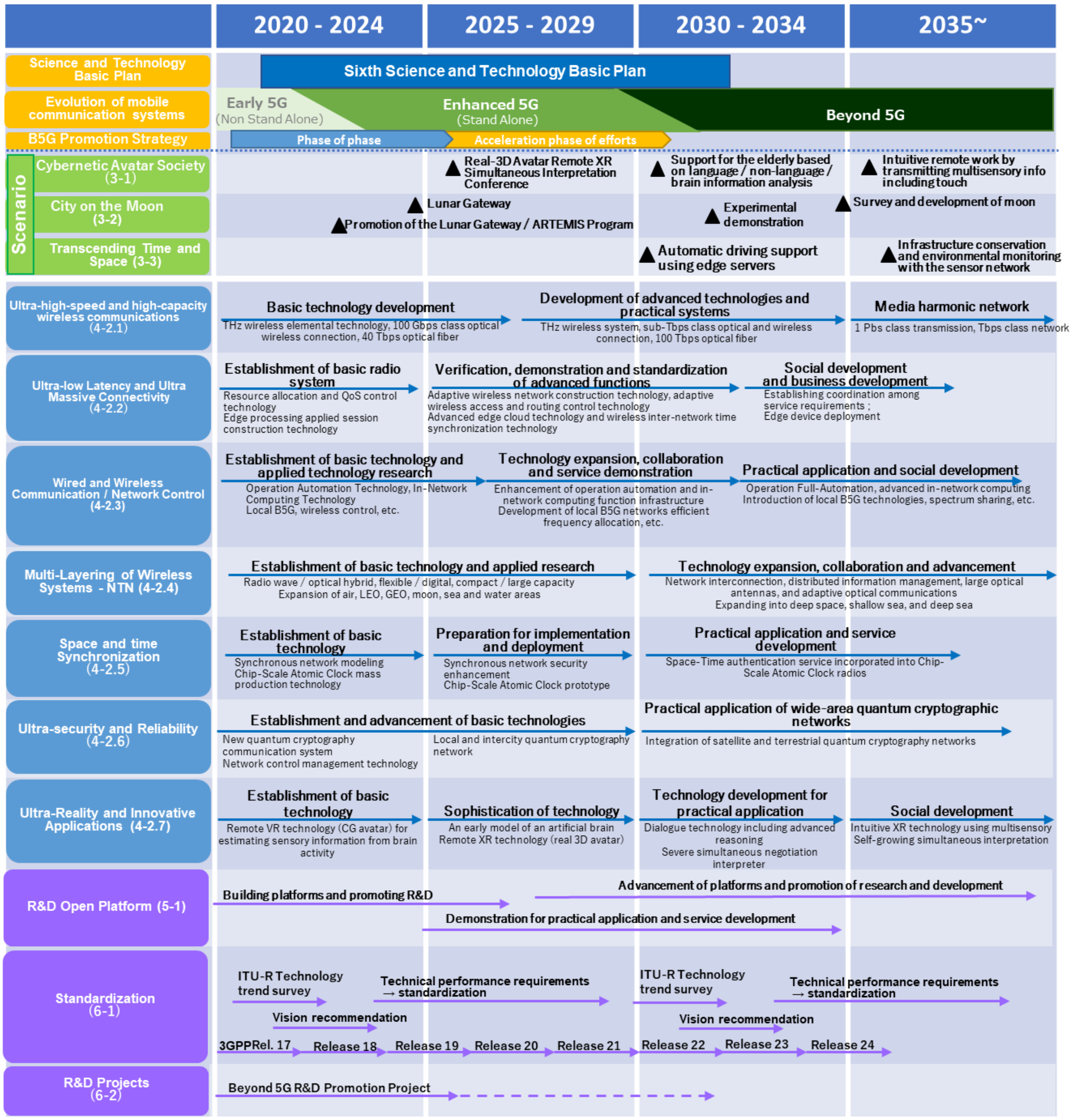
4.3 R&D Roadmap

Chapter 4 presents a separate roadmap for each of the elemental technologies. Table 4.9 shows a summary of 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



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. It mentions about 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 elemental technologies that Japan should focus on for a limited period of time. In order to effectively promote R&D of cutting-edge elemental 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 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.

In response to the above, the NICT, which specializes R&D in the information and communications field, will develop new Beyond 5G / 6G 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 formation to promote open RD 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 will be 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 preparing the survey result; Future Technology Trends, the first step in the standardization of Beyond 5G / 6G. 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 recommendation of 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. The consortium 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 NICT's 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.

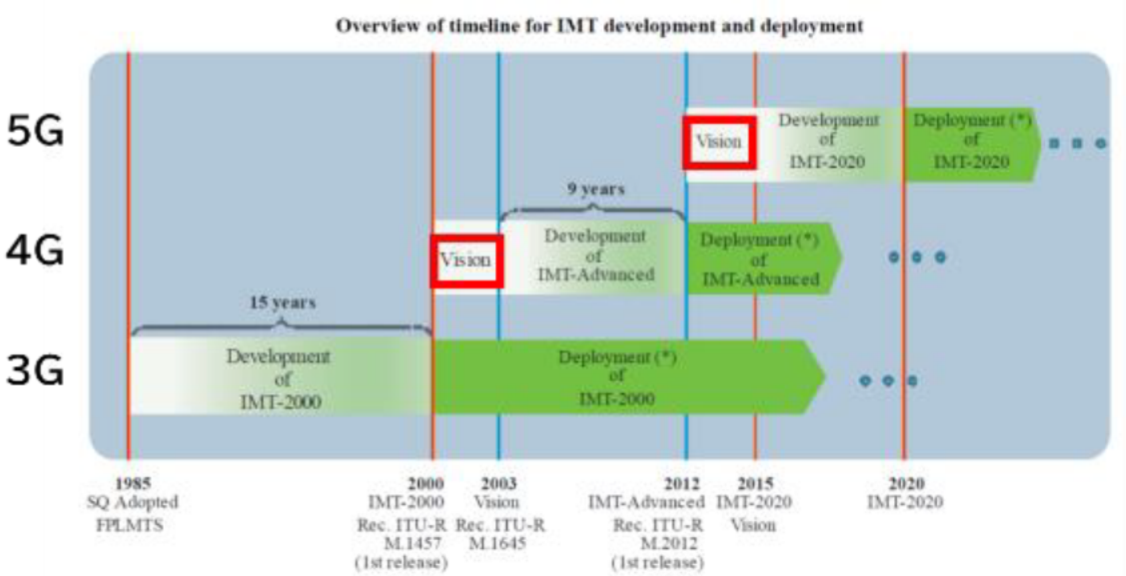


Figure 6.1: Processes in 3G, 4G and 5G (ref. ITU-R Recommendation M. 2083 Figure 1 - the red frame of Vision and 3G, 4G, 5G on the left side were added by NICT)

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

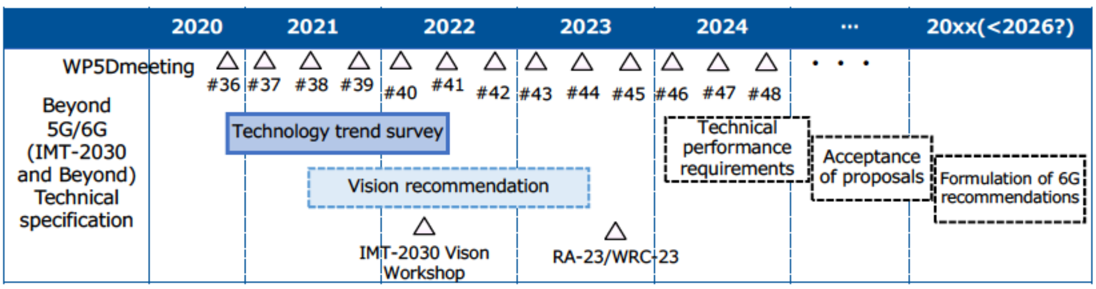


Figure 6.2: Agreed standardization process at the 34th WP5D

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 supported intensively from the government, in accordance with the R&D policy published in January 28, 2021 from 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 target, etc.)
2. General Issues widely called within the specific R&D topics, leaving the development target (numerical target, etc.) to the free ideas of the proposers.

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

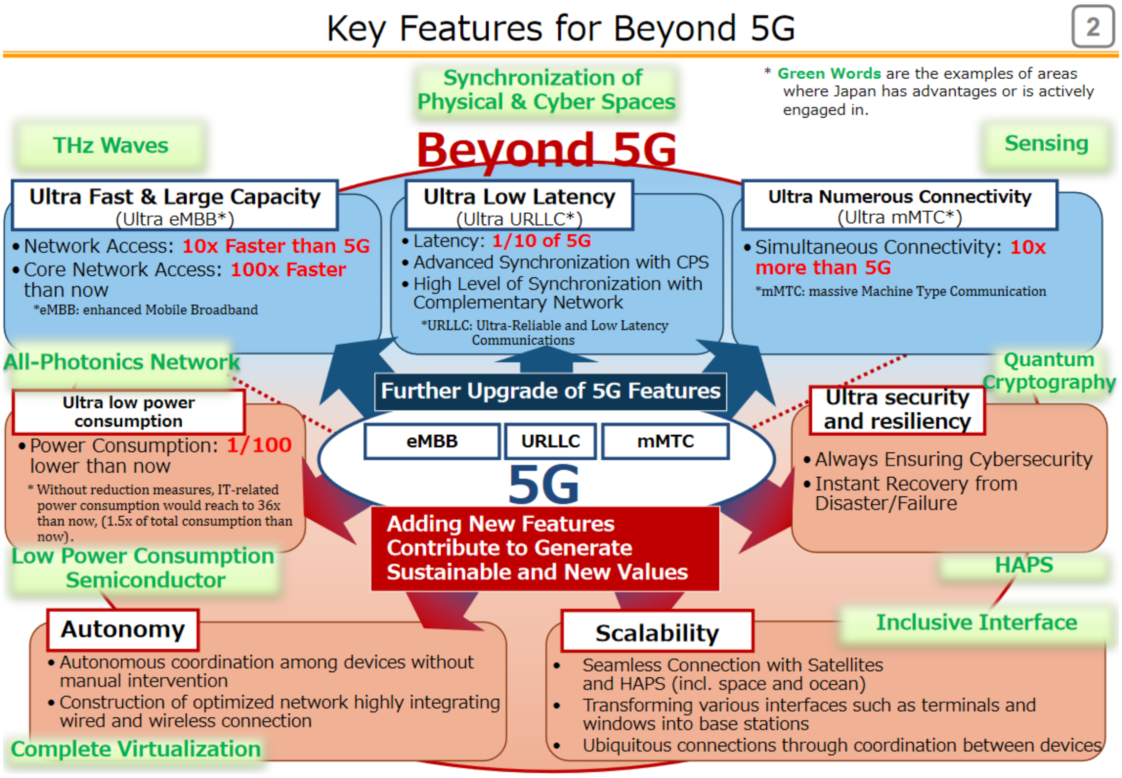


Figure 6.4: R&D Policy of Beyond 5G R&D Promotion Program, January 28, 2021.
(https://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/presentation/pdf/Beyond_5G_Promotion_Strategy.pdf)

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 the technological evolution not only in the information and communications field but also in a wide variety of fields, and to discuss with various stakeholders to realize the goals. We will continue to discuss the white paper and revise it.

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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 would like to express our deep gratitude to them for their valuable advice on the R&D direction of Beyond 5G / 6G R&D that NICT should take.

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