Beyond 5G White Paper
～Message to the 2030s～

version 4.0

December 4, 2024

XG Mobile Promotion Forum

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【Revision History】

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Ver.	Date	Contents	Note
4.0	2024.12.4	• Introduction: Added description about XGMF • Chapter 6: ➢ Section 6.7: Added NTN related document links • Conclusion: Added description about XGMF • Others: Typo corrections	

1. INTRODUCTION

1. Introduction

Through the generations, mobile communication systems have evolved from being a communications infrastructure to a life infrastructure. The adoption of fifth generation mobile communications systems (5G) is progressing in various countries. They are being used in various industries and are seen to evolve into social infrastructures that transcend the life infrastructure through collaboration and co-creation among industries. Further, the next technology after 5G, i.e., Beyond 5G/6G, will potentially unite cyberspace with the real world (physical space) and play a central role as the backbone of Society 5.0. Beyond 5G is likely to be commercialized by around 2030. As of the end of 2021, many projects and organizations related to Beyond 5G have been established in Europe, U.S., and other countries to conceptualize scenarios and technologies for Beyond 5G.Likewise, Japan, in consideration of domestic and international trends, established the Beyond 5G Promotion Consortium in December 2020 with the aim of introducing Beyond 5G speedily and smoothly and strengthening Japan's international competitiveness in Beyond 5G, towards realizing a robust and vibrant society in the 2030s.

The Beyond 5G Promotion Consortium consisted of a General Assembly and two committees, namely, the Committee for Planning and Strategy, which is tasked to examine comprehensive strategies for the promotion of Beyond 5G and write the Beyond 5G White Paper, and the International Committee, which is tasked to analyze global trends toward the promotion of Beyond 5G and disseminate Japan's efforts in the international stage. This White Paper was prepared by the White Paper Subcommittee, which is under the Committee for Planning and Strategy. The purpose of this White Paper is to envision a robust and vibrant society for the 2030s and to elucidate the use cases, communication requirements, and technologies for Beyond 5G. It also aims to promptly put together and globally communicate Japan's Beyond 5G concept, for it to be considered in international discussions, including the ITU, and for international initiatives to be established around it. The main feature of this White Paper is that the technical requirements for Beyond 5G were examined and compiled after actively incorporating opinions from the telecommunications industry as well as from a variety of other industries. This enabled the creation of a Beyond 5G Concept that is useful not only for the telecommunications industry but also for all industries, making it possible to meaningfully contribute to Beyond 5G discussions in other countries as well as in Japan.

This White Paper is divided into the following chapters.

Chapter 2. Traffic trends

This chapter describes the trends in traffic from mobile applications and use cases of Beyond 5G that are predicted to arrive around the year 2030.

Chapter 3. Market trends in the telecommunications industry

This chapter discusses market trends in the mobile communications sector, particularly changes in the share structure for smartphones, base stations, and other communication infrastructure equipment, and technical trends in components related to smartphones.

Chapter 4. Trends from other industries

This chapter identifies the current challenges in all existing industries, provides suggestions for problem solving, and summarizes the visions and dreams that industries should aspire for, as well as the performance and capabilities that are expected of Beyond 5G.

Chapter 5. Capabilities and KPIs required in Beyond 5G

This chapter identifies the unique use cases in the various industries discussed in Chapter 4 and summarizes the performance of Beyond 5G required for each use case.

Chapter 6. Technology trends

This chapter examines the trends in frequencies technologies required for Beyond 5G and clarifies the functions and values it will provide, as well as the roles it will play and the expectations of the users and markets.

In addition, to coincide with the release of the version 3.0, the results of research on technical topics that are "Japan's selling points," such as the strengths of Japan's technology and themes that are attracting attention, were compiled and published as a supplementary volume for each technical topic. In addition to the members of the White Paper Subcommittee, these supplementary volumes also contain many research results from domestic academia. The technical topics in the published supplementary volumes are as follows;

- Cell-Free Distributed MIMO
- Radio technologies for higher frequency
- Technologies on repeaters and reflectors
- End-to-end network architecture
- AI/ML
- Sensing
- Sustainability and Energy efficiency
- NTN

On April 1, 2024, the Beyond 5G Promotion Consortium was merged with the 5G Mobile Promotion Forum to form the XG Mobile Promotion Forum (XGMF). XGMF has launched several 6G-related projects, and is working together to conduct research, studies, domestic and international collaboration, and dissemination activities related to Beyond 5G/6G. This white paper and supplementary volumes created by the Beyond 5G Promotion Consortium will continue to be updated to reflect the activities of 6G-related projects of XGMF.

This White Paper was prepared with the generous support of many people who participated in the White Paper Subcommittee of Beyond 5G Promotion Consortium and 6G-related projects of XGMF. The cooperation of telecommunications industry players and academia experts, as well as representatives of various industries other than the communications industry has also been substantial. Thanks to everyone's participation and support, this White Paper was able to cover a lot of useful information for future business creation discussions between the industry, academia, and government, and for investigating solutions to social issues, not only in the telecommunications industry, but also across all industries. We hope that this White Paper will help Japan create a better future for society and promote significant global activities.

2. TRAFFIC TRENDS

2. Traffic trends

This chapter describes the trends in traffic from mobile applications and use cases of Beyond 5G that are expected to arrive around 2030.

2.1 Future trends in video traffic

The image quality of TV broadcasting is advancing in line with the Roadmap for 4K/8K Promotion [1]. While 8K broadcasting is already starting, it is expected that 4K broadcasting will further become expanded for high-definition video by around 2030. As of 2020, the household penetration rate of 4K broadcasting has reached about 10% [2]. This increase is believed to be due to innovations in video compression and extension technologies and the progress in the spread of large-capacity networks. Transmission of high-definition images has a great impact on mobile traffic. In the future, the volume of traffic for high-definition video content is expected to increase significantly. Video traffic has been growing steadily every year; it is estimated that traffic in 2030 will far exceed that in 2020.

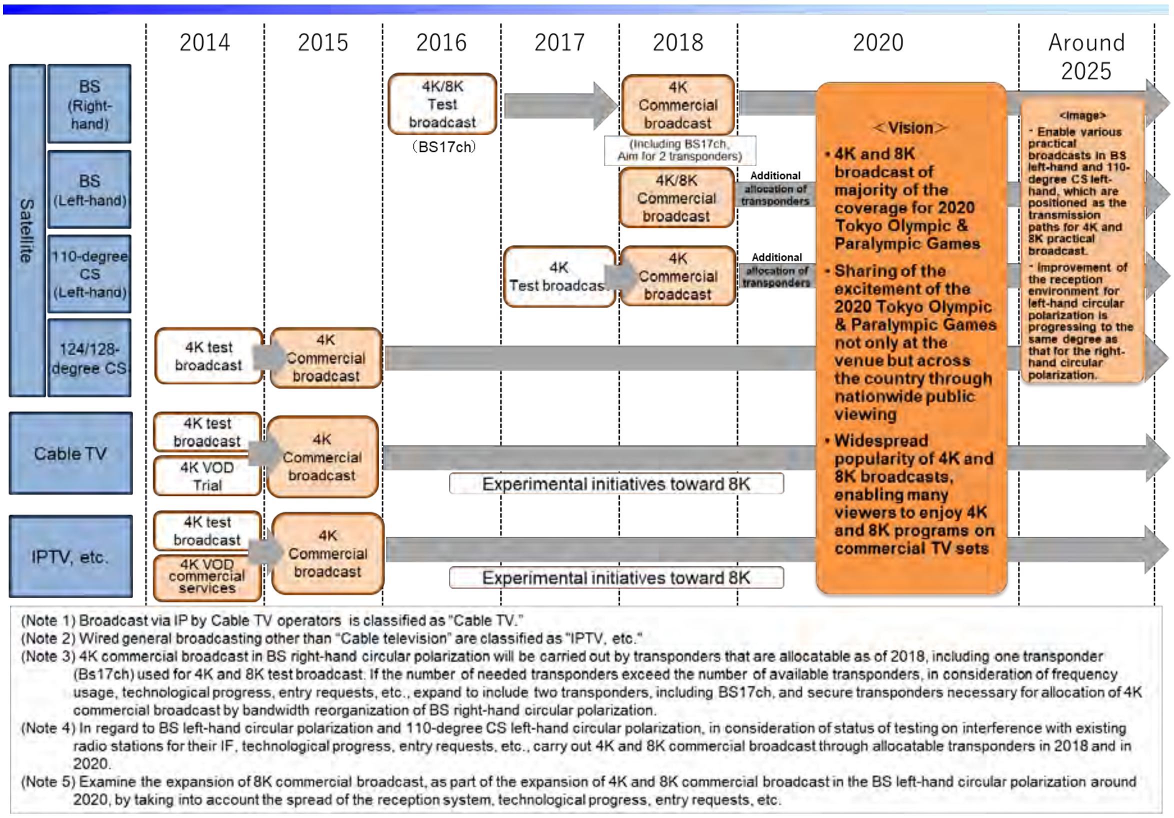

Figure 2.1-1 Roadmap for 4K/8K promotion [1]

2.2 Traffic fluctuations and environmental dependencies

Traffic volume varies depending on time, location, application, and device. The characteristics of the distribution of traffic in recent years are defined by whether use is indoor or outdoor and tend to be influenced by time of day.

Comparison of the ratio of indoor/outdoor traffic in 2021 shows that from 10 pm onwards, approximately 80% of the traffic comes from indoors.

However, by around 2030, outdoor traffic is foreseen to dramatically increase especially during the daytime due to automated driving for MaaS and other services, the delivery of goods using drones, and M2M communications. Meanwhile, indoor traffic will likely level off across different time zones after COVID-19 due to work style innovations and the promotion of teleworking across a variety of working styles.

In the future, as services become more diverse, communication devices increase, and data size increases due to increasingly high-definition content, congestion will occur due to concentration of traffic requirements in particular time zones.

Figure 2.2-1 Example of indoor/outdoor traffic variations during the day[7]

2.3 Future increase in uplink traffic

In this section, we will look at the future of uplink traffic.

In regard to the uplink/downlink traffic ratio in 2030, while downlink traffic will continue to be used in many places, the rate of increase in uplink traffic will likely be higher than that of downlink traffic. Many photos and videos taken in real time at sporting events and concert venues will increasingly be uploaded to YouTube, Twitter, Facebook, TikTok, etc. Information will also be transmitted from many remote locations and will be viewed in increasingly different ways.

Some of the applications of 5G and Beyond 5G that will become prevalent in 2030 are virtual reality (VR), mixed reality (MR), augmented reality (AR), and metaverse. Future market forecasts for these applications indicate that they will be used by around 10 million people in Japan, with the number of users worldwide expected to reach around hundreds of millions. The percentage may be slightly higher in countries other than Japan with a large young population.

"Future prospects for AR/VR-related markets 2020" [4] predict that the global market for AR/VR display devices will expand to 13.95 trillion yen in 2030, 44.8 times that of 2019. Operations are foreseen to be made more efficient to deal with labor shortages, and that education and training using AR/VR will become more common.

In regard to the content market for BtoC/BtoBtoC in 2030, two-way communications will be enhanced by Beyond 5G communications, and live streaming that enables immersive VR experiences will drive the expansion of the metaverse market.

Figure 2.3-1 Reproduced from ASCII.jp: VR Conference and collaboration tool [5]

As we approach 2030, traffic is expected to reach the petabit level with the transmission of high-definition images through broadband and high-capacity Beyond 5G technologies. In addition, the launch of multi-angle broadcasting services, the application of Beyond 5G in automated driving technologies for MaaS, the increase of communications between IoT devices with the use of drones for delivery of goods and of communications among robots, sensors, and IoT devices in the manufacturing industry, and the advent of new forms of communication as a result of the promotion of the use of virtual spaces through VR, AR, avatars, and metaverse will also contribute to the dramatic increase in traffic.

2.4 Mobile traffic forecasts for the future

This section describes the forecast for future mobile traffic.

According to the Japanese Ministry of Internal Affairs and Communications Statistics Database (from 2018 to 2021), total mobile traffic over the past three years has grown by approximately 1.3 times annually [6].

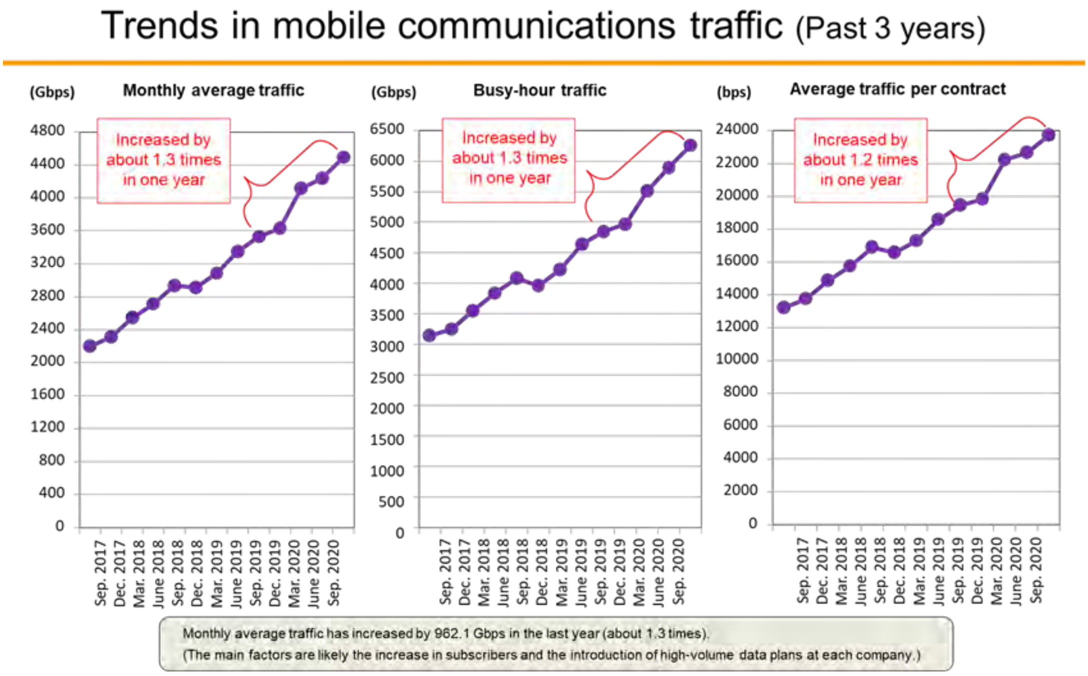

Figure 2.4-1 Trends in mobile communications traffic [6]

Next, based on the total volume of traffic on the Internet in Japan, downlink traffic accounts for almost 90% of the total traffic. In addition, downlink traffic has been growing by approximately 1.3 times annually in recent years.

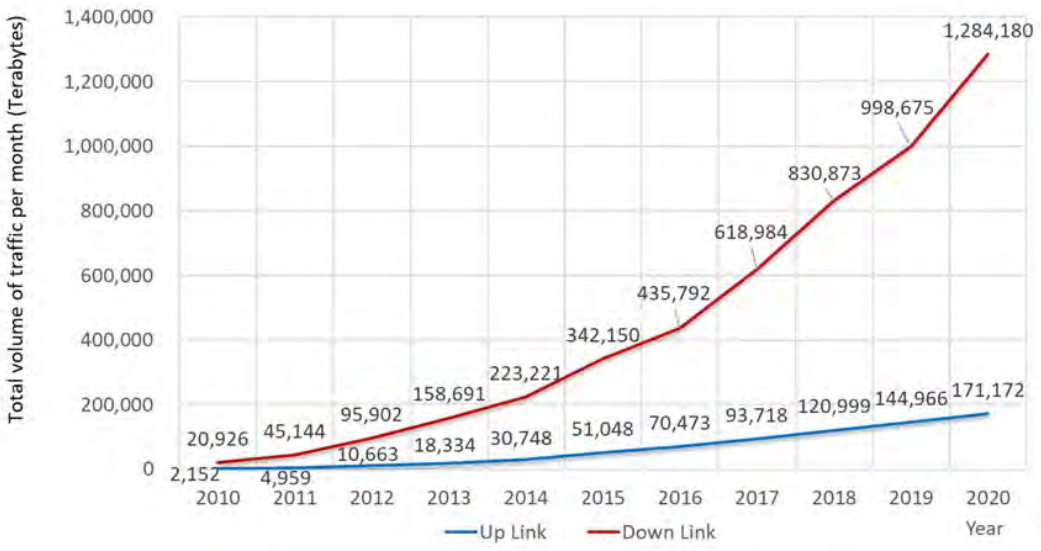

Figure 2.4-2 Mobile communications uplink/downlink trends in Japan [3]

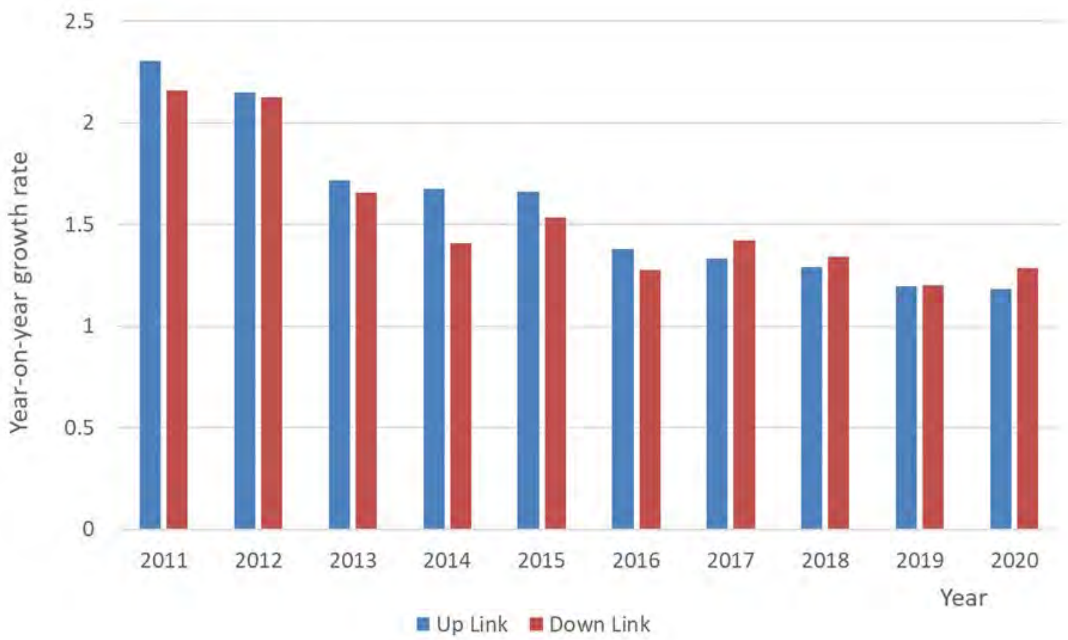

Figure 2.4-3 Mobile communications uplink/downlink year-on-year growth rate in Japan [3]

Taken together, these data suggest that on the basis of the total traffic of 1,285 petabytes in 2020, mobile traffic in 2030 is expected to reach around 17,734 petabytes.

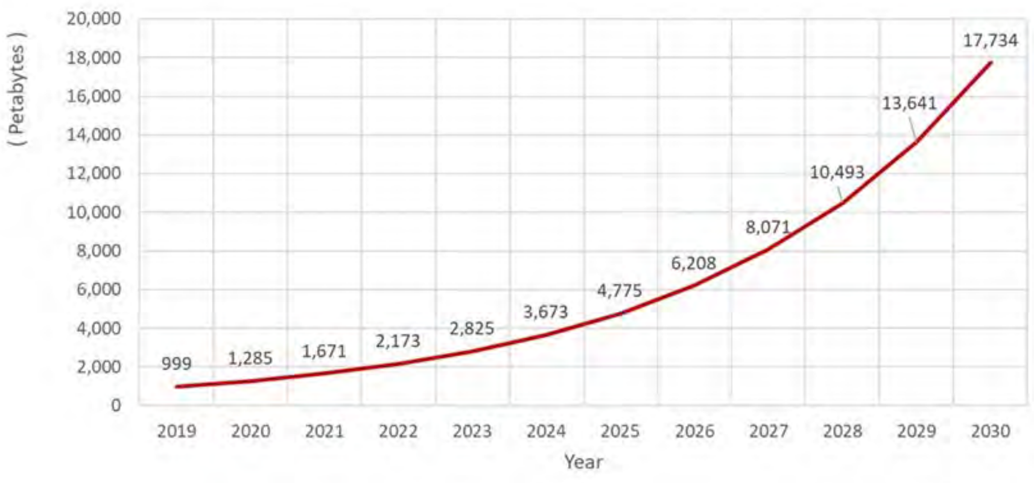

Figure 2.4-4 Example of mobile traffic forecast by 2030

Figure 2.4-4 shows an example of a future mobile data traffic forecast based on the downlink, which is higher than the uplink in the data for both types of traffic obtained from past statistics. The emergence of special and trendy services and contents for Beyond 5G in 2030 is seen to also contribute to the explosive growth in traffic.

2.5 Deployment aspect

Mobile phone systems now serve 8 billion subscribers worldwide, and the number is still increasing (Figure 2.5-1). Applying global communications standards enables sharing of the enormous cost of providing advanced information and communications among users in a huge market due to the economic effect of scale, thus creating a market in which advanced communication services are available at affordable prices.

As shown in the figure, China, India, and Europe (as a region) are in the top three positions, with the United States in the fourth position and Japan having the nineth largest number of subscribers in the world.

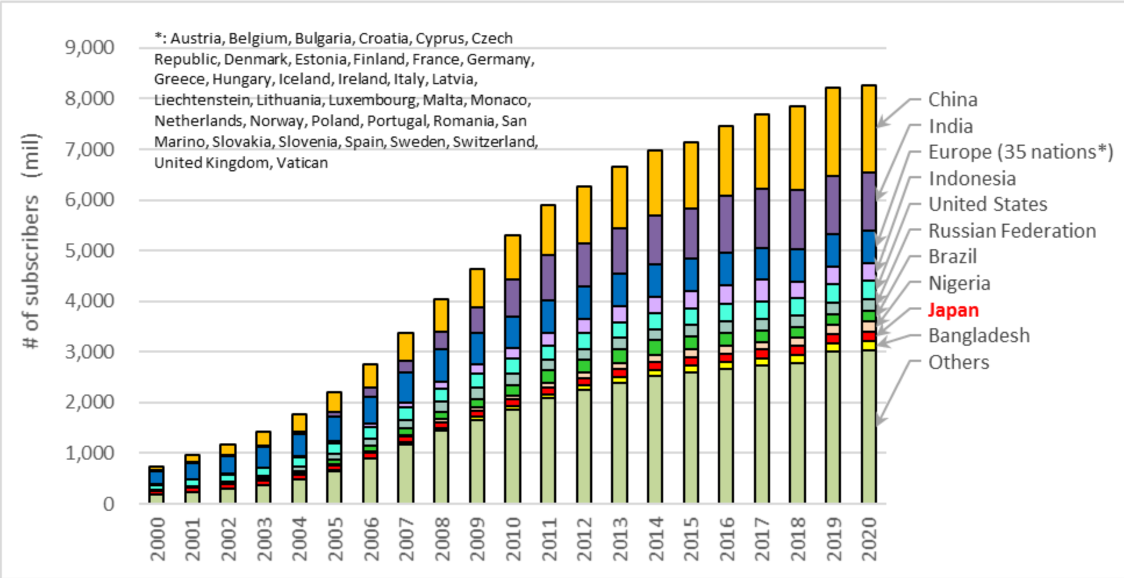

Figure 2.5-1 Number of mobile phone subscriptions worldwide [8]

The rough estimates of the size of the mobile phone market calculated by multiplying the number of subscribers by GDP-PPP [1] for each region and country, however, do not necessarily correspond to the number of subscribers (Figure 2.5-2). China, Europe, and the U.S. currently occupy the top positions, and these nations and regions have an overwhelming market share compared with the others, including Japan, which ranks fourth after the U.S.

In view of the future expansion in the regions and the accelerated development of communications in addition to human-to-human communications, such as smartphones, it seems necessary to devise ways to expand services to a new horizon of an inclusive world while utilizing the advanced and stable nationwide communications networks built thus far

1 Gross domestic product (GDP) per capita-purchasing power parity. GDP is expressed in constant international dollars per person. Data are derived by dividing constant price purchasing-power parity (PPP) GDP by total population [2].

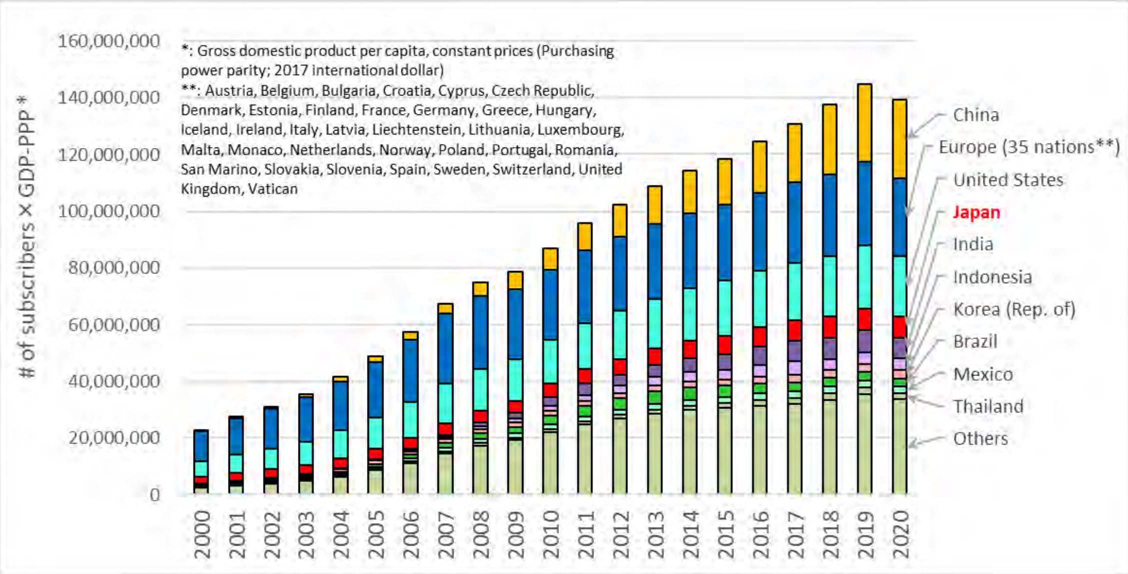

Figure 2.5-2 Number of subscribers multiplied by GDP-PPP [8][9]

At present, each region or nation has a communication system tailored to the situation of each region while maintaining compliance with the Global Standard. People share these communication system resources as they engage in social and industrial activities.

In view of the fact that Beyond 5G can have a significant impact on the world and play irreplaceable roles in the future, Beyond 5G must be repositioned as a common social infrastructure or resource that more people use in a wider range of situations as a matter of course without being aware of its existence. Although there are different views that consider the Internet and other ICT systems as a Global Commons[2] like air and water [10] [11], the value that Beyond 5G can provide as an information and communications infrastructure is clearly a rivalrous limited resource because it is provided using limited energy resources and precious radio spectrum resources that are the common property of mankind. It is also possible to provide abundant information and communications values that can be considered to be non-excludable in an artificial way. Therefore, in developing and deploying Beyond 5G systems, it is important to consider how to distribute and provide information and communications capabilities as a limited resource common to all humankind, and how to contribute to the public good of the world.

The next section describes the current status of limited frequency resources, which can be considered as one of the common resource pools, and efforts for future development of the limited radio spectrum resources.

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2 In economics, Global Commons as finite and sharable resources are defined as rivalrous and non-excludable. Although Beyond 5G is rivalrous in its use of limited frequency resources, it is technically excludable as it can be operated so as to exclude specific users or groups. Therefore it is debatable to simply define an ICT system like Beyond 5G as a Global Commons.

2.6 Summary

This section described the upcoming trends in traffic for Beyond 5G in Japan towards 2030.

The COVID-19 pandemic that started in 2020 accelerated the transition to telework and online classes, and the establishment of the new normal for online live events and games has significantly increased traffic. Moreover, traffic will continue to increase in the future as we transition to a new lifestyle that highlights changes in society, such as the shift to cashless and non-contact sales activities.

Also, in 2030, the emergence of special and trendy services and contents for Beyond 5G is seen to contribute to the explosive growth in traffic.

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3. MARKET TRENDS IN THE TELECOMMUNICATIONS INDUSTRY

3. Market trends in the telecommunications industry

This chapter discusses market trends in the mobile communications sector, particularly changes in the share structure for smartphones, base stations, and other communication infrastructure equipment, and technical trends in components related to smartphones.

3.1 Changes in the share structure for smartphones, base stations, and other communication infrastructure equipment

3.1.1 Smartphone market

Figure 3.1-1 shows the changes in unit sales by manufacturer in the global smartphone market. Total unit sales have increased 6.3 times in the 10-year period from 2009 to 2019, when the smartphone's popularity increased dramatically. Among the major handset manufacturers, Blackberry led the market in 2009, followed by Apple and two North American companies, accounting for more than a quarter of the total market. In 2019, Samsung was the top company, followed by Huawei and two Asian companies, accounting for about 40% of the total, indicating a major change in the lineup of top companies over the decade. In particular, six Chinese companies, including Huawei, Xiaomi, Oppo, and vivo, ranked among the top ten companies, accounting for 43.4% of the global shares, thereby significantly increasing their market presence. In addition, smartphone sales shares of the top five companies accounted for 69.5% of the market in 2019, compared with only 38.3% in 2009, which also points to an oligopoly in the smartphone market.

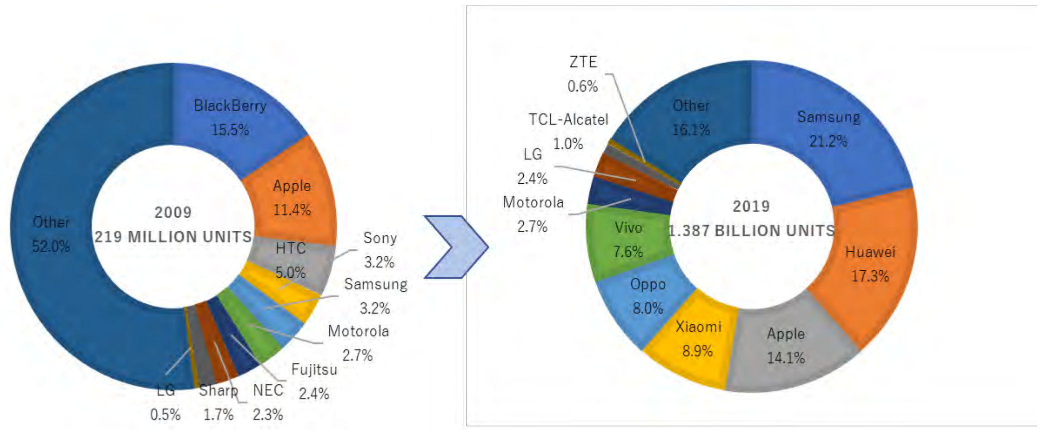

Figure 3.1-1 Changes in manufacturer shares in the global smartphone market [1]

Figure 3.1-2 shows the changes in unit sales by manufacturer in the domestic smartphone market. Apple's share remained at the top in the five years between 2014 and 2019, growing from 43.7% to 59.8%, and its products continue to be very popular in Japan. In 2014, other shares were held mostly by domestic companies followed by Korean companies; but in 2019, Chinese companies have increased their presence, while the others have failed to increase their shares.

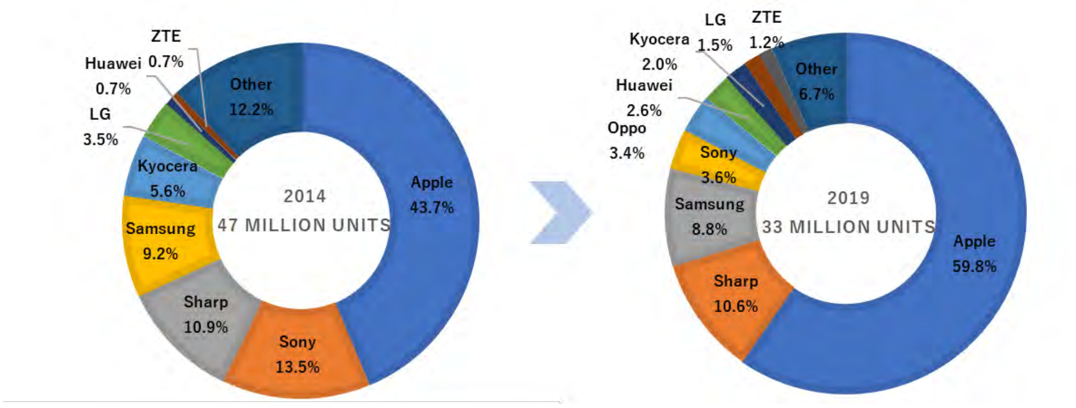

Figure 3.1-2 Changes in manufacturer shares in the domestic smartphone market [1]

Therefore, for smartphone sales, the proportion of the shares of the top few companies has increased while the remaining shares are split among the other companies, clearly distinguishing between companies that have successfully entered and expanded in the global market and those that have failed to do so in the 10 years from 2009 to 2019. Even for Beyond 5G, the market shares for smartphones are likely to change significantly.

3.1.2 Bases station market

3.1.2.1 Macrocell base station manufacturer shares

Figure 3.1-3 and Figure 3.1-4 show the changes in shipment volume of major base station manufacturers in the global and in the domestic macrocell base station markets, respectively.

In the global macrocell base station market, Ericsson was the leader in 2009, followed by Nokia and two Nordic companies, accounting for more than half of the market shares, while Huawei was the top in 2019. Over the course of the decade, Chinese and Korean companies have specially gained significant shares, with shares fluctuating among the top companies. In addition, macro base station shipment volume shares of the top five companies accounted for 96.5% of the total in 2019, compared with only 75.8% in 2009, showing that the shares of the top five companies have increased significantly.

In the domestic macrocell base station market, the top companies have not changed significantly in the five years between 2014 and 2019, unlike in the smartphone market. European companies account for more than half of the total market shares, while shares of Japanese companies have decreased from about 1/3 to about 1/4.

Thus, the lineup of companies with the highest shares in the macro base station market over the past decade has not changed significantly. No significant changes are also foreseen in the market for Beyond 5G.

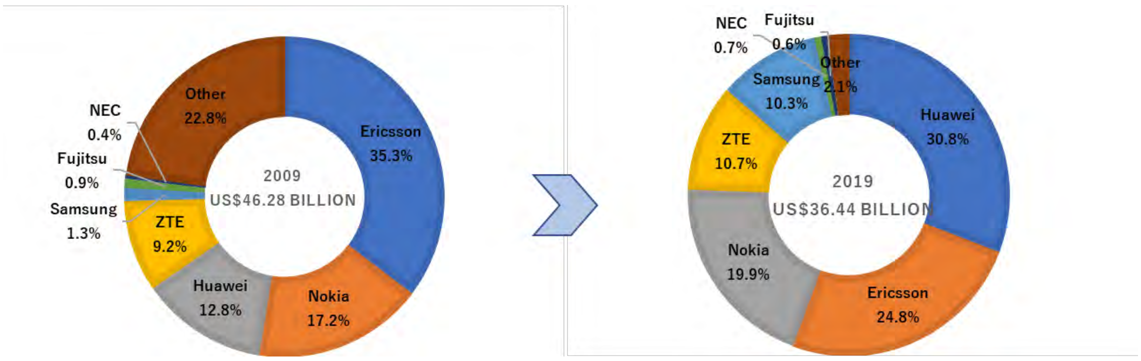

Figure 3.1-3 Changes in manufacturer shares in the global macrocell base station [1]

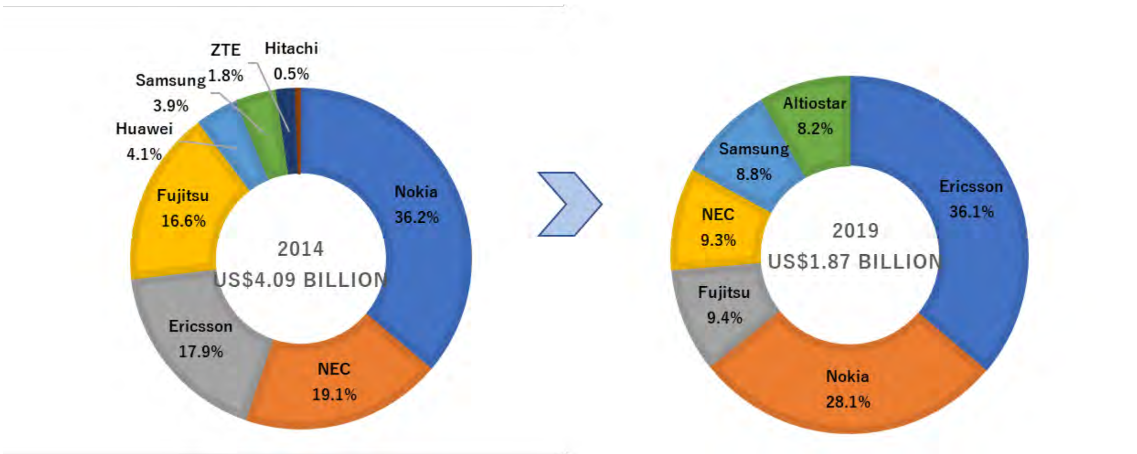

Figure 3.1-4 Changes in manufacturer shares in the domestic macrocell base station market [1]

3.1.2.2 Expansion of small cell base stations

The spread of small cell base stations in addition to the existing macrocell base stations is foreseen after 5G onwards. Small cells serve as infrastructure for deploying ultra-fast and large capacity transmission services, thus, their market is projected to expand.

The market for small cell base stations is foreseen to expand further in Beyond 5G, where further utilization of high-frequency bands, such as the terahertz band, is being considered.

3.2 Electronic components

Table 3.2-1 shows the global shares for electronic components related to smartphones and wireless communication devices. Murata Manufacturing has gained the world's top share in chip multilayer ceramic capacitors (MLCC), surface acoustic wave (SAW) filters, wireless LAN modules, and Bluetooth modules. The world's top shares for inductors and lithium-ion polymer batteries are held by TDK, those for camera actuators by Alps Alpine, and those for

CMOS image sensors by Sony. Japanese component manufacturers are evidently showing their strong presence in markets for various electronic components.

The number of critical electronic components, such as ceramic capacitors, has increased in 5G smartphones compared with 4G, and this trend will continue in Beyond 5G. In particular, since the millimeter and terahertz waves, which are expected to be utilized in Beyond 5G, consume high power during transmission, there will be a need to improve battery and antenna-related performance.

The number of critical electronic components will continue to increase as a result of the use of high-frequency bands. Capturing a high share of the market, therefore, will enable reducing costs through mass production.

Table 3.2-1 Overview and global shares of smartphone-related electronic components [2]

Smartphone related parts	Outline	Global market share (based on shipment quantity)		
		1	2	3
Multilayer ceramic chip capacitor (MLCC)	A component that controls voltage in an electric circuit	Murata Manufacturing Around 40%	Samsung EM (KR) Around 20%	Taiyo Yuden 10~15%
Surface acoustic wave (SAW) filter	A filter that extracts only the required frequency from the wireless signal	Murata Manufacturing Over 50%	Qualcomm (US) 30~35%	
Ceramic oscillator	Used as a clock signal source for digital circuits, etc.	Murata Manufacturing 75%		
Wireless LAN module	Wireless LAN module attached to mobile terminals, etc.	Murata Manufacturing 50~60%	USI (CN)	TDK
Bluetooth module	Module attached to mobile terminals, etc.	Murata Manufacturing 50%	Alps Alpine	
Inductor	Used in all high frequency circuits	TDK 25~30%	Murata Manufacturing	Taiyo Yuden
Camera actuator	Used for camera autofocus and camera shake correction	Alps Alpine 70~80%	MinebeaMitsumi	TDK
CMOS image sensor	Used with smartphone cameras, etc.	Sony 50%	Samsung (KR) 24%	OmniVision (US) 14%
Lithium-ion polymer battery	Thin battery	TDK 40~50%	Samsung SDI (KR) 30%	LG Chem (KR) 10~20%

3.3 Semiconductors

Figure 3.3-1 shows the total worldwide semiconductor sales from 2014 to 2020 and the changes in semiconductor sales for each manufacturer. Global semiconductor sales in 2014 amounted to US$340.3 billion, but it had reached US$476.7 billion in 2018. This is said to be the result of the "memory bubble" that started around 2015, with the surge in trade prices for DRAM and other products significantly boosting sales by semiconductor manufacturers. However, the sluggish demand for smartphones and PCs from 2018 to 2019 led to a downturn in semiconductors; in 2019, global semiconductor sales fell to US$422.3 billion.

Meanwhile, the semiconductor market has been growing as a result of the COVID-19 pandemic from 2019 to 2020. The demands for memory, GPU, and 5G chips have driven the growth of the semiconductor market in response to stay-at-home demands from remote work, etc., resulting to resurgence in global semiconductor sales to US$466.2 billion.

In terms of revenues by manufacturer, Intel was at the top in 2014, followed by Samsung and Qualcomm. But in 2017, Samsung, benefiting from the memory bubble, displaced Intel, which had retained the top spot for 25 years. After that, when the memory bubble burst, Intel regained the top position in 2019. As the market leader, it has captured a large portion of the market share among U.S. and Korean companies.

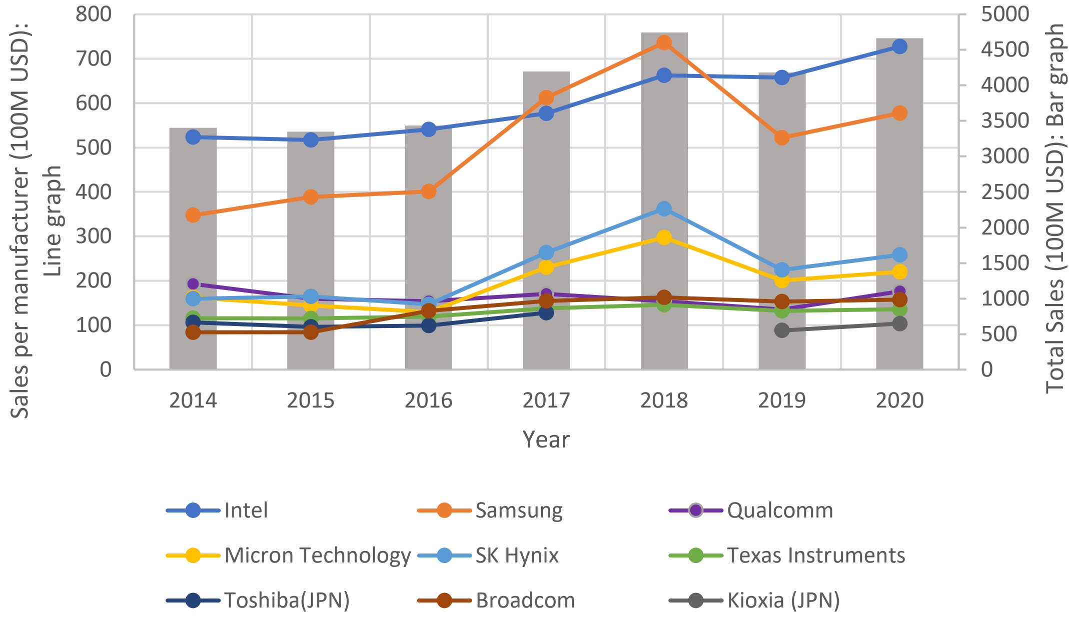

Figure 3.3-1 Changes in manufacturer shares in the global semiconductor market [3]-[9]

3.4 Wireless access network power consumption

Figure 3.4-1 and Figure 3.4-2 respectively show the domestic and global network-related power consumption [10]. Although the graph shows data for 2018 and 2030, energy consumption data for 2030 are estimates that consider only the increase in the number of macrocell and small cell base stations, without considering future power-reduction technologies. The blue graph represents the power consumption of the core and metro networks, while the orange graph represents the power consumption of the access networks. Core networks are high-capacity, ultra-high-speed communication networks that serve as the hub of the networks connecting domestic sites to the world, and the metro networks are the networks that connect the core networks to the access networks. Access networks are networks that connect users to the network edge.

Figure 3.4-1 and Figure 3.4-2 show similar trends in domestic and global network-related power consumption in 2030 and 2018, with an increase of approximately four to five times in 2030 compared with 2018. Power consumption of access networks is significantly larger than those for core and metro networks, with base stations accounting for majority of the power consumption of access networks. As shown in section 3.1.2, the number of macrocell and small cell base stations is predicted to increase in the future. Likewise, wireless traffic is also predicted to increase, as shown in Chapter 2. If no specific measures are taken, power consumption per base station will increase, and the number of base stations may also increase. The development of technologies to reduce power consumption for Beyond 5G will, therefore, become increasingly important.

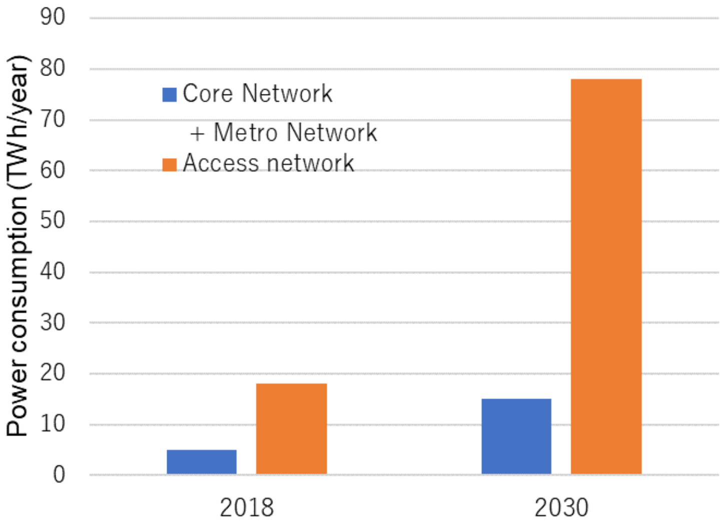

Figure 3.4-1 Domestic network-related power consumption

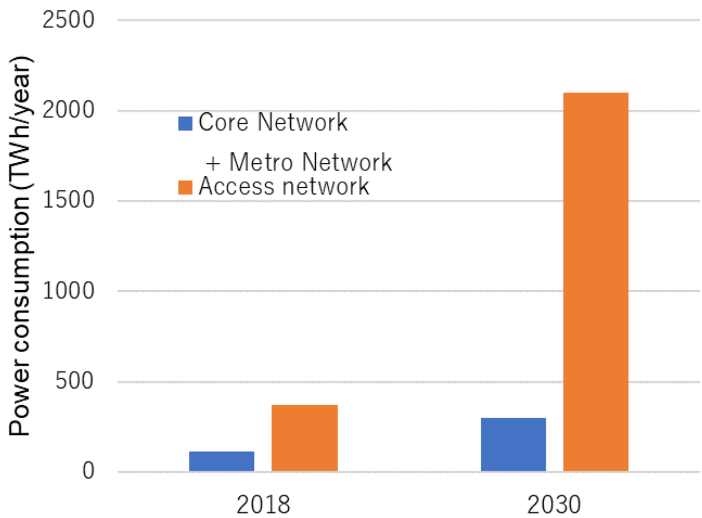

Figure 3.4-2 Global network-related power consumption

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4. TRENDS FROM OTHER INDUSTRIES

4. Trends from other industries

Mobile systems, which have driven the evolution of the times, are expected to contribute to solving various social challenges in the future. For this reason, figuring out the performance and capabilities required for Beyond 5G requires an understanding of the reality of a wide range of industries, unlike for 5G and earlier technologies. Therefore, in this chapter, we identify the challenges not only in the telecommunications industry, but also in all existing industries. This chapter provides suggestions for solving problems and summarizes the visions and dreams that industries should aspire for, as well as the performance and capabilities that are expected of Beyond 5G. There are use cases and scenarios that can be achieved with 5G and earlier, and there are those that can be expected with Beyond 5G. The following sections present a two-pronged description of use cases and scenarios to distinguish those that are achievable with 5G and those with Beyond 5G.

Below, we classified all existing industries into 15 sections, with each section studied, analyzed, and written by different authors. While all industries require digitalization and the power of modern mobile systems, the current state of digitalization and use of mobile systems varies by industry, thus, the future requirements also vary by industry. The different sections, therefore, vary in their content and length.

4.1 Finance

While the digital transformation of the whole society is ongoing, the financial sector, such as banks, securities, and insurance providers, is rapidly more integrating and collaborating each other and it will have new services.

This section examines the future of the financial industry considering these trends.

4.1.1 Current situation and challenges

As in other industries, new services using block chain and AI are also being offered in the finance industry. The COVID-19 pandemic has also led to the uptake of non-face-to-face sales and cashless online transactions. The number of players in the financial sector is also increasing, by the entry of other industrial players, such as retail, telecommunications, and service providers. The finance, especially the insurance industry may be impacted by promoting DX of other industries.

The major challenges in these changes are reducing the current operational costs and shifting to high-value-added businesses.

- Reduce the operating costs

  Operating costs must be reduced in conventional services, such as deposits and loans, due to the decline in profits caused by the continuing low interest rates and the decreasing exchange transaction fees. As a result, financial branches and offices are being consolidated or downsized, and conventional facilities (such as ATMs) in branches are being trimmed down. Likewise, efforts are being made to reduce operational costs by moving from mainly on-site face-to-face (offline) business to online business such as home, workplace and any outside, etc., using mobile networks.

- Shift to high-value-added business

  Along with reducing operating costs, it is imperative to increase profits by shifting from existing businesses to high-value-added businesses. Some examples are new investment management services such as wrap accounts and consolidated customer investments, other alternative investments such as real estate and commodity investments, which are different from stocks, bonds, and other traditional investments, and other advisory services to offer M&A for institutional investors.

4.1.2 Future vision

Along with the digitalization of customer contact points following the move from face-to-face to online and cashless operations, and the shift to high-value-added businesses, financial services are envisioned to move toward the integration of various services and to new services that involve other industries, in addition to the advancement of existing services.

- Evolution of existing services

  The use of AI to exploit big data, such as customer data collected during business operations, will improve operational efficiency and lead to diversification of services. Examples of big data applications include the use of credit analysis in financing, the use of portfolio analysis in investment, and the use of driving performance from driving recorders for automobile insurance menus.

- Integration with other industries

  Presenting various services offered by the financial industry as APIs and providing them as Banking-as-a-Service (BaaS) will enable the provision of services in cooperation with other industries. Financial services can be embedded using BaaS in service applications for other industries (embedded financing).

- Emergence of new financial services

  With the spread of digital currencies such as e-money and cryptocurrency, the future financial services will go beyond existing services, such as through the adoption of central bank digital currency (CBDC) and the secondary use of transaction data as big data.

- Impact from other industries

  New type of insurance service and financial service will start in accordance with the evolution of other industries.

4.1.3 Applications achievable with Beyond 5G

The following are applications achievable with Beyond 5G to realize the future vision of financial services depicted in section 4.1.2.

- Penetration of the digital currency society
  It will realize the society where all transactions in the industry even as retail, are digitalized
- Emergence of branchless banking services using holograms and other technologies
  It will sophisticate in-person services
- Provision of advanced security services
  It will apply higher security guaranteed by the Beyond 5G network to financial services to enable user-friendly, high-security services
- Provision of new insurance service
  - Automobile insurance service for self-driving car
  - New vehicle insurance service such as UAV
  - Insurance service for activities in new environment such as space and sea
  - Disaster insurance service using more improved prediction accuracy

4.1.4 Capabilities required in Beyond 5G

Table 4.1-1 indicates the required capability to achieve the above applications envisioned for the finance industry and this section describes the roles of Beyond 5G networks in terms of the network requirements.

Table 4.1-1 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Digital currency society	x	x	x	x				x		
Branchless banking services using holograms and other technologies	x	x	x	x				x		
Advanced security services				x						

(a) Ultra-massive connectivity

To perform real-time analysis of big data, such as customer and IoT data, networks must provide massive simultaneous connectivity for the evolution of existing services, such as the credit services and insurance menus mentioned above.

(b) Ultra-fast and large capacity, ultra-low latency

Ultra-fast and large capacity, ultra-low latency will be required for transactions of financial products, especially with the higher volume of transactions via virtual currencies and the acceleration of real-time trading of stocks.

Following the transition from in-person to online business, ultra-fast and large capacity, ultra-low latency network infrastructure will be needed to ensure sufficient communication capacity and real-time performance, such as for sales operations utilizing different devices (e.g., TVs and speakers) and different UIs (e.g., holograms).

(c) Ultra-security, resiliency and reliability

A high level of security that incorporates individual consent will be necessary because of the need to handle data that include personal information. This is especially important when many players offer services, such as in the secondary use of transaction data and in collaboration with other industries.

(d) Universal coverage

The regional digital divide should be eliminated, i.e., a wide coverage that includes heterogeneous radio and device collaborations should be provided to enable users of financial services to have access to the services using mobile communications anytime and anywhere, not only from home or at workplaces.

Although some of these services and requirements can be provided even with 4G and 5G networks, Beyond 5G will enable further advancements, such as real-time analysis of large data and improvement of UX.

Figure 4.1-1 shows the Financial Industry in Beyond 5G era.

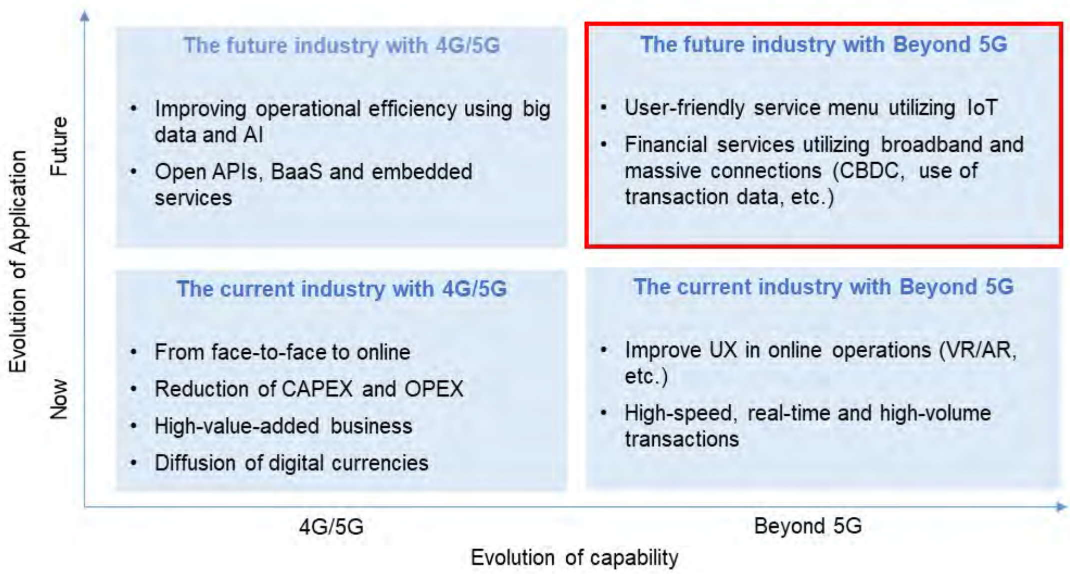

Figure 4.1-1 Financial Industry in Beyond 5G era

4.1.5 Summary

This section examined the current situation and future vision of financial industry and described the capabilities for Beyond 5G that are needed to the future vision. The required capabilities would be ultra-massive connectivity, ultra-fast and large capacity, ultra-low latency, ultra-security, resiliency and reliability and universal coverage.

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4.2 Construction and Real Estate

4.2.1 Current situation and challenges

Building a sustainable construction industry is the challenge in the construction and civil engineering sector. Looking at the number of workers by industry, we see that while the overall number has been increasing since 2012, the number of workers in the construction sector has decreased from 6.18 million in 2002 to 5.04 million in 2010, and has levelled off in recent years (4.99 million in 2019). In addition, the aging of workers in the construction industry is higher compared with the average for all industries, making it increasingly difficult to secure future workers. The percentage of workers aged 55 and older increased by 10.4% from 24.8% in 2002, to 35.2% in 2019.

Given the worsening and more frequent occurrence of natural disasters, it is imperative to continue to pursue strategies for developing social infrastructures that directly contribute to economic revitalization and national resilience, such as disaster risk reduction and mitigation and countermeasures for aging infrastructures. Therefore, demands for the industry are high. The effective job-openings-to-applicants ratios are also high; namely, 5.86 for construction, civil, and survey engineers, 5.21 for civil engineering occupations, and 5.02 for construction occupations in 2019. (The total for all occupations is 1.45 in 2019).

Also, with the continuing aging and decline of the population, the construction industry must undergo workstyle reforms by improving wage levels and expanding holidays, as well as enhance productivity by utilizing ICT.

The use of ICT in the construction industry has become a pressing issue in other countries as well. Many of the tasks are done outdoors and usually involve many workers and organizations in different construction processes. Work planning, management, and safety are also important issues because workers deal with trucks and heavy construction machinery, as well as hazardous chemicals and heavy materials. Extensive use of ICT to monitor workers and construction equipment, to remotely control heavy equipment, and to automate site operations will enable sustainable and efficient construction operations and improvement of site safety. These ICT-related initiatives are collectively referred to as "Construction 4.0."

The real estate industry is an important core industry that supports people's lives and economic development. It will thus continue to grow and develop toward 2030. The number of workers in the real estate industry is 1.337 million, with about 50% of them over 60 years old as of 2015, pointing to an aging workforce. Future challenges include population decline, increase in idle real estate, deterioration of real estate, aging workforce and shortage of successors, support for the diversified lifestyles made possible by new technologies, enabling safe and secure real estate transactions, and creating a stock-type society. The

COVID-19 pandemic has led to restrictions in business activities, sluggish demand for rentals, and an increase in the vacancy rate.

To promote the use of ICT in all construction and production processes—from research and surveying to design, construction, inspection, maintenance, and renewal—the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has implemented the "i-Construction" initiative, which is aimed at dramatically improving productivity. Under the i-Construction initiative, MILT is promoting the dissemination of ICT construction, which aims to actively utilize machine-control and machine-guidance technologies to achieve precise and efficient construction by automatically controlling construction machinery using 3D data. In addition, since construction is basically outdoor work and is easily affected by weather conditions, it is important to specify and digitize the concrete work standards based on such requirements.

The following are examples of innovative i-Construction initiatives.

- 3D surveying using UAV
- Construction by ICT construction machinery utilizing 3D surveying and design data
- Assembly automation systems that perform rebar arrangement and binding operations using robot arms
- Remote inspection using wearable cameras
- Programming of know-how and automation of operations of deep cement mixing barges
- Infrastructure facility inspection utilizing small drones for use in small spaces
- Streamlining and sophistication of construction planning using remote-participation VR
- MILT acquired an outdoor Local 5G radio station license in March 2021.

The following are the ICT use cases for services in the real estate industry:

- Vacant-home management using IoT
- Efficient regional operations through IoT (e.g., efficient regional service operations using data obtained from sensors, cameras, etc.)
- Environmental control systems that increase office intellectual productivity (use of AI and IoT to analyze room temperature, humidity and employee vital data)

4.2.2 Future vision

The future construction sector will likely see the introduction of innovative technologies, such as 5G, AI, robots, and the cloud, into the construction and infrastructure domains. Initiatives to save manpower in supervision and inspection will also be pursued through on-site verification of unmanned construction technologies and use of video data and technologies to support construction site workers. In particular, unmanned construction using 5G systems with “high speed and high capacity,” “multiple connectivity,” and “low latency” capabilities will be effective in improving productivity in the construction industry.

Greater efficiency and sophistication of operations will be pursued by further promoting the spread of Construction Information Modeling (CIM) and Building Information Modeling (BIM), which utilize 3D models to develop and manage social infrastructures.

New technologies such as AI and IoT will also be utilized in the real estate sector. For example, online property viewing using VR and real estate management services leveraging AI, IoT, robots, etc., will be adopted to improve efficiency and convenience. AI-based investment advice services will be used in real estate investment. Further, accuracy and safety in real estate transactions will be enhanced through settlement and transaction methods using communications between remote locations, electronic signatures, and block chain technologies.

4.2.3 Applications achievable with Beyond 5G

The following are the possible applications for Beyond 5G in the construction and real estate sectors.

- Remote installation in cooperation with experienced technicians – Use of VR technology by on-site workers to perform installation and construction work in cooperation with experienced technicians in remote locations
- Remote installation by experienced technicians - Installation and construction through remote operation of construction machinery or robots using haptics and VR technologies
- Maintenance and management of infrastructure, buildings, and real estate by connecting all construction components by IoT - Installation of sensors and constant monitoring of vibration, temperature, humidity, gas, etc. for preventive maintenance and management
- Construction through physical space and cyberspace - Convergence of physical space and cyberspace through Beyond 5G systems: Design is carried out in cyberspace, and during actual construction, equipment is positioned while environmental sensors detect temperature, humidity, gas emission, etc. to ensure that construction is proceeding as designed in cyberspace and to identify any problems in the management of construction materials and in the site environment.
- Complete automation where construction machinery and robots carry out the construction and building process - Self-driving vehicles carry equipment on behalf of workers, automatic construction machinery carry out the installation, and robots

perform the construction automatically. Support by digital twins using Beyond 5G systems will enable immediate response to problems as they arise.

- Use of digital twins in real estate management, trading, and investment
- Information provision during disasters and emergencies - Development of a system that can immediately provide information on passable roads and evacuation routes based on bridge vibrations, water levels, and other environmental conditions during the occurrence of earthquakes, tsunamis, torrential rains, and other natural phenomena
- Online property viewing using VR

4.2.4 Capabilities required in Beyond 5G

Table 4.2-1 shows the capability requirements for Beyond 5G based on the applications described in section 4.2.3.

Table 4.2-1 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
- Remote installation by experienced technicians - Remote installation in cooperation with experienced technicians	X	≦1ms		X						
Use of digital twins for automatic construction and infrastructure maintenance		X		X		X	1 or 2cm			
Maintenance and management of infrastructure and by connecting construction components by IoT			X		X		1 or 2cm			
Use of digital twins in real estate management, trading, and investment				X						
Online property viewing using VR	X	X								

Figure 4.2-1 shows the fusion of the evolution of the construction and real estate industry and the technological evolution of Beyond 5G.

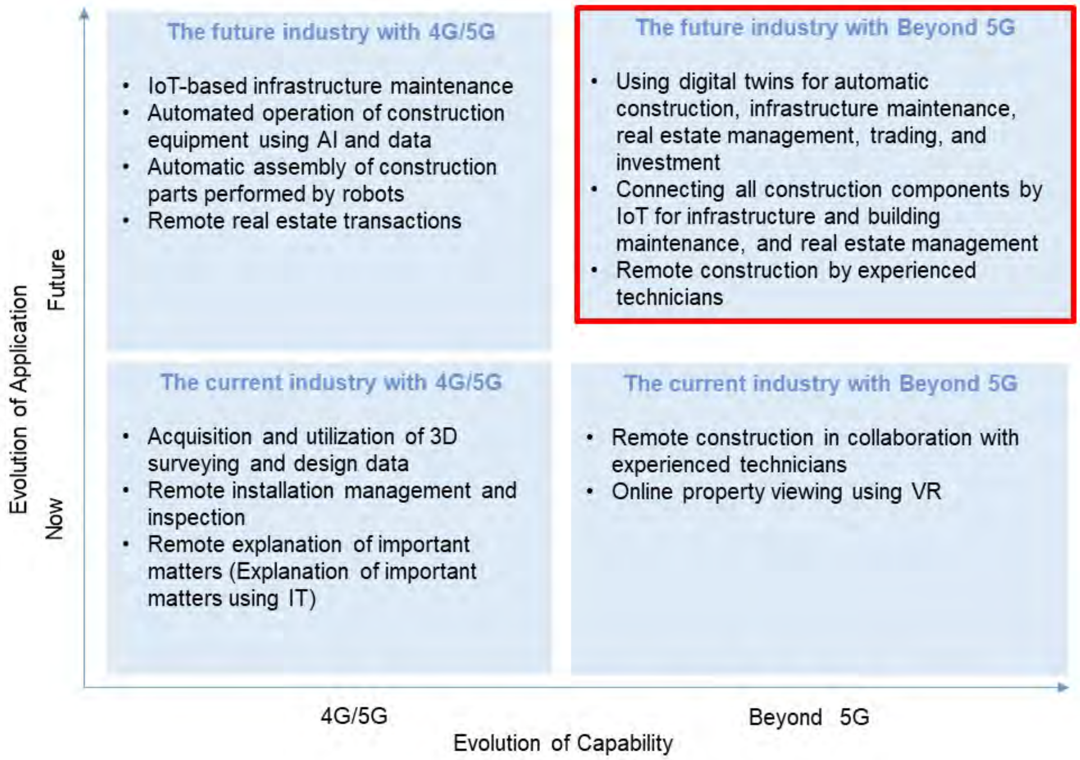

Figure 4.2-1 Construction and Real Estate industry in Beyond 5G era

4.2.5 Summary

In this section, we examined the current situation and challenges of the construction and real estate industries and described the future images for each sector as well as the applications achievable with Beyond 5G. The required capabilities would be ultra-low latency, ultra-fast and large capacity, ultra-security, resiliency and reliability, and ultra-low power consumption exceeding those of 5G. In addition, high-precision positioning and sensing, and time synchronization accuracy will be imperative.

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4.3 Logistics and Transportation

4.3.1 Warehousing and Logistics

The warehouse and logistics industry provides extremely important social infrastructures. The storage and retention of a variety of materials, including industrial products, raw materials, fresh or processed foods, and even waste, as well as their transport to where they are needed through roads, sea, air, and railway keep people's lives and industrial production activities extremely efficient.

In this section, taking into account the challenges facing the warehouse and logistics industry, such as the declining population, the increasing uncertainty over the global economy, and the coronavirus pandemic, we discuss the future vision for the industry toward achieving sustainable growth and stable national life, as well as applications and capabilities achievable with Beyond 5G.

4.3.1.1 Current situation and challenges

The current logistics policy in Japan is in line with the "Comprehensive Logistics Policy Outline (FY2021-2025)" [4], which was decided by the Cabinet in June 2021. The present situation of logistics is summarized in this policy outline and in the current trends surrounding logistics [5]. The logistics industry is faced with problems related to labor shortage, vulnerability of the distribution network against disasters, changes in the international logistics environment, and the introduction of new technologies. To respond to these problems, Japan's logistics industry has to deal with the following:

1. Response to the serious decline in population and labor shortages
2. Ensuring the safety and security of the people amid the worsening and more frequent occurrence of disasters
3. Enhancing digitalization and innovation through the realization of Society 5.0
4. Ensuring the sustainability of the global environment and attaining the SDGs
5. Response to the coronavirus pandemic

4.3.1.2 Future vision

The following measures are being taken in response to the issues listed in section 4.3.1.1

1. Thorough optimization of the entire supply chain by promoting logistics DX and logistics standardization (achieving simple and smooth physical distribution)
    - (1) Stronger push for digitalization of logistics
    - (2) Promotion of automation and mechanization initiatives aimed at addressing labor shortages and enabling non-contact and non-face-to-face logistics
    - (3) Acceleration of efforts to standardize logistics
    - (4) Construction of logistics and commercial distribution data infrastructure, etc.
    - (5) Training and securing of advanced logistics personnel

2 Promotion of measures to address labor shortages and structural reform of logistics (making the industry appealing to future workers)

(1) Improvement of the working environment necessary to adhere to the maximum limit of overtime work regulations for truck drivers

(2) Efforts to ensure stable transportation for coastal shipping

(3) Promotion of innovative measures to improve labor productivity

(4) Streamlining of distribution channels for agricultural, forestry and fishery products, food, etc.

(5) Ensuring sustainability of last-mile delivery in sparsely populated areas

(6) Measures to secure new labor force

(7) Strengthening of public relations regarding logistics

3 Construction of a strong and sustainable distribution network (robust and flexible logistics)

(1) Construction of a resilient and sustainable distribution network that functions even under emergency situations such as during pandemics and major disasters

(2) Building of a distribution network that contributes to sustainable growth and the strengthening of the international competitiveness of Japan’s industries

(3) Building of a distribution network that ensures the sustainability of the global environment

Although these measures outline the policy planned until FY2025, the technological innovations that Beyond 5G will bring about will likely lead to more sophisticated logistics services in the 2030s. In particular, various applications using innovative communications and network technologies based on Beyond 5G are envisioned in the digitalization of logistics, automation and mechanization, standardization of logistics, construction of data infrastructure, last-mile distribution, and in the building of distribution networks.

4.3.1.3 Applications achievable with Beyond 5G

The following is a summary of the applications that are achievable with Beyond 5G toward the realization of the future vision of logistics depicted in section 4.3.1.2.

- Use of Beyond 5G IoT in warehousing and logistics
  - Example: Tracking and management of location of packages through the use of RF tags and the low-cost, advanced IoT technologies offered by Beyond 5G
- Automatic operation of machines, robots, etc., using Beyond 5G local communication networks in warehouses and distribution facilities
  - Example: Communication and network support inside warehouses and distribution facilities

- Example: Support for automatic operation of machines and robots
- Example: Monitoring of interactions between people, machines, and robots in warehouse and distribution facilities, and avoidance of accidents
- Example: Digitalization, use of IT, and automation of ports so called “cyber ports”

- Streamlining, manpower savings, and speedy transport through the use of drones, connected cars, or ships in logistics
  - Example: Last-mile delivery using drones or self-driving vehicles
  - Example: Unmanned, remote monitoring and maintenance using drones
  - Example: High-speed delivery using high-speed railways, high-speed vehicles, and high-speed drones
  - Example: Automatic or semi-automatic, efficient, high-volume transportation by platooning or use of road trains
  - Example: Mass transportation and modal shift by self-navigating ships or automatic freight trains
  - Example: Cooperation with next-generation mobility (transportation), such as unmanned taxis and flying taxis
  - Example: Integration with Smart Cities
- Global coverage through the use of NTN, etc., including offshore routes
  - Example: Logistics support through global coverage using satellites and HAPS
- Optimization of logistics using BD/AI, application of Beyond 5G cloud and digital twins
  - Example: Look-ahead for production and delivery, optimization and automation of mixed loading and routing
  - Example: Optimization, streamlining, remote operation, and training using AR
  - Example: Security and privacy protection against cyber-terrorism and crime
  - Example: Support for network and cloud redundancy and complementarity against natural disasters

4.3.1.4 Capabilities required in Beyond 5G

In section 4.3.1.3, we summarized the applications for warehousing and logistics that are achievable with the use of Beyond 5G. In this section, we examine the capabilities for Beyond 5G in each application.

➢ Use of Beyond 5G IoT in warehousing and logistics
  - Ultra-low power consumption: There are many applications where battery charging is not possible in tracking luggage or storing goods for a very long time. Ultimately, battery-less IoT devices will be required through the use of backscatter communications.
  - Ultra-massive connectivity: Numerous connectivity will be required in warehouses and distribution facilities that handle many packages.

- Automatic operation of machines, robots, etc., using Beyond 5G local communication networks in warehouses and distribution facilities
    - Ultra-low latency, time synchronization accuracy, ultra-security, resiliency and reliability: Low latency, high time synchronization accuracy, and high resiliency will be required for automatic operation of machines and robots.
    - Positioning and sensing: Wireless sensing combined with wireless communication will require high-precision location information for automatic operation of machines and robots.
    - Ultra-security, resiliency and reliability: Physical security within the facility, communication and network security, and resilience against disasters, terrorism, or crime will be needed.
- Streamlining, manpower savings, and speedy transport through the use of drones, connected cars, or ships in logistics
    - Ultra-low latency, time synchronization accuracy, ultra-security, resiliency and reliability: Low latency, high time synchronization accuracy, and high resiliency will be required for automatic operations.
    - Positioning and sensing: High-precision location information for automatic operations will be required.
- Global coverage through the use of NTN, etc., including offshore routes
    - Universal coverage: Network connectivity through satellites and HAPS will be needed for areas that cannot be covered by ordinary ground networks.
- Optimization of logistics using BD/AI, application of Beyond 5G cloud and digital twins
    - Ultra-fast and large capacity: Large communication capacity will be needed for big data and digital twins.
    - Machine learning and artificial intelligence: More efficient production and delivery will be needed, including efficient analysis of large amounts of data and demand forecasting.
    - Shift to cloud, network virtualization and slicing, edge computing, etc.: High-level network functions will be required for various applications in warehousing and logistics.
    - Ultra-low latency, time synchronization accuracy, ultra-security, resiliency and reliability: Real-time digital twin updates will require low latency, high-precision time synchronization, and highly reliable communications.
    - Positioning and sensing: Wireless sensing combined with wireless communication will require the creation of digital twins using high-precision location information.
    - Ultra-security, resiliency and reliability: Privacy and confidentiality protection, as well as resilience, redundancy, and complementarity against disaster, terrorism, and crime will be needed.

The capabilities required by each above mentioned application are shown in Table 4.3-1.

Table 4.3-1 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
IoT in warehousing and logistics			X		X					
Automatic operation		X		X		X	X			
Drones, connected cars or ships in logistics		X		X		X	X			
NTN, etc., including offshore routes								X		
Cloud and digital twins	X	X		X		X	X			

Applications in warehousing and logistics industries in Beyond 5G era is shown Figure 4.3-1.

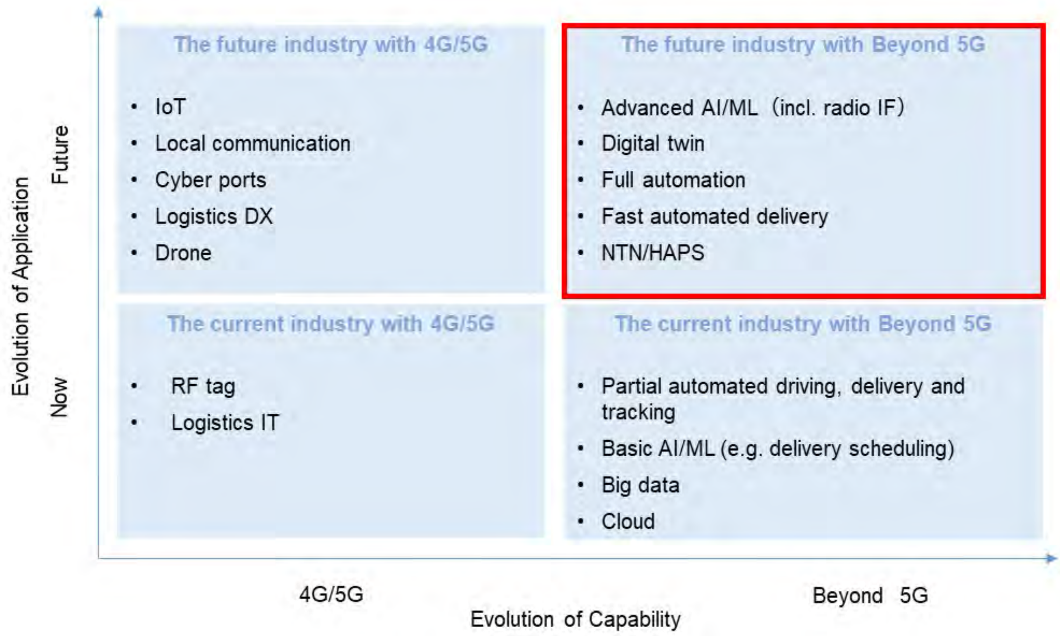

Figure 4.3-1 Warehousing and Logistics industries in Beyond 5G era

4.3.1.5 Summary

This section examined the current situation and future vision of warehousing and logistics and described the capabilities for Beyond 5G that are needed to the future vision. The required capabilities would be ultra-low power consumption, ultra-massive connectivity, ultra-low latency, time synchronization accuracy, ultra-security, resiliency and reliability, positioning and sensing, universal coverage, ultra-fast and large capacity, machine learning and artificial intelligence, and cloud capabilities.

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4.3.2 Aviation

4.3.2.1 Current situation and challenges

The number of air travelers is on an increasing trend, reflecting growth of the global economy. As of 2021, due to the impact of the COVID-19 pandemic, passenger traffic has temporarily declined since 2020, but the International Air Transport Association (IATA) has predicted that it will grow steadily starting 2023 by 5% above the level before COVID-19 [1]. If the effects of the pandemic are mitigated, global demand for air travel should expand to 5.5 billion passengers in 2030.

Forecasts made prior to the pandemic pointed to market growth in communication services for aircraft passengers by approximately 1.5 times over the five years beginning in 2021 [2]. In addition, a survey showed that one in three passengers considers the availability of telecommunication services when selecting an airline [3]. Passenger demand for comfortable space and time within the aircraft is seen to increase further.

Technical evolution of aircraft is being pursued through the use of low-carbon fuels, use of electric power, acceleration of flight speed, and use of wireless connections for non-passenger communications in the aircraft. The introduction of electric power is predicted to start around 2025, and the ratio of electric power use rising to 4.4% in 2035. For business jets that travel a distance of several tens of kilometers, adoption of fully electric engines is being considered, and for regional jets that travel more than several hundred kilometers, use of hybrid or fuel-cell-based systems is being considered [4]. Further, technology development is also underway to increase flight speed. Supersonic airliners, which have disappeared from commercial use after the Concorde [5], will likely be reintroduced. Likewise, sub-orbital flights combining large-scale rockets and "Starship" spacecraft will enable high-speed point-to-point travel [6]. Shifting to wireless connections for communication wiring in aircraft is desirable to reduce weight; for example,100,000 wires with a total length of 470 km weigh a total of 5,700 kg [7].

Air traffic management systems are being designed for safe, secure, and efficient operations. Advanced air traffic management systems are currently being developed, e.g. through the Collaborative Actions for Renovation of Air Traffic Systems (CARATS) roadmap by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) in Japan [8], the Single European Sky ATM Research (SESAR) program in Europe [9], and the Next Generation Air Transportation System (NextGen) project in the U.S. [10].

In light of these developments, the challenges facing the aviation industry in 2030 are: responding to the growing demand for global aviation, meeting diverse aviation needs, becoming more climate- and environment-friendly, enhancing air traffic control, and further improving safety and security [11].

(1) Responding to the growing demand for global aviation

The increased demand for air travel will require the capacity to handle high-density operations at congested airports and areas; improvement of access to airports, including via land and sea; reduction of time spent on passenger procedures; and addressing the shortage of human resources in aviation industry including pilots.

(2) Meeting diverse needs

The services required of the aviation industry are becoming more diverse, e.g. the use of business jets and other aircraft by companies, organizations, or individuals for commercial purposes will become more widespread. Services at airports and aircraft must be improved to suit diverse passenger needs. Other than passenger demand, the demand for air cargo transport fueled by global e-commerce is also increasing, pointing to the need for computerization of cargo processing and streamlining of hazardous materials checks. Demands are also growing for new services such as drones and flying cars, e.g. air taxis.

(3) Climate and environment friendliness

Realizing a decarbonized society entails the use of fuel-efficient aircraft and equipment and further weight reduction. The International Civil Aviation Organization (ICAO) is aiming to improve fuel efficiency by 2% each year and not increase the total volume of emissions after 2020. For jet fuel for aviation, sustainable aviation fuel (SAF) is being developed to reduce CO_2 emissions. In Japan, the domestic SAF produced at pilot plants passed the international standards quality inspection for jet fuel for aviation and has been supplied for actual scheduled operations [12]. SAF is seen to become widely used. In addition, measures to reduce CO_2 emissions in airport facilities and vehicles, as well as to turn airports into renewable energy hubs, are also required for the decarbonization of airports [13].

(4) Sophistication of air traffic control

A system for controllers to accurately determine the position of the aircraft and support simultaneous departures and arrivals even under poor visibility is needed at busy airports handling many departures and arrivals. Likewise, sophistication is required in terms of enabling satellite navigation for all flight phases, creation of a readily accessible comprehensive network of operational information, international sharing of information, coordinated air traffic operations, and enhancement of weather information use such as through creation of weather forecast information specifically for aviation and utilization of local weather information around aircraft.

(5) Safety and security

As a measure against terrorism, advanced safety inspection equipment that can reduce the burden while increasing the rigor of security inspections must be introduced.

4.3.2.2 Future vision

On the basis of the current state and challenges of the aviation industry described in section 4.3.2.1, and the need for the industry to enhance efficiency and develop services through further innovation in response to the growing global demand and expanding market, we envisioned the following four future images for the aviation industry.

- Safe, secure, convenient, and comfortable air travel
  Provide passengers with safe, secure, and stress-free transportation and comfortable in-flight services.
- Sustainable air transport
  Improve fuel efficiency and achieve decarbonization through sophistication of aircraft. Eliminate manpower shortage through piloting assistance and unmanned operations.
- High-density operations
  Increase density of operations through advanced air traffic control.
- Introduction of new aviation services
  Develop non-traditional aircraft services using drones and flying cars. The comeback of supersonic aircraft will significantly reduce aircraft travel time.

4.3.2.3 Applications achievable with Beyond 5G

The following are the applications achievable with Beyond 5G towards realizing the future vision for the aviation industry described in section 4.3.2.2.

Services for safe, secure, convenient, and comfortable air travel

<u>Application 1-1: Safe, stress-free travel</u>

Provide the best routes and means of transportation from passengers' homes to airports and within airports. Use advanced safety inspection equipment, such as high-performance body scanners and X-ray inspection apparatus in safety inspections to improve security and reduce inspection time. Centrally manage check-in and boarding gates using facial recognition and biometrics to reduce the burden on passengers. Enable all users to travel comfortably inside vast airports through automated, AR-aided navigation and platooning using personal mobility services. Shorten delays in pick-up and enable tracing of luggage through luggage management using smart tags. These technologies will contribute to the resolution of challenges (1), (2), and (5).

<u>Application 1-2: Comfortable in-flight services</u>

Provide more comfortable space and time by providing personalized environment and entertainment in aircraft. Automatically select and suggest personalized air conditioning, lighting, seating arrangements, and dining services. Provide entertainment devices that are also linked to mobile devices (smartphone, tablet, and PC) as shown in Figure 4.3-2, to provide a communications environment similar to that at home. Use immersive VR/AR in the aircraft to provide new entertainment for extended air travel. In addition, provide in-flight communications which improve the operation efficiency of cabin crew and allow for sharing important information among cabin crew and grand staff. These technologies will contribute to the resolution of challenge (2).

Figure 4.3-2 VR/AR in aircraft

Application 1-3: Support of grand operations

Wireless communications with ultra-low latency, ultra-security, resiliency and reliability that covers all areas of airport enable automated driving and operation management of airport mobility vehicles, such as baggage carriers, ramp buses and snowplow vehicles. In addition, for aircraft maintenance, large amount of maintenance data can be uploaded and analyzed by ultra-fast and large capacity, which contributes to shorter maintenance times. These technologies will contribute to the resolution of challenge (1) and (5).

Advanced aircraft for sustainable air transport

Application 2-1: Improved fuel efficiency and decarbonization

Progress in the use of new materials and wireless connections inside the aircraft will lead to improved fuel efficiency and reduced CO_2 emissions due to the reduction in the weight of the aircraft. Converting wiring inside aircraft into wireless connections requires a high-speed security process that does not interrupt communications is necessary. Use of wireless connections will enable configuring aircraft equipment irrespective of wiring. These technologies will contribute to the resolution of challenge (3).

Application 2-2: Piloting assistance and operation control

Advancements in air traffic control and aircraft sensors will enable navigating aircraft with one instead of two pilots or by unmanned operations. Unmanned operations require fine-grained control in conjunction with operation control, especially during takeoff and landing, and are supported by ultra-security, resiliency, ultra-low latency communications between ground control and aircraft. In case of bad weather especially turbulence caused by cumulonimbus clouds or unexpected events, the system will autonomously capture and share information detected by sensors, such as peripheral conditions (cloud development, wind speed, wind direction, etc.), vibration of the aircraft, and subtle equipment conditions, with the control center in real time. In addition, ultra-fast and large capacity communications between aircraft and aircraft allow to share detailed information in real time. These technologies will contribute to the resolution of challenge (1).

Air traffic control for efficient navigation

Application 3-1: High-density operations

As shown in Figure 4.3-3, high-density operations at crowded airports will be achieved by improving the accuracy of air traffic control and increasing the control-processing capacity, thereby increasing the number and reducing the waiting time for takeoffs and landings. To improve the accuracy of air traffic control, high-precision weather forecasting and aircraft control will be carried out to enable simultaneous takeoff and landing of multiple aircraft even in bad weather. In addition, sophistication of satellite navigation systems will enable improving the operation rate by increasing landing opportunities under poor visibility conditions [11]. To increase control-processing capacity, controlled air space will be divided in accordance with altitude to increase the number of aircraft that can be handled by control operations. Moreover, globally centralized management of all aircraft routes from departure to arrival will improve predictive capability and facilitate comprehensive management of navigational information, thereby enabling smarter air traffic control and more efficient navigation. These technologies will contribute to the resolution of challenges (1) and (4).

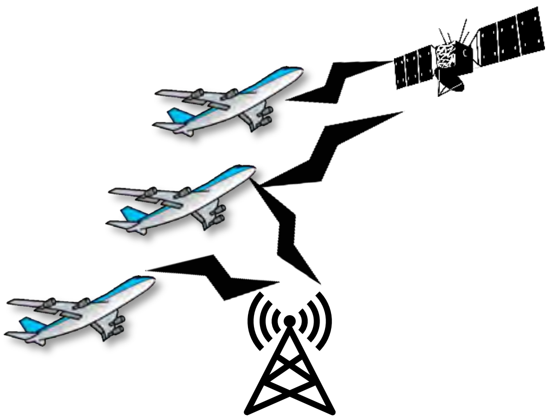

Figure 4.3-3 High-density operations

Introduction of new aviation services

Application 4-1: Drones, flying cars

The drone market is expanding, with drones increasingly being used for logistics, metering, surveillance, disaster response, infrastructure inspections, and other activities. In terms of airspace and flight methods, legislation in each country will progress along with advances in drone performance and capability, and use of drones for various applications will become more prevalent. Also, as examples of flying cars, taxis and emergency vehicles will start to be operated over the air to reduce travel time. Navigation can either be manned by pilots or unmanned through autopilot or remote-controlled operations. Preventing accidents in the airspace where drones and flying vehicles travel and ensuring safe and convenient navigation for both manned and unmanned flights will require precise positioning, advanced sensing functions, ultra-security, resiliency and reliability and ultra-low-latency communications for controlling the aircraft. Technologies for ultra-fast and large capacity communications with fast-moving aerial objects will also be needed for communications with aircrew and passenger smartphones and other electronic devices. These technologies will contribute to the resolution of challenge (2).

<u>Application 4-2: Supersonic aircraft</u>

The problems associated with supersonic passenger aircraft were the sonic boom (the loud thunderous sound generated by shock waves) and poor fuel efficiency. Designing aircraft to minimize the sonic boom will expand the airspace for supersonic flights. Likewise, designing aircraft to reduce air resistance will improve fuel efficiency, promote the use of supersonic passenger aircraft, and significantly reduce travel time between major cities. High-altitude routes, including outer spaces (altitudes above 100 km), will also likely be included as navigational routes. There will be a need for extending coverage, tracking supersonic movement, and achieving low-latency communications for control signals, ultra-fast and large capacity mentioned in application 1-2 for passenger services in these airspaces. These technologies will contribute to the resolution of challenge (2).

4.3.2.4 Capabilities required in Beyond 5G

This section discusses the requirements for Beyond 5G to realize the use cases mentioned in section 4.3.2.3.

<u>Application 1-1: Safe, stress-free travel</u>

- Ultra-fast and large capacity, ultra-low latency for implementing image recognition and biometric authentication for many passengers
- Vehicle-to-vehicle communications, positioning and sensing for personal mobility
- Smart tags using low-cost, battery-free, low-power devices for luggage tracking
- Ultra-low power consumption communication, positioning and sensing

<u>Application 1-2: Comfortable in-flight services</u>

- Use of ultra-fast and large capacity inside aircraft
- Flexible communication routing to meet traffic demands between aircraft and base stations (e.g., utilizing multiple routes such as GEO, LEO, HAPS, and ATG)
- High security to prevent unauthorized access to in-flight communications

Application 1-3: Support of grand operations

- Ultra-low latency, ultra-security, resiliency and reliability to support automated driving and operation management
- Ultra-fast and large capacity for uploading aircraft maintenance information

Application 2-1: Improved fuel efficiency and decarbonization

- Wireless aircraft connections in aircraft
  - Ultra-fast and large capacity for IFE (In-Flight Entertainment) monitors in the passenger seats
  - Ultra-low latency, ultra-security, resiliency and reliability and ultra-low power consumption sensor devices for wireless aircraft connections (harness) that are comparable with wired connections

Application 2-2: Piloting assistance and operation control

- Expansion of coverage to include airspace to enable ultra-security, resiliency and reliability
- Ultra-low latency between control towers and aircraft and between aircraft and aircraft
- Ultra-reliable, ultra-low latency between the aircraft controller and multiple sensors

Application 3-1: High-density operations

- High-precision positioning and sensing, environmental sensing, and ultra-reliable, ultra-low-latency over the air
- Seamless terrestrial and non-terrestrial communications

Application 4-1: Drones, flying cars

- Expanded aerial coverage
- Ultra-security, resiliency and reliability, ultra-low latency, positioning and sensing at low altitudes for remote control
- Ultra-fast and large capacity with fast-moving objects

Application 4-2: Supersonic aircraft

- Expanded coverage to include outer space, and continuous communications during ultra-fast travel

Table 4.3-2 summarize required Beyond 5G capabilities for the application of the aviation industry.

Table 4.3-2 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
1-1 Stress-free travel	X				X		X			
1-2 Comfortable in-flight services	X			X						Flexible communication routing
1-3 Support of grand operations		X		X						
2-1 Improved fuel efficiency and decarbonization	X	X		X	X					
2-2 Piloting assistance and operations control		X		X	X			X		
3-1 High-density operations		X		X						Seamless terrestrial and non-terrestrial communications
4-1 Drones, flying cars	X	X					X	X		
4-2 Supersonic aircraft		X						X		continuous communications during ultra-fast travel

Figure 4.3-4 maps the applications for the aviation industry with the development of the industry on the vertical axis and the development of communication networks on the horizontal axis. The upper right quadrant shows the applications achieved by both the development of the aviation industry and the realization of Beyond 5G.

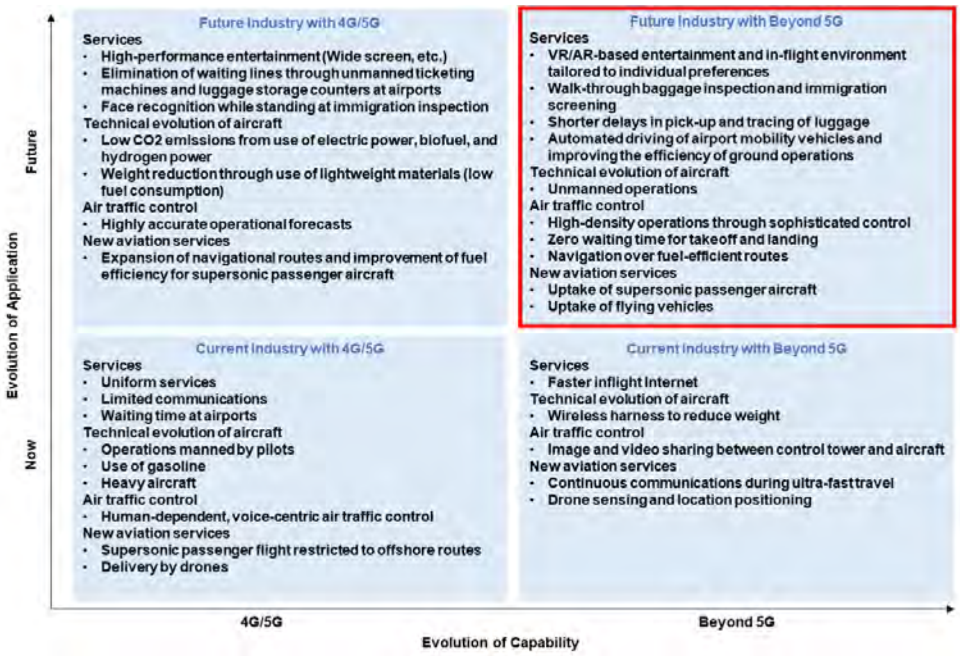

Figure 4.3-4 Aviation industry in Beyond 5G era

4.3.2.5 Summary

This section examined the current situation and future vision of aviation and described the capabilities for Beyond 5G that are needed to the future vision. The required capabilities would be ultra-fast and large capacity, ultra-low latency, ultra-security, resiliency and reliability, ultra-low power consumption, positioning and sensing and universal coverage.

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4.3.3 Railway

4.3.3.1 Current situation and challenges

From 2020 onwards, demand for rail travel will likely shrink due to the population decline, the changes in working styles, the advances in the Internet society, and the commercialization of automated driving technologies [1], [2]. Therefore, existing railway businesses will most likely undergo reduction in profits, making it urgent to improve the quality of transportation services that are centered on railways, and to evolve and grow the services [3].

Meanwhile, a shift toward environmentally friendly rail freight transportation is foreseen in line with the advent of the carbon-neutral era. Also, under the new normal era, it will be necessary to strengthen existing railway businesses by utilizing digital technology and to create new revenue businesses by promoting DX [4]. Going forward, the railway industry needs to maintain and improve profitability both through the enhancement of existing businesses and the exploration of new businesses.

In consideration of these developments, the industry must shift from providing services centered on railway infrastructures into creating new values for society centered on "abundance" in daily life, toward 2030. Further technological innovations are needed to improve efficiency, and to expand and develop services. To achieve this, we envisioned the following four future images for the railway industry.

- Safe and secure railway transportation with zero accidents
- Driverless operations and early restoration of train operation schedules in the event of disorders
- Further enhancement of the appeal of transportation services and optimal, comfortable, and seamless mobility
- Building cities where services are individually optimized and everyone can live with contentment

The railway industry in 2030 should: (1) achieve zero accidents and early restoration in the event of a disorders, (2) respond to the serious aging and population decline, (3) mitigate the deterioration of infrastructure systems and enhance the appeal of services, and (4) build distributed society in response to the over-concentration in urban areas.

<u>Challenge 1: Achieving zero accidents and early restoration in the event of disorders</u>

Railway transport is a service that involves being responsible for people's lives and property; therefore, first and foremost, requires safety. In addition to realizing the ultimate goal of completely eliminating accidents, the prompt restoration of railway transportation services from disruptions due to natural disasters and equipment failures is an unavoidable challenge to address.

Challenge 2: Responding to the serious aging and population decline

As the aging and decline of the population continue, there will be a serious shortage of personnel needed in the provision of railway transportation services and the maintenance and operations of railway equipment. Driverless operations, introduction of robots to operational and maintenance work, and AI-based smart maintenance in accordance with the conditions of equipment and trains are therefore imperative.

Challenge 3: Mitigating the aging infrastructure systems and improving services

The functions of railway transport must be maintained through appropriate response to imminent massive earthquakes, intensifying meteorological disasters, and aging infrastructures [5]. It is also imperative to deal with the aging of the systems supporting railway transport. Moreover, various life and work styles are required under the new normal era. Demands for on-board remote work services in-transit and for MaaS services that seamlessly combine railway and non-railway transportation means are increasing.

Challenge 4: Building distributed society in response to the over-concentration in urban areas

The coronavirus pandemic has triggered the demand for various life and work styles not bound by location or time through the fusion of transport and communications, from the traditional center-oriented urban development where people and functions are concentrated in metropolitan areas. The creation of distributed society where the city centers function together with satellite cities and suburban areas must be considered. Cites should enable lifestyles that harness mobility robots in various scenarios [6].

4.3.3.2 Future vision

We will focus on four future images we envision for the railway industry in 2030: (1) safe and secure measures, (2) automation, (3) improving transportation services, and (4) distributed society.

Future vision 1: Safe and secure measures

- Improvement of railway safety using IoT and sensor technologies
- Operational support by robots and camera surveillance of station platforms and level crossings
- Use of drones and robots to monitor situations in disaster areas and accident sites
- Operation control and status monitoring using ultra-reliable communications
- Early restoration of train operation schedules in the event of transport disorders
- Smart maintenance using AI in accordance with the conditions of the equipment and trains

Future vision 2: Automation

- Driverless operations via remote control and autonomous driving
- Early restoration of train operation schedules in the event of transport disorders
- Introduction of robots for operation and maintenance work
- Remote control of maintenance cars
- Smart maintenance using AI in accordance with the conditions of the equipment and trains

Future vision 3: Improving transportation services

- Next-generation ticket and payment systems that provide all-in-one travel information, purchase and payment functions
- Seamless collaboration combining the best transportation means with other providers and MaaS
- Touch-less and gate-less ticket gates for smooth railway use
- In-transit remote work services supporting a variety of life and work styles
- Capturing inbound demand through enhanced multilingual translation and cashless payment services
- High-capacity, low-latency next-generation railway radio

Future vision 4: Distributed society

- Building distributed society that connect city centers and regions
- Smart cities where mobility and robots are used in various scenarios
- Free living spaces that are optimized for diverse individual lifestyles

4.3.3.3 Applications achievable with Beyond 5G

The following are the applications achievable with Beyond 5G in the railway industry.

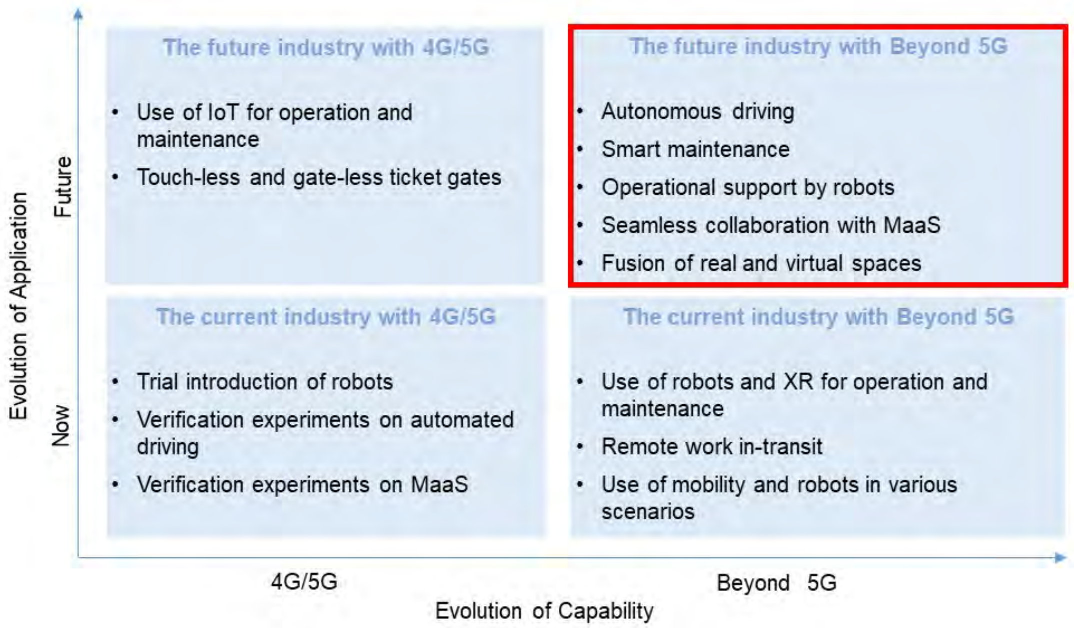

Figure 4.3-5 Railway industry in Beyond 5G era

4.3.3.4 Capabilities required in Beyond 5G

Table 4.3-3 represents the required Beyond 5G capability given in the previous section.

Table 4.3-3 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Autonomous driving		Several ms		10^{-6}			x			
Smart maintenance	x	x		x	x		x			
Operational support by robots	x	x		x						
Seamless collaboration with MaaS		x	x					x		
Free living spaces	x	x		x			x	x		

4.3.3.5 Summary

This section examined the current situation and future vision of the railway industry and described the capabilities for Beyond 5G that are needed to the future vision. The required capabilities would be ultra-fast and large capacity, ultra-low latency, ultra-massive connectivity, ultra-security, resiliency and reliability, ultra-low power consumption, positioning and sensing, and universal coverage.

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4.4 Telecommunications, IT

4.4.1 Current situation and challenges

Telecommunications and IT has continued to advance in various ways in recent years, with the speed and capacity of ICT infrastructure increasing, use of smartphones expanding rapidly, and emergence of the Internet of Things (IoT) which connects a wide range of objects to networks.

The COVID-19 pandemic continues to spread rapidly around the world. Restrictions on people's movements have led to complete reliance on ICT, such as for telework. Also, disasters and drastic changes in the global situation have highlighted the need to secure means of communication in the event of an emergency. Clearly, we must further enhance the sophistication and resilience of ICT infrastructures and thoroughly review the relevant systems to support the digitalization of society.

To maintain smooth social life and economic activities, it is necessary to solve following issues and promptly realize an environment in which 5G and other ICT infrastructure can be utilized comprehensively. This will also require implementation of mechanisms to project phenomena occurring in physical space into cyberspace using real-time big-data and to discover solutions through digital transformation, by creating smart solutions and promoting reliable and free flow of data [1].

i. Consolidate advanced communications infrastructure

Transitioning to a data-driven society will require collection of as much of the latest data as possible using various types of sensors, regarding various phenomena occurring everywhere, whether on land, at sea, in the air or in space. To implement safe and reliable synchronization of this extremely advanced data everywhere, spanning both physical space and cyberspace, will also require communications infrastructure that is even more advanced than 5G, which features high speed in addition to low latency and massive connectivity. This will require data networks, which form a nervous system encompassing the entire country, to be consolidated with advanced optical networking. This is expected to lead to extremely large volumes of data flow and corresponding increases in energy consumption, so communication infrastructure that can deliver this data safely, while keeping a check on the environmental load, is also needed [1][2].

ii. Build platforms that work autonomously

We expect that all kinds of machines, such as industrial and household robots and self-driving vehicles, will be able to obtain information about their own location, orientation, acceleration, and other nearby external factors and operate autonomously, but certain technologies and rules will need to be established in order for this to occur smoothly [2].

iii. <u>Strengthen security and disaster resilience</u>

With the expansion of IoT, we expect that various social systems such as traffic and logistics systems will be subject to optimized control using ICT. With ICT expanding through all of society in this way, it is more important than ever to strengthen the security and disaster resilience of these ICT systems. Achieving this will require planning to ensure the reliable, free and safe flow of data, maintaining cyber-security, protecting personal privacy, and promoting disaster prevention measures. Wired and wireless networks throughout Japan will also need to be consolidated to provide stable, high speed and large capacity, even during disasters, and to minimize regional disparity [1][2].

4.4.2 Future Vision

The following are concrete aspects of the society anticipated for 2030s [1].

1. An inclusive society
   - A society in which everyone can play an active role, by eliminating various types of disparity, including regional, national, and other geographical barriers and other impediments such as age.
   - This will require technologies such as "extreme telepresence," which will provide users with realistic experiences accessing anywhere in the world, even from home, through avatars and robots; and "extreme cybernetics," which will extend users' physical and cognitive abilities by providing real-time support for their thoughts and actions, using wearable devices or other means.

2. A sustainable society
   - A society achieving sustainable growth and convenience, without loss for society, by replicating the real world in cyberspace, performing optimizations there, and feeding back the results to the real world.
   - This could be implemented by technologies such as "ultra-mutual-control networks," which will enable transport systems without congestion or waiting for traffic lights by having objects collaborate in controlling each other; and "ultra-real-time optimization,; which could eliminate waste of food and other products by using AI to estimate demand and coordinating supply among many locations in real time.

3. A dependable society
    - A human-centered society in which everyone can work with confidence and the bond of trust is not shaken, with communication networks, which are societal infrastructure, guaranteeing safety and security autonomously.
    - Such a society would be realized by establishing technologies such as "ultra-autonomous security," which would guarantee safety and security using AI to automatically detect, defense and repair issues in the background; and "ultra-fail-safe networks," which would maintain uninterrupted communication even during disaster, by flexibly and autonomously changing aspects such as network structure, power consumption and how power is supplied.

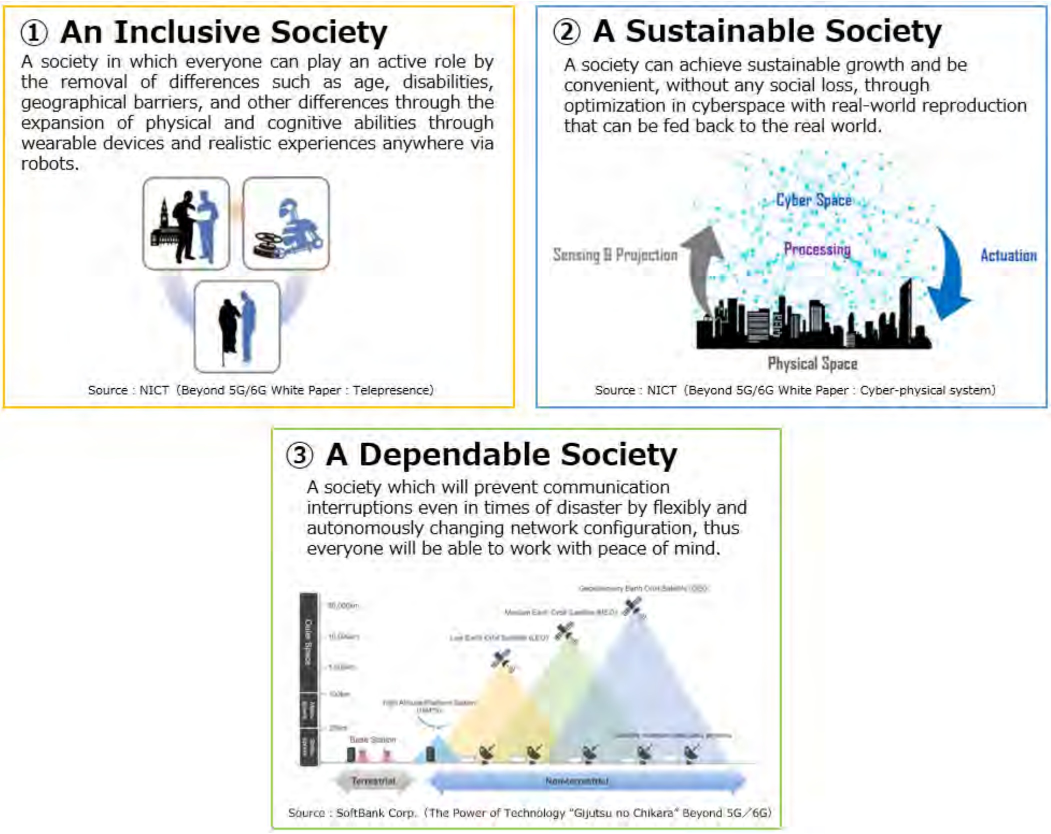

Figure 4.4-1 Three aspects of the society vision for the future

4.4.3 Applications achievable with Beyond 5G

Beyond 5G is expected to realize the followings as the technological evolution.

- **A vigorous and resilient society through development of CPS**

Cyber Physical Systems (CPS) are advancing, with interactions among objects in physical space being reproduced in cyberspace in the form of digital data. By analyzing this huge amount of digital data using AI and other techniques, conditions in physical space can be understood at any time, and decisions about what to do next in physical space can be made, based on the information.

Transition to data-driven society, which maximizes use of CPS in social and economic activity, can create new value from the large amounts of accumulated data, give form to implicit knowledge, transition from analyzing the past to predicting the future, and move from partial optimization to total optimization. From another perspective, it will enable the items and services needed to be provided to the people that need them, when they need them and only what they need. This will achieve “Society 5.0,” resolving various societal issues and losses, while also enabling economic growth.

CPS is expected to develop with the introduction of 5G, which features high speed, low latency, and massive connectivity, but in the 2030s, we can expect physical space to be recreated in cyberspace with even more speed and detail. As a result, functions in physical space will be expanded by cyberspace, and even when circumstances are inadequate in physical space, social and economic activity will continue smoothly with support from cyberspace, creating a resilient and vigorous society [1].

- **Digitalization with no one left behind, for a safe and secure society with no digital divide**

This part of the vision is to create a society that enables a diversity of happiness, in which all people have more opportunities to encounter and experience the value of digitalization and can benefit from it regardless of geographic, economic, bodily or other constraints they may or may not have, in an environment that enables all people and organizations to use the digital technologies they need, when they need them, and to choose services suited to their own needs. This will contribute to increasing productivity and creating new added value, and even if a pandemic or other natural disaster should occur in the future, effects on life and the economy will be held to a minimum, maintaining a resilient society that can continue to function [3].

4.4.4 Capabilities required in Beyond 5G

To realize the future vision, in addition to further advancement of 5G functions, the following Beyond 5G capabilities will be required.

A vigorous and resilient society through development of CPS requires Society 5.0, which enables both social life and economic activities through cyberspace by means of Beyond 5G’s Ultra-fast and large capacity, Ultra-low latency, Ultra-massive connectivity (Figure 4.4-2).

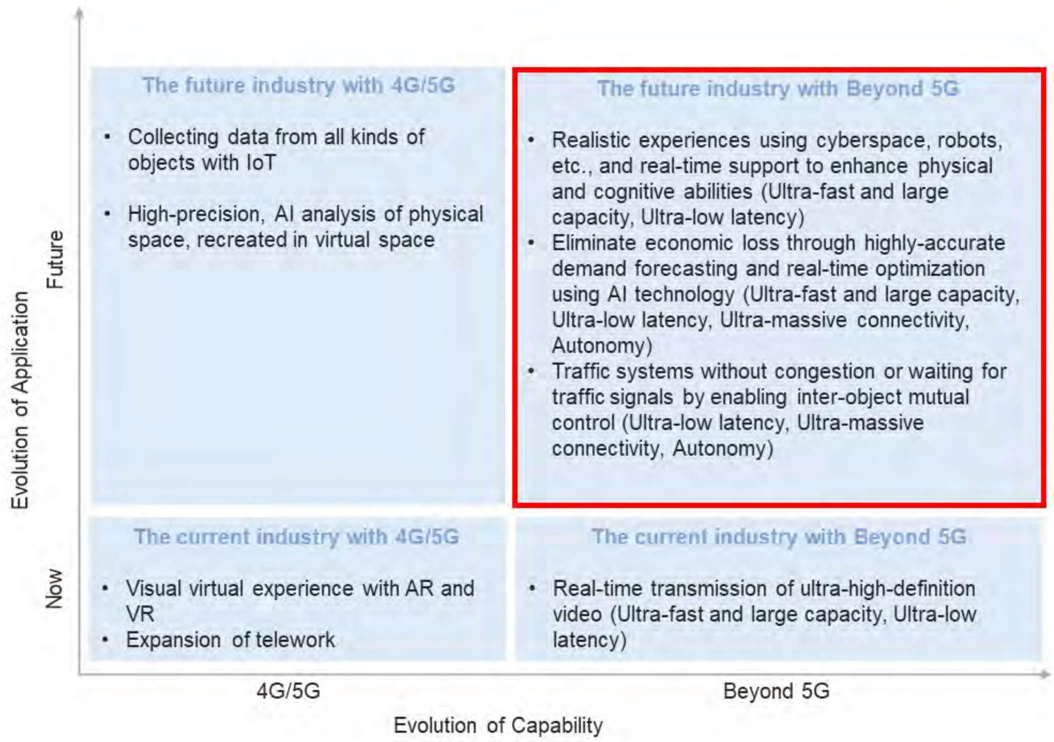

Figure 4.4-2 Telecommunication and IT industries in Beyond 5G era
(A vigorous and resilient society through development of CPS)

Digitalization with no one left behind, for a safe and secure society with no digital divide, all people can benefit from digitalization and work with peace of mind, with security guaranteed autonomously. Furthermore, 100% coverage of the national land by terrestrial and non-terrestrial networks are expected to solve the issue of developing a stable network that will not lose communications even in the case of disasters (Figure 4.4-3).

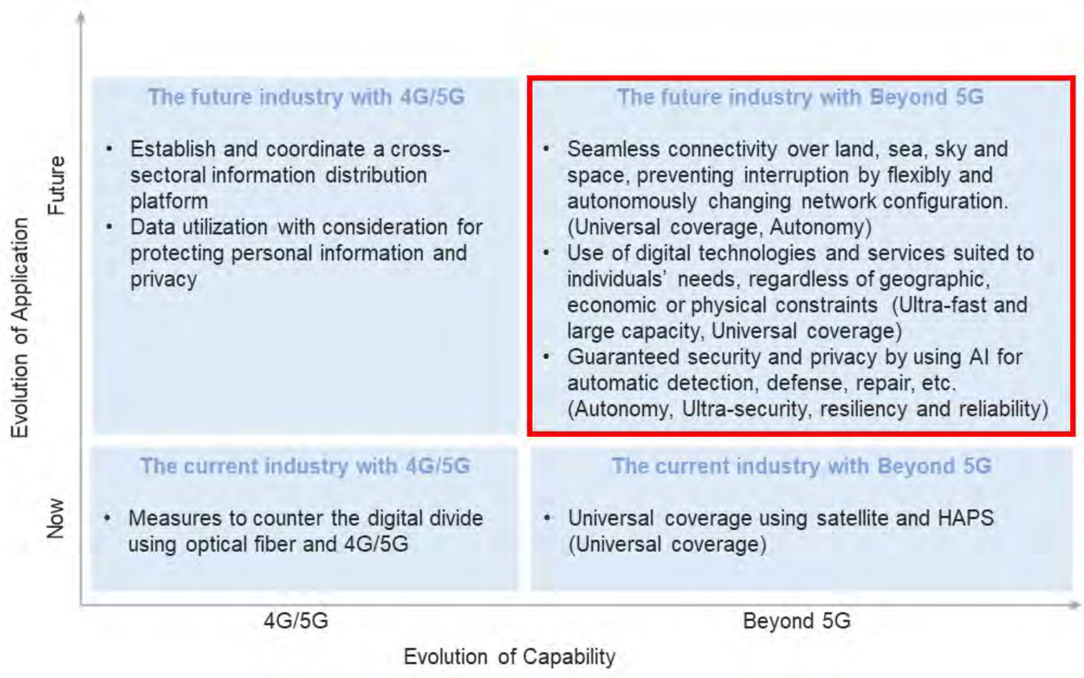

Figure 4.4-3 Telecommunication and IT industries in Beyond 5G era
(Digitalization with no one left behind, for a safe and secure society with no digital divide)

Table 4.4-1 shows the capabilities required in Beyond 5G to realize the societies described above.

Table 4.4-1 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
A vigorous and resilient society through development of CPS	X	X	X						X	
Digitalization with no one left behind, for a safe and secure society with no digital divide	X			X				100% land coverage	X	

4.4.5 Review of 5G

The White Paper Committee of the Beyond 5G Promotion Consortium conducted a review of 5G with the aim of leveraging discussions of issues related to the standardization and commercialization of 5G in discussions for Beyond 5G.

The following are some of the opinions given during the review.

- For 5G, three usage scenarios (enhanced Mobile Broadband, Ultra-Reliable and Low Latency Communications, and massive Machine Type Communications) were defined at the initial stage of standardization, clarifying the major directions for ensuing discussions. 5G became widely recognized because the usage scenarios were simple and easy to understand, and relevant standards organizations such as 3GPP, ITU, and GSMA worked together to promote 5G.

- With the addition of ultra-low latency and massive simultaneous connectivity to ultra-high speed, the addition of functions for new markets such as V2X, and the guarantee of network flexibility through the introduction of network slicing, 5G served as a network that could meet a wider range of communication requirements.
- The emerging demand for high-speed communications in smartphones and other devices was promptly responded to by expanding the scope of its applications while releasing relevant specifications in stages. Also, the adoption of technologies for utilizing 4G core network infrastructures for 5G and of technologies for sharing frequencies between 4G and 5G has led to the early deployment of 5G.

Therefore, in 5G, there were many aspects in standardization and commercialization that had been effectively carried out for promoting the smooth progress of its standardization and uptake. These initiatives should be followed in Beyond 5G.

On the other hand, there were also opinions about the need for improvement in the future.

- The advancement in functionality has widened the scope and prolonged the period of standardization, leading as well to higher cost of system development and operations.
- While the three usage scenarios were widely recognized by users, there were cases where gaps arose between the actual network performance and the expectations of the users. This is because the indices only refer to the wireless section, the performance values were not guaranteed, and all the requirements at the time of introduction could not be met due to the phased release.

As a possible measure to address these issues, functions should be selected by taking into an account the needs of actual users, the implementation of the system, and the status of operations, among other factors. Going forward, we must try to avoid creating undue expectations and gaps, such as by clarifying the release timing of functions and devising ways to properly communicate network performance.

4.4.6 Summary

This section described the application achievable with Beyond 5G in consideration of the social situation surrounding the telecommunications and IT industries, the importance of upgrading ICT infrastructures, the envisioned future, and the issues to address. The required capabilities would be ultra-fast and large capacity, ultra-low latency, ultra-massive connectivity, ultra-security, resiliency and reliability, universal coverage, and autonomy. Points that should be considered in future discussions were also mentioned based on a review of 5G issues. Beyond 5G is a key element that enables seamless communications regardless of location, bridging the digital divide and bringing about a smarter society. Beyond 5G should bring about further development of the telecommunications and IT industries in the future.

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4.5 Media

4.5.1 Current situation and challenges

This section summarizes current conditions in the media industry, including television and radio broadcasting, publishing, printing, newspapers, advertising and social media.

- Television and radio broadcasting

  Television and radio broadcasting are a familiar societal platform that provides highly accurate information and a wide range of content to all residents, from emergency broadcasts to entertainment programming. Television and radio broadcasts are provided through terrestrial and satellite broadcasting, cable, and also through internet television and radio services [1]. In recent years, program catch-up and simultaneous distribution are becoming common over the internet, and initiatives are progressing, which allow access to content at any time or at any location, with devices other than the TV or radio, such as a PC or smartphone [2]. Broadcast services are also being expanded to support content with even higher resolution, using 4K and 8K technology, as demonstrated by the 4K/8K distribution of the opening ceremony and video from some competitions in the 2021 Tokyo Olympics. In addition to higher-resolution video, experiential content using 360-degree video and 3D video is also being investigated. Broadcasting is also expected to continue to be an important medium in the future, and promises to deliver a diverse range of services and content on a variety of devices, including televisions and radios, but also wearable devices such as extended-reality (XR) glasses and even microscopic XR devices that will allow users to enjoy content without particular awareness of the device at all [3]. On the other hand, surveys have shown that viewers, and particularly the younger generation, are spending more time watching video and enjoying music online than they are watching television or listening to the radio [4].

- Printing, publishing, newspapers and advertising

  These industries, including newspapers, magazines, books and comics, encompass a wide range of genres, from information to entertainment, and provide a wide range of very specialized information on many topics and regions. This information is provided on paper media, but also can be viewed on PCs, smartphones and other devices, so there are multiple ways to access the content, according to users' lifestyle or other factors. Considering the comic market as an example of this trend, in just a few years since e-comics began to appear, the e-comic market exceeded paper-based media (comic books and magazines), accounting for more than half of the market in 2020 [5]. With this trend toward digitization of publishing, there is also a shift toward digital advertising [6]. We expect that, as with video and audio broadcasting, it will be possible to enjoy services and content on various devices in the future.

- Social media

  Social media, including social networking services (SNS), blogs, video distribution services and others, are popular as tools that enable users to distribute their own content and communicate with each other easily over the internet. It has earned a place as a new source of information for many because it can deliver content better suited to each individual's interests, and can provide very specialized content very quickly. The breadth of content that individuals can distribute themselves has also expanded, with blogs and SNS for text and image content, and services like YouTube and TikTok for video content. With the global COVID-19 pandemic since 2020, the need to stay home has led to increased subscribers to video distribution services, and with fewer opportunities for real live events, online live events have also increased, expanding the range of content and services utilizing these digital platforms [7,8]. We expect development of social media content, with these digital platforms at its core, will continue to accelerate in all genres in the future.

As described above, digitalization of content is advancing in media industry. We can expect that content will continue to become more diverse and richer, and that changes in application and content trends will become more dynamic in the future. As such, ways to provide various content and applications securely and efficiently will require further investigation.

4.5.2 Future vision

Content and services in the media industries are already being provided online using digital platforms, and it is expected that in 2030 and thereafter, almost all content will be provided online, and be accessible through the internet. As such, users will not be limited by time, physical location or device, and will be able to receive a wide range of services and content matching their individual lifestyles. Users will also be able to deliver richer services and content of their own easily, regardless of time, physical location or device. As content becomes richer, we can expect even more immersive media, including holographic communication and internet embodiment. Concepts such as cyber-physical systems (CPS), digital twins and the metaverse are examples of service-linked distribution that use virtual space as a platform. In addition to providing conventional media content in virtual space, we expect new media services that exceed the physical constraints of the real world will also be provided. Further, as media content grows and diversifies, personalization is expected to become a more important element, so that users can easily enjoy content suited to their preferences. Technologies such as AI will be used to optimize content distribution for individual users, and the scope of optimization studied will range from application-layer, such as recommending and selecting content to distributed to users, to lower layer aspects such as optimizing how the selected content will be distributed (e.g.: optimizing the delivery path, including access technology and device).

4.5.3 Applications achievable with Beyond 5G

As application achievable with Beyond 5G to realize the future vision of media depicted in section 4.5.2, holographic communication can be considered.

4.5.4 Capabilities required in Beyond 5G

Concepts expected for Beyond 5G are summarized below, based on the anticipated future for media industry as described in the previous section.

- Beyond 5G will enable everyone to access digital content at anytime, anywhere, and using any type of device, and every user will be able to distribute their own content. A global ecosystem that makes possible a rich and diverse multimedia application developer community will be built.
- More immersive media experiences through holographic communication and embodiment of the internet
- Provision of services suited to individual users' viewing environment and devices.

Expectations from a technical perspective are summarized below.

- Further improvements in frequency efficiency, expanded coverage, and reduced latency.
- Support radio access systems and network architectures to enable efficient content delivery using both broadcast and communication.
- Utilize AI to implement diverse personalization and customization.

Figure 4.5-1 shows a mapping between the conceptual and technical aspects described above.

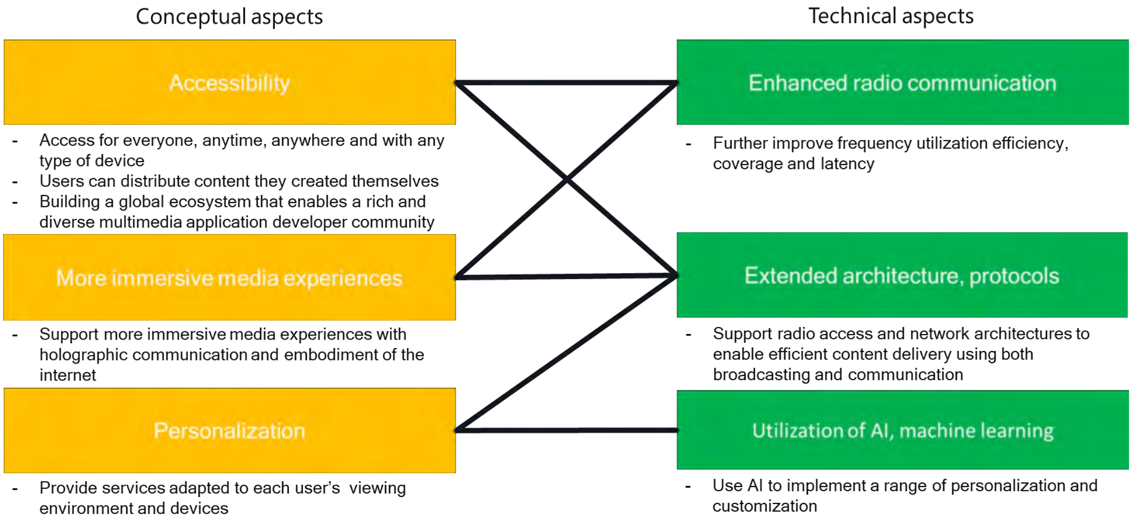

Figure 4.5-1 Expectations for Beyond 5G

Table 4.5-1 summarizes the capability required for Beyond 5G based on the application described in section 4.5.3 and the expectations for beyond 5G addressed above.

Table 4.5-1 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Holographic communication	X									

4.5.5 Summary

This section examined the current situation and future vision of media industry and described the capabilities for Beyond 5G that are needed to fulfill the future vision. The required capabilities would be ultra-fast and large capacity such as throughput of tens to hundreds of Gbps.

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4.6 Energy, resources and materials

4.6.1 Current situation and challenges

The energy, resources and materials industry consists of the industries producing raw materials, mainly through mining mineral resources and harvesting in forestry, and other industries that procure and process those raw materials and supply materials to other industries. These raw materials, including ferrous and non-ferrous metals, non-metals, plastics, and paper are used in a wide range of other familiar products and are the basis for many other industries [1]. This section deals with trends in the mineral-resource and paper-production industries.

- Mineral resource industry

  In the mineral resource industries, ferrous and non-ferrous (copper, aluminum, rare metals, rear earths, etc.) are produced by a limited number of countries. In recent years, demand for resources by emerging nations has resulted in wide fluctuations in metal prices, along with other issues such as the prospect of resource nationalization, so that securing and procuring resource supplies globally has become more important. Goals for mineral resource industries to achieve a sustainable society in terms of these resources include securing foreign resources, maintaining reserves, conserving and developing alternate resources, recycling, and developing marine resources. Note that recycling, or collecting used products and recovering non-ferrous metals has been called “urban mining,” and advances in this technology and operations are promising, while developing marine resources is also promising for supplying resources in the future [2].

  Mining worksites are harsh work environments in terms of safety and the environment, and there are cases where new technology has been introduced to automate mining equipment and transport trucks, to improve safety and security for workers and reduce mining costs. Such sites can be expected to continue using machinery for automation and improving efficiency [3][4]. Worksites for developing marine resources, which are promising in the future, are similarly expected to be harsh, so we can expect that use of machinery to automate and improve efficiency and safety will also be important.

  On the other hand, industries that refine and process mineral resources are more like manufacturing industries, with large-scale production facilities and high energy consumption, so they have initiatives to reduce carbon and environmental impact, and we can expect them to continue improving efficiencies with big data, automating by introducing robots and other measures for digital-transformation (DX) of production as well as introducing energy-saving machinery impact, and we can expect them to continue improving efficiencies with big data, automating by introducing robots and other measures for digital-transformation (DX) of production as well as introducing energy-saving machinery.

- Paper industry

In the overall paper industry, the structural trend toward paperless workflows and shrinking demand is unavoidable due to improvements in usability of electronic media with development of digital technologies, but there is some increase in demand for cardboard (demand for use with foodstuffs and increased exports to China, but relatively low demand from EC). To improve profit margins in the industry, paper manufacturers are suspending and reorganizing factories to reorient their business toward cardboard and working on developing new business. Examples of new businesses include developing cellulose nanofiber (CNF) as an alternative to plastic, and power generation using biomass [5].

Companies in the paper industry have long been involved in the reforestation business and paper recycling activities, in efforts to maintain resources and protect the environment [6][7]. In reforestation, effort has been put into forest management to absorb and fixate carbon dioxide as has been developed overseas recently, and enable sustainable resource procurement, while also increasing the value of forests [8]. To maintain resources, mechanization of logging and timber transport in reforestation sites and forest management is being done, but there is still much work that depends on manual labor in planting and maintaining forests, such as clearing underbrush, so it would be desirable to implement more efficient, safe and secure work environments. Possibilities being considered by the forestry industry include using machinery to automate and improve efficiency in both planting and maintaining forests as well as harvesting and transporting timber, and also introducing remote monitoring to prevent illegal logging and for other purposes [9].

In paper recycling, Japan has a relatively high recycling rate. Advanced recycling projects utilizing IoT technology and big data are being studied and proposed as “venous industries: industries that turn solid industrial waste into reusable resources in production” and use these types of systems could significantly increase rates of recycling [10].

Enterprises producing pulp and paper are also more like manufacturing industries, with large-scale production facilities and high energy consumption, so they have initiatives to save energy and reduce carbon emissions. The industry has taken the lead in declaring (in Jan. 2021) a goal of net-zero CO_2 emissions from production activity by 2050. According to the declaration, this includes initiatives to use renewable energy, to introduce energy-saving equipment and low-carbon vehicles and to improve efficiency with advanced production systems, but in the future will also include use of environmental materials in society (CNF instead of plastic), and expanding CO_2 capture and fixation through forestry [11].

- Issues

The following are issues to be promoted in the resource-mineral and paper-making industries, looking forward to 2030.

  - Automation, improved efficiencies using robotics and machinery, and remote operation and monitoring in mining, marine resource and timber harvesting workplaces
  - Currently, the scope of mechanization and automation is limited, and remote operation equipment is not widespread enough. An objective for the future will be to improve efficiencies by using AI to formalize implicit knowledge from experienced workers in the field and introduce automatic robots. To achieve this, it will be important to consolidate ICT infrastructure such as communication environments with Local 5G.
  - Use of renewable energy to reduce carbon emissions by facilities in resource processing industries and use of IoT and big data to improve efficiencies.

Energy can be conserved by improving production efficiency, automating processes and optimized monitoring of processes such as fault detection. To achieve this it will be important to consolidate ICT infrastructure such as communication environments with Local 5G in factories.

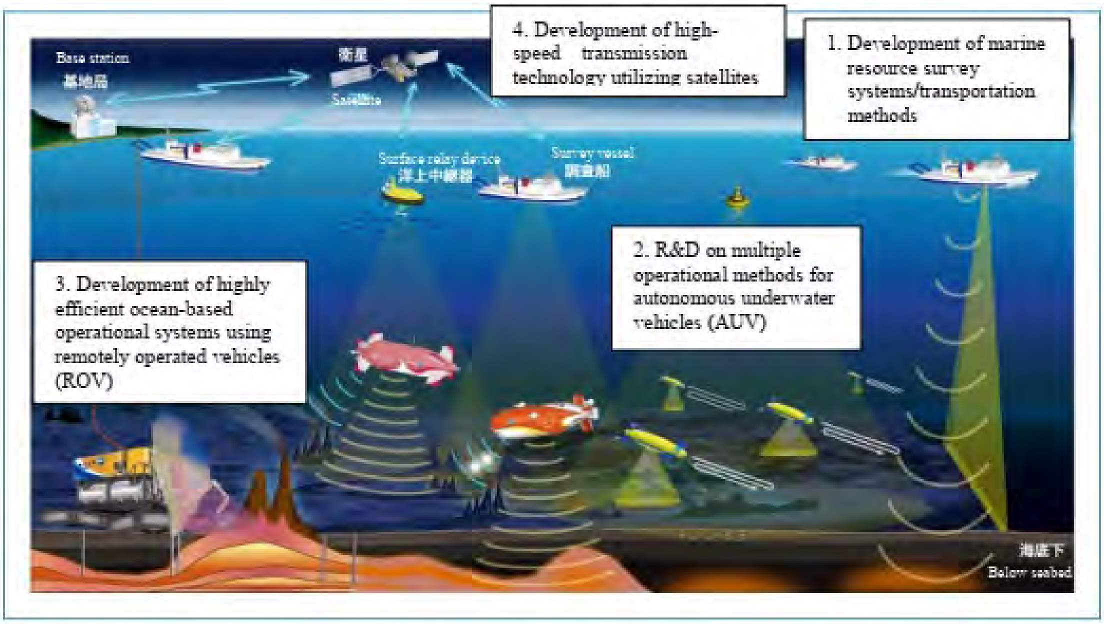
Use of IoT in recycling systems to collect, share and use various types of data (waste material data, storage locations, facility operations data, collection vehicle movement data, etc.), as a form of "Venous industry."

IoT data is used to assess the amount and quality of waste materials, to match supply with demand, to operate collection vehicles efficiently, and to optimize facilities operation and management. It will be important to promote digitalization by consolidating ICT infrastructure, such as the IoT communications environments used to collect the diverse sensor data.

4.6.2 Future vision

- The mineral-resource mining worksite

As mining or marine resource projects become more remote or deeper, advanced communication environments with ultra-low latency and ultra-security and resiliency will be completed, robots and automated systems will be introduced, and remotely operated machinery and drone monitoring will be introduced, reducing personnel and other costs and improving work environments. Big data collection and use of AI is advancing with IoT devices linked seamlessly to the cloud rather than using special and closed local systems, and operational optimizations such as prediction of excavation equipment failure by operations management systems are being implemented. Beyond the excavation worksites, there are also plans to transport the extracted resources, seamlessly linking with transport management systems to implement optimization of the entire value chain



Source: “Recommendations for Developing a New Basic Plan on Ocean Policy -Ocean Policy for Society 5.0-”,Keidanren(Japan Business Federation), *prepared by the Keidanren Secretariat based on website of the Cabinet Office Council for Science, Technology and Innovation
“Next-generation technology for ocean resources exploration(Zipangu in the Ocean)” SIP[13]

Figure 4.6-1 Marine resource survey technologies [12]
developed as part of the Zipangu in the Ocean program [13]

- The forestry worksite

Systematic tree planting is being established for sustainability of paper resources, and communication environments are being improved, even in forested mountain areas, and similar operations management systems using robotics and drones to support work, operate machinery remotely, provide remote monitoring and other tasks, are being implemented to improve efficiencies, reduce personnel and other costs and improve work environments.

Automation of logging | Automatic cable-yarding system | Autonomous driving Forwarder

Source: Excerpt from “Forestry Innovation Field Implementation Promotion Program”, Forestry Agency[9]

Figure 4.6-2 Vision for forestry through innovation

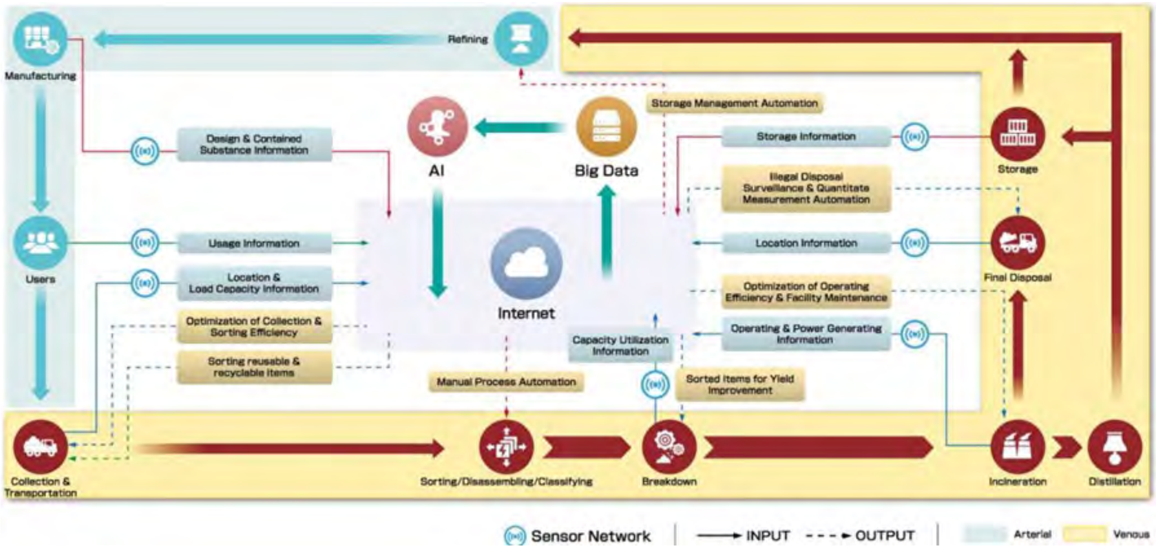
- Factories and recycling

In mineral-resource and paper-production resource processing industries, manufacturing DX is also spreading, with manufacturing IoT using ultra-low latency, ultra-security, resiliency and reliability, ultra-fast and large capacity communication, resulting in optimization of work to increase productivity, save energy, and reduce CO_2 emissions.

Mineral resource processing industries have an important role as the core processing facilities recycling raw materials, and a mineral resource collection network has been built, collecting and using recycling data between group refineries and other companies’ refineries, and each refinery is processing recycled resources on a just-in-time basis. Each refinery understands the operational state of facilities, and is able to operate with overall efficiency using a secure data-sharing and utilization platform.

Similarly, recycling of paper and cardboard is also being done in a just-in-time fashion using infrastructure for collecting and sharing IoT data. As described above, attribute data (location, characteristics, quantity, etc.) regarding the materials collected in recycling activity is collected at various locations, visualized and shared using a secure data sharing and utilization platform, and used to provide necessary processing information, optimize collection routes and otherwise improve overall supply chain efficiency to operate as an efficient “venous industry”.

Services such as the above will be built using cyber-physical systems (CPS) and virtual systems in the Beyond 5G era.



Source: IoT Council of Waste Management and Recycling Web page

Figure 4.6-3 IoT use in the waste management and recycling area [14]

4.6.3 Applications achievable with Beyond 5G

- Remote control and automated operations in restricted access zone

  To ensure the sustainability of the paper industry, a commitment to systematic tree planting is required. Because forested sites located in mountainous areas do not have good human access, remote monitoring, remote control, and automated operations are needed to efficiently grow trees. In addition, to address resource depletion and national bias, active exploration and mining of offshore resources as well as mine development are required.

- Industrial product lifecycle management

  In order to realize a sustainable society, management throughout the life cycle of industrial products shipped from factories is required. Example would be total amount indicator management for mining, separating and refining rare earths in urban mining, and rare earth product traceability.

4.6.4 Capabilities required in Beyond 5G

- Enhanced communication environments with expanded coverage

  In areas such as mountains, mountainous forests and on the sea, where the communications environment is inadequate with 5G, universal coverage will be implemented using satellites (ultra-low-orbit satellites, etc.) or HAPS, making it possible to use ultra-fast and large capacity and ultra-low latency communications environments. This will enable radio communication to be used even in places where it is difficult for people to reach and work, and to automate work or use robots at locations with harsh work environments. For example, using drones for survey work in mountainous or forested mining locations, operating equipment remotely in real-time and promoting power-saving in on-site equipment contributes to sustainability of equipment monitoring and production (parts/material monitoring/preservation system). Projects searching for and mining mineral resources in the seas surround Japan are also examples of using such communication environments. In addition to the above technologies, implementation of underwater communication and sensor technologies that can be used in marine environments are also promising.

- Expansion of automated operations and remote control with ultra-low latency communications

  In the Beyond 5G era, immersive device remote control systems using on-site high-definition video (8K, etc.) / sensors and HMDs / vibration devices are expected as use cases. In this application, highly detailed images are sent. Thus, ultra-fast and large capacity communications are required. In addition, allowed video transmission delay time is 100 msec or less between the site and the operator is desirable to prevent Visually Induced Motion Sickness [15]. This video transmission delay time is classified into a communication delay in Beyond 5G, a delay due to image processing for video compression / decompression processing, and a delay required for display on HMD. For example, the delay due to image processing for video compression and decompression is estimated to be 40 milliseconds or less in consideration of technological progress [15]. In addition, it is desirable that the processing delay time required for display on the HMD is 15 milliseconds or less in order to prevent VR sickness associated with the movement of the viewpoint when wearing the HMD [16]. From these, the performance required for Beyond 5G is 45 milliseconds.

- Reduced power consumption and ultra-massive connectivity

  Ultra-massive connectivity and universal coverage can be used for attaching IDs to all industrial products (traceability) for managing recycling, for managing state at all locations (tracing state of recycling work at disposal facilities) and performing collection work more efficiently. To allow devices to be installed without concern for power supplies at all locations will require a ultra-low power consumption distributed network that can operate for a long time on batteries and use multi-hop relaying, as well as contactless power supply for devices.

A summary of capabilities for each application is shown in Table 4.6-1, A summary of the above discussion is shown in Figure 4.6-4.

Table 4.6-1 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Remote control and automated operations in restricted access zone	X	≦40ms (E2E)						X		
Industrial product lifecycle management			X		X			X		Contactless power supply

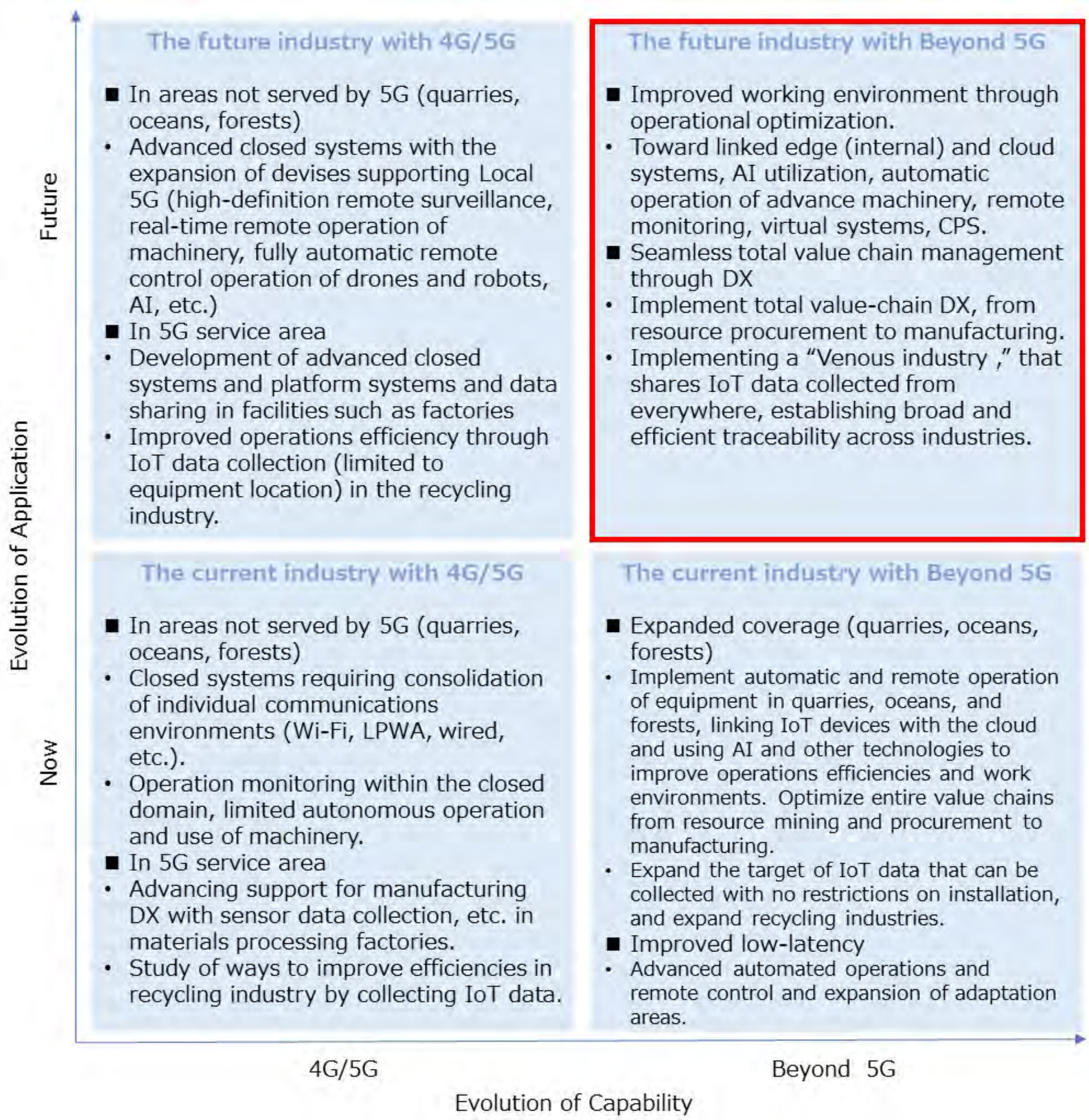


Figure 4.6-4 Mineral resource and paper industries in Beyond 5G era

4.6.5 Summary

This section examined the current situation and future vision of mineral resource and paper industries and described the capabilities for Beyond 5G that are needed to the future vision. The required capabilities would be ultra-fast and large capability, ultra-low latency, ultra-massive connectivity, ultra-low power consumption and universal coverage.

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4.7 Automotive

4.7.1 Current situation and challenges

- Current society and its challenges
  - Restriction in means of transportation in rural areas [1]

    The Japanese population has continued to decline after peaking in 2008, and it has been increasingly difficult to maintain public transportation in the regions due to lack of drivers and deteriorating profitability.

    In addition, while rural areas are characterized by high private vehicle utilization rates, residents without a driver's license may experience restrictions in means of transportation in the daily life.

  - Travel time constraints due to population concentration in urban areas [1]

    Urban areas are characterized by regions with high population density and high utilization of private vehicles as well as regions with high utilization of public transportation.

    In both cases, there are many areas with severe traffic congestion and long travel and commuting times, which reduce quality time for daily life. Furthermore, as the aging of the population progresses, the number of residents who cannot travel using private vehicles increases, thereby possibly limiting the freedom of movement among the elderly citizens.

    On the other hand, in areas where public transportation is highly utilized, the concentration of private vehicles and logistics vehicles causes traffic congestion, which results in reduction of quality time for daily life.

  - Energy and environmental issues[2]

    To achieve carbon neutrality, Japan has declared a policy of reducing greenhouse gas emissions by 46 percent until 2030 and to virtually zero by 2050 (both compared with 2013). Accordingly, the Ministry of Economy, Trade and Industry has announced its "Green Growth Strategy through Achieving Carbon Neutrality in 2050," which includes the industrial policies in the automotive industry. The policies toward carbon neutrality in the automotive industry mainly advocate for a shift to electric vehicles, the use of decarbonized fuel, and the development of infrastructures to support the use of electric vehicles and decarbonized fuel. At the same time, as part of "changing the way vehicles are used," there is also a need for social implementation of high-precision digital maps, over-the-air (OTA) functions, and short-range communication functions, which are foundational to next-generation transportation systems.

    Environmental issues that have become global in scale and traffic accidents caused by driver's negligence have become common social issues not only in Japan but also around the world. Automobiles are in the midst of technological innovations, such as shift to electric power, connected, and automated driving, as the industry endeavors to solve these problems. Further, there are also rising expectations for the introduction of comprehensive mobile services such as sharing and Mobility as a Service (MaaS), in consideration of the society in which these platforms are implemented [8].

- Current status of safety driving assistance
  - ITS-related services [3], [4], [5]

Universal traffic management systems (UTMS) under the jurisdiction of the National Police Agency have been deployed on ordinary roads in all prefectures. Mechanisms have been socially implemented to reduce pollution, such as exhaust gas, noise, and vibration, by directing traffic flow through the control of traffic signals and by encouraging the use of public transportation systems such as buses. Although currently limited to some areas and some vehicles, ITS Connect, which is promoted by the ITS Connect Promotion Consortium, provides services such as notification of the presence of emergency vehicles through direct vehicle-to-vehicle communications, and issuance of alerts to drivers upon detection of oncoming vehicles and pedestrians at intersections through road-to-vehicle communications. Its use as V2X technology in the future is also anticipated, as demonstration experiments are being carried out under the Cross-ministerial Strategic Innovation Promotion Program to study its applications in automated driving.

On expressways and motorways, toll collection is carried out by the ETC system under the jurisdiction of road operators, contributing greatly to the automation of toll stations and mitigation of congestion. In addition to traditional ETC applications, ETC2.0 has recently enabled the provision of services such as traffic avoidance support, cashless payment, safety driving support, and disaster assistance.

  - Safety driving assistance enabled by 4G and 5G [6]

Both 4G- and 5G-based cellular V2X (C-V2X) technologies are compatible with wide-area services utilizing cloud and AI. They can provide a wider range of safety driving assistance than conventional ITS, such as forecasting various hazards that may occur around the vehicle while driving and assisting the driver in making the necessary actions for avoiding collision during emergencies.

Further, they can also be flexibly operated without depending on communication infrastructures for different service applications. They can be used in different communication formats; namely, for short range communication services such as Vehicle To Vehicle (V2V), Vehicle To Infrastructure (V2I), and Vehicle To Pedestrian (V2P), which are directly provided without cellular networks, as well as for relatively wide-area services such as Vehicle To Network (V2N), Infrastructure To Network (I2N), and Pedestrian To Network (P2N), which are provided over cellular networks and the cloud.

In addition, in combination with the enhanced functionalities of in-vehicle human machine interfaces (HMI) and head-up displays (HUD), high-value-added services such as AR navigation, which provide more intuitive, real-time, and safety driving support, will become widespread, and new connected services combining traditional ITS and infotainment will emerge.

- Current status of automated driving
  - Autonomous driving [7]

The current possible level of automated driving is Level 3, wherein the in-vehicle system performs all dynamic driving tasks on expressways (in limited domain or operational design domain (ODD)) and enables drivers to respond appropriately to intervention requests from the system when it is not possible to continue automated operations. Although the vehicle carries out automated driving autonomously and hands-off and eyes-off driving is possible, wherein the driver is partially relieved from obligations to steer the wheel or look ahead, the driver must still be prepared to intervene and drive any time.

  - Automated driving technologies where 4G and 5G can contribute

Dynamic maps and software for different ECU (Electronic Control Unit) and on-board media can be downloaded any time via OTA. Some of the information elements of dynamic maps will be collected from the vehicle to the edge data center, and databases will be linked across sectors to provide a variety of high-value-added services.

In addition, V2I infrastructure collaboration with roadside cameras, traffic lights, sensors, etc. can complement the automated driving functions, thus, enabling higher visibility around automated-driving cars compared with autonomous driving. It can, therefore, contribute to the reduction of handover operations between automated driving Level 3 and lower levels. In terms of communication systems, it will be possible to develop the different forms of communications used in automated driving, such as road-to-vehicle, vehicle-to-vehicle, and pedestrian-to-vehicle communications, using a single standard. It can also contribute to promoting the uptake and creation of a global ecosystem for automated driving.

- 5G Use Cases and Communications Requirements

In this section, typical use cases defined in 5G that is expected to be further evolved are shown below, which can clarify the evolution path from 5G to Beyond 5G.

  - Cooperative maneuver / Emergency trajectory alignment

In this use-case, information on the driver's intention, trajectory corrections/changes necessary to avoid e.g. obstacles and prevention of the accidents is shared with surrounding vehicles. Then, cooperative control of steering, acceleration and brakes takes place.

At autonomous driving Levels 2 and 3 [15], communication requirements for sharing the driver's intention with surrounding vehicles, such as changing lanes and merging at the highway, are a data rate of 0.5 Mbps, a message size of 300-400 Bytes, an end-to-end maximum latency of 25 msec., and a communication reliability of 10^{-2} [13, 14].

At autonomous driving levels 4 and 5 [15], when an obstacle is detected, the trajectory for accident prevention is calculated and the surrounding trajectory is immediately detected. The safety-critical situation is communicated to the adjacent vehicles, which perform the trajectory correction in order to carry out the urgent reaction cooperatively. The communication requirements for this situation include a data rate of 30 Mbps, the maximum end-to-end latency of 3 msec. Reliability of communications is specified to be 10^{-5} within a 500-meter range [14].

- Cooperative perception

The on-board sensor information of the vehicle, or the sensor data from the UE-type RSU, can be exchanged in real time between adjacent vehicles to sense the environment. This is the use case with the assumption that sensing performance is enhanced as such to help prevent accidents.

At autonomous driving levels 2 and 3 [15], V2X-supported vehicles detect and categorize the user vehicles that cannot periodically send messages for ITS services. V2X-supported vehicles periodically transmit the classification of obstacles detected by their sensors, moving velocity, and direction. To achieve this, the message size is 1600 bytes and the maximum end-to-end delay is 100 msec. and 10^{-2} reliability [14].

For autonomous driving levels 4 and 5 [15], it aims to detect areas that are not visible to local sensors, such as behind corners of houses, curves, or objects (i.e., omnidirectional visual field). Assuming data with low- and high-resolution, the communication requirements are 50 Mbps with codec compression and 1 Gbps for raw data, a maximum end-to-end latency of 3msec., and a communication reliability of 10^{-5} (in emergency case) [14].

- Remote Driving

This is a use case for remote control of a vehicle by one operator for a short period of time. The operations of construction vehicles and snow removing vehicles are mainly assumed. Messages of remote driving application (camera data, sensor data, status data, confirmation, etc.) are sent from the controlled vehicle to the remote operator via the network. Meanwhile, the remote operator sends command messages of remote driving application to the vehicle via the network. In this case, the data rate is 25 Mbps (uplink) / 1 Mbps (downlink) and the end-to-end latency is 5 msec. and communication reliability of 10^{-5} [14].

4.7.2 Future vision

- Vision of society in 2030
  - Rural areas

    Residents will use automated-driving-based mobile services to travel between public and commercial facilities. Community buses and shared taxis will be available, enabling everyone to travel freely, leading to revitalization of the regions.

    Various services using mobile vehicles, such as telemedicine, food, and retail will be available without the need for elderly people to travel [1].

  - Urban areas

    Residents will travel to their destinations through automated driving, enabling free use of travel time for work and communicating with family and friends. Various means of transportation will be seamlessly integrated, enabling efficient transportation to each destination [1].

  - Mobility as a Service (MaaS)

    Multiple public transportation systems and other transport facilities and services will be optimally combined to establish a common mobility platform for searching, booking, settling payments, etc. This will enable the uptake of mobility services that are highly convenient for everyone, both for rural and urban areas [1].

  - Use of vehicles

    In anticipation of the digital society of Beyond 5G in 2030, vehicles will be used as edge devices to perform as much advanced information processing as possible, including automated driving, in order to minimize power consumption in networks and cloud data centers. High-precision digital maps, OTA functions, and short-range communication functions, which are foundational to next-generation transportation systems, will be implemented in vehicles [2].

  - Deployment of robust cloud-based networks

    With the spread of connected vehicles equipped with automated driving functions, all sorts of data, such as the several hundred types of sensor data for different vehicles, camera images, and LiDAR (Light Detection And Ranging) point cloud information, will be always transmitted and stored on the network via wireless communications and will be used to continuously update high-precision digital maps. The volume of communication data is estimated to become 100 times more[9], and new vehicle sales for automated-driving vehicles to become 100 times more than those in 2020 [10]. Combined, these numbers point to the processing of a massive volume of data over the network. Therefore, robust cloud-based networks will be deployed to provide sufficient storage resources to handle such massive amounts of data, as well as provide computing power for servers to process those data without delay.

➢ Collaboration with Smart Cities

Social implementation of smart cities will move forward to address the social issues in Japan, such as population decline and energy consumption problems. As a result, the functions and roles of vehicles will change significantly. For example, connecting electric vehicle (EV) and plug-in hybrid vehicle (PHV) batteries with home energy management systems (HEMS) will enable flexible response to power supply and demand from power companies, leading to optimization of power demands across the city. Vehicles will, therefore, become more integral to society and people's lives.

4.7.3 Applications achievable with Beyond 5G

- Safety driving assistance

Beyond 5G's inclusive infrastructure and the application of Network as a Service (NaaS) will enable the resilient functionality for vehicles to continue to use a variety of services through satellite, High Altitude Platform Station (HAPS), and inter-vehicle communications, even when traffic infrastructure is down, such as in the event of a disaster. In addition, being able to provide communication resources in accordance with each user's usage and service requirements, also by coordinating and collaborating with the systems using different technologies and interfaces, it is possible to efficiently and flexibly operate a wide range of resources, and further to enhance and evolve Beyond 5G capabilities and services. Taking these views into consideration, it is necessary to keep an eye on the evolution of other technologies (for example, IEEE 802.11bd). Also, sensing functions that use high frequency bands for Beyond 5G base stations will enable higher resolution, wider range, higher-precision angle positioning, and more accurate detection of fast-moving objects than conventional radar, thereby greatly facilitating the development of infrastructures that contribute to safety driving assistance and automated driving.

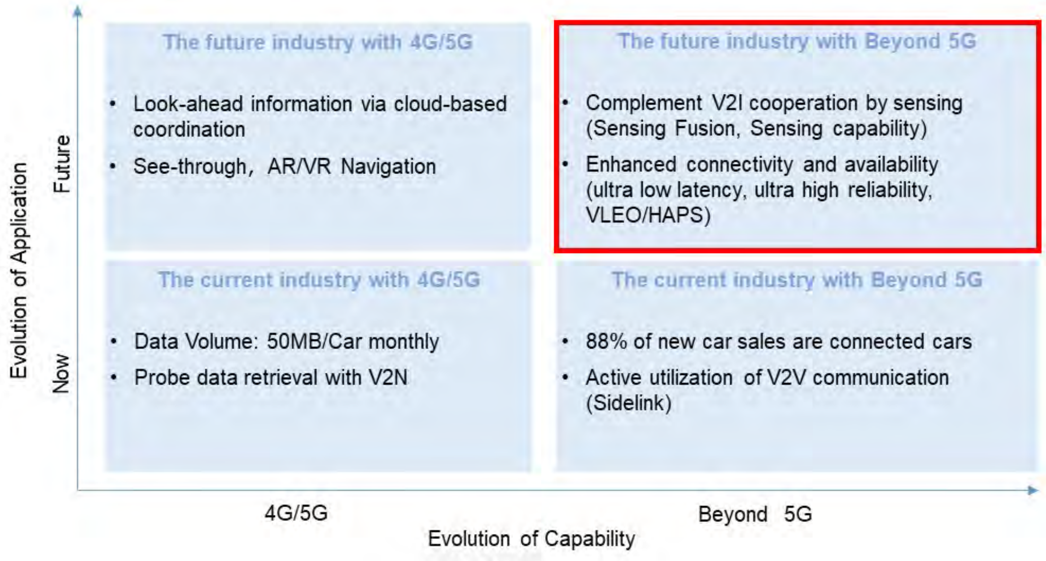

Figure 4.7-1 Automotive Industry in Beyond 5G era (Safety driving assistance)

- Automated driving

New functions integrating sensing and communications to be introduced in Beyond 5G will bring about the benefits of shared hardware and shared spectrum between radar and communication functions and will contribute to the design of future vehicle models [12].

Sensing functions of Beyond 5G base stations will enable higher resolution, wider range, higher-precision angle positioning, and more accurate detection of fast-moving objects than conventional radar, thereby greatly facilitating the development of infrastructures that contribute to automated driving, as well as safety driving assistance. Also, by complementing the information from LiDAR and other sensors that should be mounted on vehicles, these infrastructures can enhance positioning accuracy as well as reduce vehicle prices, which will also contribute to promoting the spread of automated-driving vehicles.

Infrastructure collaboration via Beyond 5G, ultra-fast and large capacity transmission of uncompressed data, sensing, and AI will also enable more accurate and rapid acquisition and transmission of information required for remote vehicle-control decisions. This will in turn contribute to the reduction of the number of remote monitoring and remote operation personnel and to the expansion of remote monitoring and remote operation areas [12].

Further, with ultra-fast and large capacity communications, Beyond 5G will enable the transmission of imaging data of road conditions and traffic information, thereby contributing to the maturity of the dynamic map infrastructure.

As we move toward an advanced automated driving era, the computational processing capacity required for learning and reasoning on singe vehicles is foreseen to expand dramatically as various sensors become more sophisticated. Although multiple- (or other-) viewpoint information obtained by single vehicles is limited, the computation load may cause the neural network to excessively expand and may prevent carrying out calculations within a very short span of time solely by relying on the vehicle's GPU and NPU capabilities. These possibilities should be considered. In order to address these requirements, distributed learning and inference, involving intelligence relying on multiple cars and base stations (edge clouds with AI), is required for network-assisted automated driving with the integration of Beyond-5G and AI

On the infrastructure side, as a consideration for a low-carbon society, advanced AI operations for automated driving will be controlled to dynamically allocate functions between the vehicle and the edge cloud according to the data center PUE (Power Usage Efficiency). It will also have the ability to distribute training data storage for automated driving AI algorithms between the vehicle edge cloud and the data center (federated training)

Possible applications include enhancing the robustness of OTA security through quantum cryptography, use of ultra-fast and large capacity communications for digital twin technology to eliminate head-on collision accidents through timely and adaptive decision-making based on the situation at intersections without traffic signals, and suggesting emergency avoidance actions to the driver by prediction of dangerous situations.

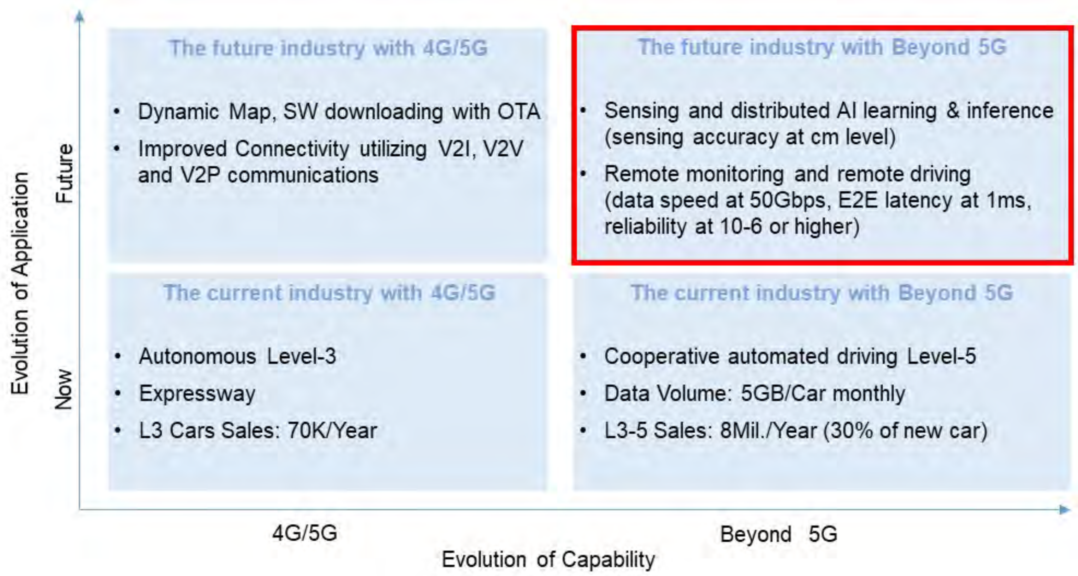

Figure 4.7-2 Automotive Industry in Beyond 5G era (Automated driving)

4.7.4 Capabilities required in Beyond 5G

(a) Ultra-fast and large capacity

For the dynamic maps used in safety driving assistance and automated driving, assuming the use of 12 5.5-megapixel in-vehicle cameras (Sony IMX490) to take 10 images per camera, uploading images every 10 seconds, and applying lossless compression at 25%, the required transmission speed will be around 100 Mbps per vehicle [16]. Also, assuming the use of 12 4K-cameras taking 10 images per camera, uploading images every second, and applying lossless compression at 25%, the required transmission speed will be around a few Gbps per vehicle.

Traffic density (number of vehicles/km) will reach 108 vehicles /km in cases such as during traffic congestion in highways [11]. Assuming 5 to 20 % of those vehicles upload images to a server in the cloud at the same time, the simultaneous connection capacity per cell needed for roadside units or base stations will be more than 10 Gbps.

(b) Ultra-low latency

For remote driving, since the remote driver controls the vehicle on the basis of images from the in-vehicle camera, data with two different sizes must be exchanged simultaneously between the vehicle and the control network; namely, the image and the control signal. Remote driving in the 5G era was mainly envisioned for robotic applications such as for construction vehicles and snow blowers. In Beyond 5G era, however, remote driving applications will be more diverse, including use in regional mobility services and the removal of vehicles parked on roads during disasters. The requirements for such applications need to be properly defined.

Transmitting an approximately 8K image from the vehicle to a remote location at 60 fps with no compression will require a transmission speed of approximately 50 Gbps for the uplink wireless section. On the other hand, for the control signals, the current 100 msec operating cycle of many in-vehicle sensors will be optimized for automated driving in the 2030s, which will require an end-to-end communication delay [13][14] of 1 msec[3] and communication reliability[4] [14] of 10^{-6} or higher.

(c) Ultra-security, resiliency and reliability, positioning and sensing

Sharing of collective perception for safety driving assistance entails not only omnidirectional sharing of sensor information by multiple vehicles, but also responding to events such as emergency trajectory correction by taking advantage of Beyond 5G sensing capabilities. As a requirement, performance exceeding the requirements of 5G must be achieved; namely, low end-to-end latency of less than 1 msec and high communication reliability of 10^{-6}, while maintaining the data transmission speed expected for 5G; namely, 1 Gbps over a range of 500 meters or more.

Further, improving environmental sensitivity through sensor fusion and sharing technology is crucial for enhancing safety driving assistance and automated driving, as information from LiDAR and other sensors that should be mounted on vehicles can be complemented on the infrastructure side. Sensor fusion and sharing also has the same requirements as those for collective perception mentioned above.

On the other hand, Beyond 5G base station sensing will be useful when the vehicle is running singly in rural areas or at night in urban areas. The use of high frequency bands with ultra-wide bandwidth, ultra-multiple-elements-based MIMO in base stations, and distributed sensing with highly coordinated multiple cells should enable sensing accuracies at the centimeter level, beyond what 5G or its extension technologies are capable of, without the use of dedicated receivers such as IoT devices.

(d) Ultra-low power consumption

Sidelink have potential for use in the sharing of collective perception with roadside units and surrounding vehicles, i.e., in cooperative safety driving assistance and automated driving. However, currently, the data envisioned for transmission on the sidelink are very limited in size (from a few hundred bytes to a few kilobytes), such as for control and synchronization signals. In the Beyond 5G era, enabling the

[3] In the whole section 4.7, the values of end-to-end communication delay are proposed by referring to the requirements of 3GPP release 16

[4] In the whole section 4.7, communication reliability is equivalent to Block Error Rate

transmission of various sensor data that include images will make it possible to transmit and process data in a distributed way, making it imperative to actively reduce the load on host networks and wireless interfaces and to lower the power consumption in data centers.

(e) Ultra-security, resiliency and reliability

The application of quantum cryptographic communications on the air interface is necessary to guarantee the update of different ECU programs via OTA.

(f) Autonomy

As we move toward an advanced automated driving era, the computational processing capacity required for learning and inference on singe vehicle is foreseen to expand dramatically as various sensors become more sophisticated. Although multiple- (or other-) viewpoint information obtained by single vehicles is limited, the computation load may cause the neural network to excessively expand and may prevent carrying out calculations within a very short span of time solely by relying on the vehicle's GPU and NPU capabilities. These possibilities should be considered. In order to address these requirements, distributed learning and inference, involving intelligence relying on multiple cars and base stations (edge clouds with AI), is required for network-assisted automated driving with the integration of Beyond-5G and AI.

(g) Universal coverage

Use of coverage extension technologies through communications with vehicles and roadside units and with satellites and HAPS, for example, to ensure communication channels for emergency vehicles during disasters, or to provide connected services outside the cellular network even for ordinary privately owned cars (e.g., for making emergency calls) should become possible.

Beyond 5G capabilities required by each of the above use cases are mapped into Table 4.7-1.

Table 4.7-1 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Update of dynamic map utilizing vehicular sensor information	Multi-Gbps/user, Multi-10Gbps/cell									
Remote monitoring and control for remote driving	~50Gbps	E2E transmission latency = 1msec		10^{-6} or better						
Collaborative perception in Safety driving assistance: sensor info in the vehicle supplemented by infrastructure (Sensor fusion sharing)	~10Gbps	E2E transmission latency = 1msec		10^{-6} or better			Sensing with cm-level accuracy			
Coverage enhancement and emergency support in disaster situations by communications between vehicles/ roadside equipment and satellite/HAPS for disaster assistance								X		
Distributed learning and inference based on multiple cars and base stations (edge cloud)	X	X							X	
Management of programs updates in a car via OTA etc.	X			Applying Quantum encrypted communications						

4.7.5 Summary

This section examined the current situation and future vision of automotive industry and described the capabilities for Beyond 5G that are needed to fulfill the future vision. The required capabilities would be ultra-fast and large capacity, ultra-low latency, ultra-security, resiliency and reliability, high accuracy positioning and sensing, and universal coverage.

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4.8 Machinery

Machines are the foundation for human life activities, production and distribution of goods, social infrastructure, and energy use. In addition to enhancement of performance, efficiency, and reliability of machinery through various mechanical improvements, system optimization is also progressing with the evolution of sensors and the use of ICT. In particular, there are high expectations for a significant improvement in efficiency due to the direct connection between machines and machines, or between machines and system control. Japan is a developed country facing its own unique set of challenges, namely, compensating for the decline in the workforce through automation, manpower saving, and use of robots that cooperate with humans, i.e., reducing environmental impact at all stages of work has become imperative.

Table 4.8-1 Expected progress in machinery sector

Items	Expected progress
Design of machines	● Increase in design efficiency through remote collaboration and use of digital twins ● Design that incorporates contactless power and use of wireless technology for wired networks ● Optimum design for fuel, mechanical, and control efficiency through AI/HPC
Manufacture of machinery	● Optimized production through use of digital twins and connected cyber factories ● Streamlining of distribution networks, decentralization of manufacturing locations, and local production for local consumption ● Robots, AGV, layout-free factories, 3D printers
Autonomous control of machinery	● Manpower saving, full automation, and autonomy of control and mechanical operations using AI ● Automated driving (sensing accuracy and density, positioning, optimum control) ● Optimum operational control through high-precision positioning and communications
Expansion of range of machinery activity	● Air, stratosphere, space, ocean, underwater, and underground coverage
Intelligent machines capable of cooperating with humans	● Autonomous robots (using AI for control and improvement of work accuracy and speed) ● Human augmentation (organ/sensory extension, multi-sensory, one-to-many remote operations) ● Service robots (communications, alternative to consumer electronics)
Monitoring and maintenance of machinery	● Acquisition of operational data (data type, sampling, target points) ● Analytics and feedback (optimal load balancing of devices, edge, and cloud)

The following sections describe the expectations for 2030 and the issues that need to be resolved for each area of the machinery industry. This section focuses on the manufacturing, construction, and agriculture, forestry, and fisheries fields as typical industrial fields in which machinery is applied, and takes up machine tools, construction machinery, and agricultural machinery, which are the main equipment in each field. It also refers to robots, which are indispensable in considering how to deal with future social issues such as the declining birthrate and aging population, declining working population, and natural disasters. In addition, considering the expansion of the range of activities of machinery, ships (shipbuilding), are also taken up as fields that handle large machinery that represents land, sea, and air mobility. Since railways, aircraft and automobiles are described in section 4.3.3, section 4.3.2 and section 4.7 respectively, they are not discussed in this section.

4.8.1 Machining Equipment

4.8.1.1 Current situation and challenges

- Current situation

ICT is being used on individual devices for performance improvement and maintenance purposes, and verification and practical applications are being studied to achieve system-level application.

  - Techniques for improving machining accuracy using a deductive approach such as motion control have been conventionally implemented (e.g., suppression of chatter vibration based on empirical facts and mathematical modeling).
  - Verification and commercialization of factories that use failure detection and edge computing have started.

- Challenges

Further improvements in performance, such as in precision and processing capacity, and increased diversity to handle new materials and special processes, will be needed.

Considering the entire manufacturing process including logistics, it is also necessary to address issues related to the supply chain, value chain, eco model, etc. However, this section focuses on the issues related to the manufacturing process itself.

  - Improvement of processing accuracy and throughput
  - Chip control and processing
  - Failure detection
  - Modeling of various materials and automatic machining in accordance with the material
  - Process monitoring and optimization
  - Ability to carry out complicated special processing

4.8.1.2 Future vision

ICT-based processing will become more precise and faster, maintenance efficiency will be improved, and the range of supported materials and conditions will be expanded.

- Use of IoT data for detection of failures, automatic assessment of tool life, and automatic replacement of tools
- High-speed, high-precision processing based on machining data collected using local 5G and related technologies, suitable for all sorts of materials and special processes
- Realization of production manufacturing and production processes that can flexibly respond to demand fluctuations through synchronized production through digital twins of production sites

4.8.1.3 Applications achievable with Beyond 5G

The main future prospects for the utilization of 5G and Beyond 5G in factories are the improvement of performance based on collected data, the use of intelligent machining processes and large-scale sensor networks, and the implementation of ultra-low-speed, low-latency motion control.

- Automatic collection, sorting, and data center forwarding of processing data (Application 1)
- Estimation of tool life through collection of data on quantity of state during tool breakage and feature extraction
- Provision of dynamic solutions such as improvement of control performance based on collected data
- Handling of processing that is unprecedented for single factories
- Factories that are completely unmanned, automatic generation of global machining plans (Application 2)
- Elimination of need for wired connections around sensors and tools, eradication of effects of cable disturbance
- Advancement of direct teaching method, which "inculcates" appropriate tasks while humans are in contact with robots (Application 3)
  (Enable direct teaching safely, no matter where the operator is, through VR or AR space)

4.8.1.4 Capabilities required in Beyond 5G

Capabilities required for Beyond 5G to achieve above mentioned applications are summarized in Table 4.8-2. Machining equipment industry in Beyond 5G era is shown in Figure 4.8-1.

Table 4.8-2 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Application 1			X			X	X		X	
Application 2	X	X	X	X		X			X	
Application 3	X	X		X		X	X		X	

Figure 4.8-1 Machining equipment industry in Beyond 5G era

4.8.1.5 Summary

This section examined the current situation and future vision of Machining equipment industry and described the capabilities for Beyond 5G that are needed to the future vision. The required capabilities would be ultra-fast and large capacity, ultra-low latency, ultra-massive connectivity, ultra-security, resiliency and reliability, time synchronization accuracy, positioning and sensing and autonomy.

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4.8.2 Construction Machinery

4.8.2.1 Current situation and challenges

- Current situation

A comprehensive attempt is being made to solve the problem of fewer construction workers and increasing construction needs.

- Since 2020, there has been a lack of construction operators resulting from the population decline.
- Highly urgent and dangerous tasks have been increasing due to natural disasters and deterioration of infrastructures.
- ICT has been used to improve operational efficiency and to manage the life cycle of construction equipment.

- Challenges

Automation and remote control of construction machinery show promise, but both are still under development.

- The range of possible automation of construction machinery is limited.
- Remote-control interfaces are bulky and expensive.
- Urbanization has led to an increase in tasks that need to be carried out in small spaces and within limited time in urban areas.

4.8.2.2 Future vision

Productivity and safety of construction work are foreseen to improve beyond the use of construction machinery.

- Ability to carry out construction work through automation
- Ensuring safe and secure construction work through remote monitoring and control from the operator room
- Maximizing efficiency of work and construction equipment operations through the use of digital twin technology

4.8.2.3 Applications achievable with Beyond 5G

Beyond 5G will be used in scenarios such as “promotion of manpower saving and full automation,” “safe and secure remote construction machinery operation by anybody,” and “spatially and temporally flexible construction management.” Expectations and aspirations for the future are described below.

(1) Promotion of manpower saving and full automation (Application 1)

- Application of robot technology to construction machinery and advancement of automatic functions

- Application of remote construction machinery operation technology to tasks not amenable to automation
- Operation and management with few operators through automatic operation of multiple construction machinery and optimal scheduling of remote operations

(2) Safe and secure remote construction machinery operation by anybody (Application 2)

- Remotely operated construction work from a clean and safe operator room
- Intuitive motion and sensory communication through a simple operation interface
- Low-latency, high-bandwidth communication networks and adaptive communication control based on network conditions

(3) Spatially and temporally flexible construction management (Application 3)

- Smart maintenance using AI in accordance with the conditions of the construction machinery
- Seamless construction planning and on-site work using digital twin technology
- Use of ICT for rental and sharing of construction equipment and flexible work style for operators

4.8.2.4 Capabilities required in Beyond 5G

Capabilities required for Beyond 5G to achieve above mentioned applications are summarized in Table 4.8-3. Construction machinery industry in Beyond 5G era is shown in Figure 4.8-2.

Table 4.8-3 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Application 1		X		X		X	X		X	
Application 2	X	X		X		X			X	
Application 3		X		X		X				

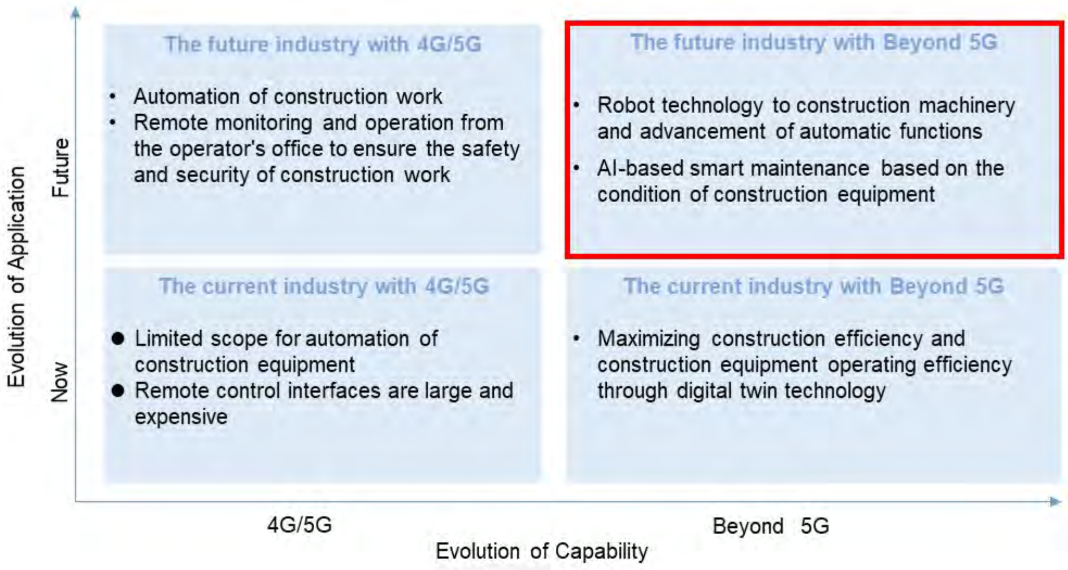

Figure 4.8-2 Construction Machinery industry in Beyond 5G era

4.8.2.5 Summary

This section examined the current situation and future vision of Construction Machinery industry and described the capabilities for Beyond 5G that are needed to the future vision. The required capabilities would be ultra-fast and large capacity, ultra-low latency, ultra-security, resiliency and reliability, time synchronization accuracy, positioning and sensing and autonomy.

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4.8.3 Agricultural Machinery

4.8.3.1 Current situation and challenges

- Current situation

Due to the decline in number of agricultural workers and the aging of the population, significantly improving agricultural productivity has become imperative.

  - The number of agricultural workers continues to decline as the population decreases.
  - The aging of agricultural workers is progressing as a result of the declining birthrate and aging of the population.

- Challenges

It is imperative to promote “smart agriculture” utilizing advanced technologies such as ICT.

  - Formalization of the implicit knowledge of skilled workers in pruning work, etc.
  - Significant reduction of costs for introducing and maintaining automated robots
  - Increase in scale of agricultural management, increase in consolidation and scale of agricultural lands
  - Development of ICT infrastructure for communications, etc.
  - Measures to cope with changes in farmland environment caused by global warming

4.8.3.2 Future vision

Smart farming will be applied in all aspects of agricultural production, beyond automation and sophistication of agricultural machinery.

- Maximum manpower savings in agriculture, wherein agricultural workers only focus primarily on remote monitoring, supervision, and decision-making through the automation of all tasks, such as pruning and harvesting
- Use of smart agricultural systems for automatic management of optimum cultivation environment in response to changes in weather conditions, etc.
- Use of systems that support selection of the best sowing times and varieties based on long-term weather forecasts, such as cool summers, etc.
- Use of remote agricultural systems that enable management and production of farming areas in remote areas, including overseas locations
- Use of systems that automatically generate production and shipment plans in response to consumer demand forecasts and growth conditions of agricultural products

4.8.3.3 Applications achievable with Beyond 5G

Below are the expectations and aspirations of what “smart agriculture” should be able to accomplish in the future.

Smart Agriculture

- Formalization of the implicit knowledge of skilled workers and automation of pruning in accordance with the ambient environment (Application 3)
- Support for harvesting of multiple varieties using automated agricultural machinery through change of attachments and software updates, etc.
- Selection, harvesting, and shipping of the best agricultural products by properly judging their maturity
- Remote operation and management of automated agricultural machinery, failure time prediction, and maintenance and repair of failures (Application 1)
- Unified remote management of information on growth conditions, maturity, and health of agricultural products and farm animals
- Optimum control of temperature, humidity, lighting conditions, feed, etc.
- Enabling skilled workers to provide remote instruction and support to new farmers (Application 2)
- Automatic guidance of farm animals in accordance with time of day and health of animals, automatic clean-up of barns during grazing of animals
- Remote animal examination by veterinarians
- Provision of advice on the best planted vegetables and varieties based on past data on growth and climate conditions, soil environment, etc.

4.8.3.4 Capabilities required in Beyond 5G

Capabilities required for Beyond 5G to achieve above mentioned applications are summarized in Table 4.8-4. Agricultural machinery industry in Beyond 5G era is shown in Figure 4.8-3.

Table 4.8-4 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Application 1	X	X				X				
Application 2	X	X								
Application 3	X	X					X			

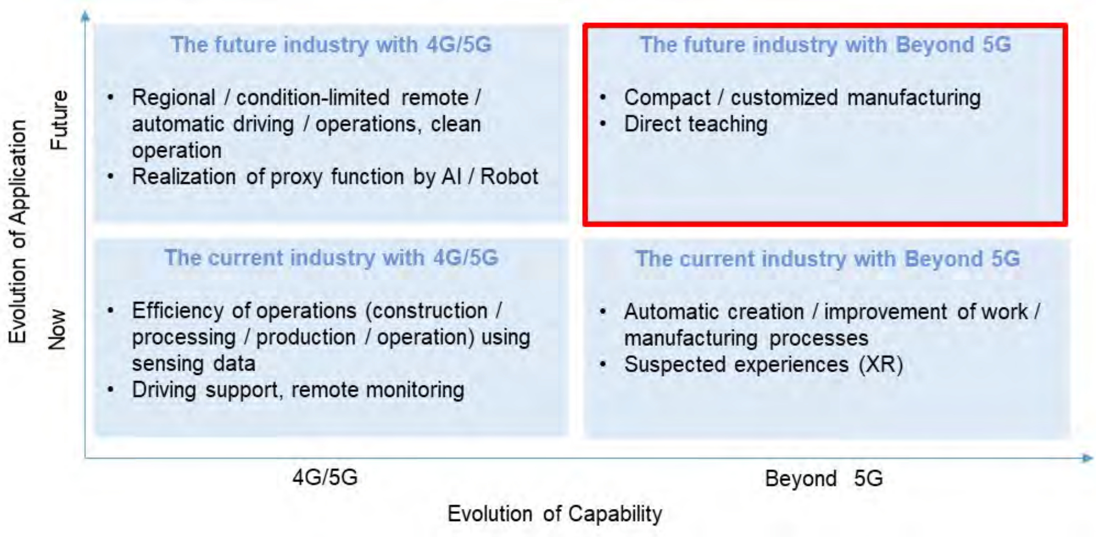

Figure 4.8-3 Agricultural machinery industry in Beyond 5G era

4.8.3.5 Summary

This section examined the current situation and future vision of agricultural machinery and described the capabilities for Beyond 5G that are needed to the future vision. The required capabilities would be ultra-fast and large capacity、ultra-low latency, positioning and sensing.

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4.8.4 Robots

4.8.4.1 Current situation and challenges

- Current situation

Robots will be used to eliminate labor shortages due to the declining birthrate and aging population and in the new normal society, and to realize a society where people can live more comfortably. In addition, robots are changing from stand-alone to positioned in systems connected to networks and clouds. This section describes service robots. Other robots are described in other chapters as appropriate.

  - More pronounced shortage of labor due to declining birthrate and aging population
  - Increase in remote communications toward a new normal society
  - Expectations for the utilization of robot technologies to realize a society that allows for diversity

- Challenges

Challenges include coordination with DX, safety, and communications to achieve coexistence and collaboration between humans and robots.

  - Limited scope of automation by robots and the remaining big difference in cost performance compared with humans
  - Insufficient non-verbal communications in functions to communicate with video-only telepresence robots
  - Use of robots in physical space is very limited despite signs of progress of their use in virtual space.

4.8.4.2 Future vision

The labor shortage caused by the declining birthrate and the aging population will be eliminated, and people's lives will be enriched.

- Workforce supplementation through automated robots
- Balance of safety and security with remote communications
- Extension of the body and spirit through the pseudo-body in virtual and physical spaces

4.8.4.3 Applications achievable with Beyond 5G

The following are the expectations and aspirations of what can be accomplished in the future; namely, “workforce supplementation using robot technology,” “remote communication robots capable of non-verbal communication,” and “pseudo-body robots that can be operated by anybody.”

(1) Workforce supplementation using robot technology (Application 1)

- Sophistication of automatic functions
- Application of remote-control technology to tasks not amenable to automation
- Operation and management with few operators through automatic operation of multiple robots and optimal scheduling of remote operations

(2) Remote communication robots capable of non-verbal communication (Application 2)

- Sophistication of technologies for communicating the five senses
- Application of technologies to infer and transmit operator emotions, intentions, and mood
- Application of safe and immersive interaction technologies

(3) Pseudo-body robots that can be operated by anybody (Application 3)

- Intuitive motion and sensory communication through a simple operation interface
- Global, low-latency, high-bandwidth communication networks and adaptive communication control based on network conditions
- Construction of a system that has low barriers to initial deployment, transportation, and installation

4.8.4.4 Capabilities required in Beyond 5G

Capabilities required for Beyond 5G to achieve above mentioned applications are summarized in Table 4.8-5. Robotics industry in Beyond 5G era is shown in Figure 4.8-4

Table 4.8-5 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Application 1	X	X		X		X	X		X	
Application 2	X	X		X		X	X		X	
Application 3	X	X		X		X	X		X	

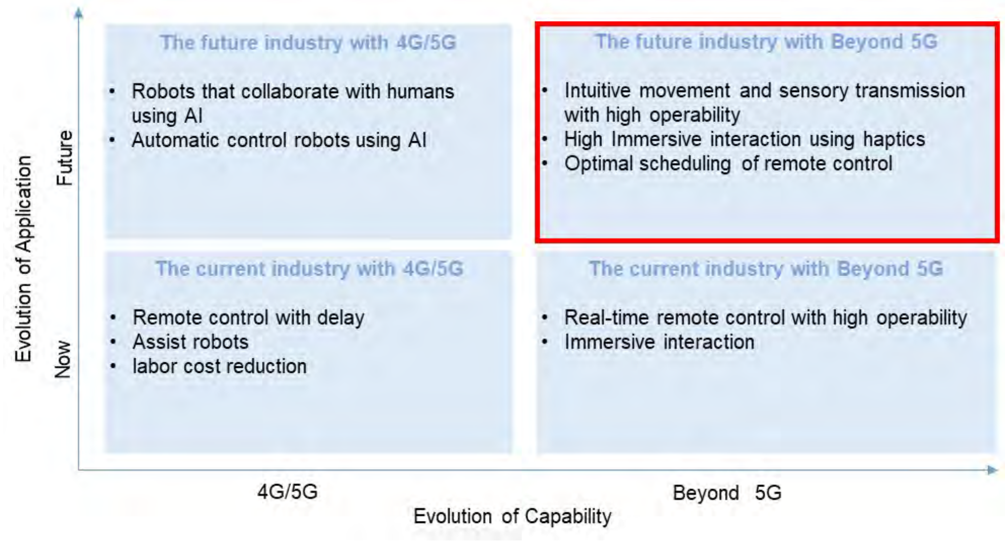

Figure 4.8-4 Robots in Beyond 5G era

4.8.4.5 Summary

In this section, based on the results of a survey of the current status and issues of the robot industry, the expected future image of these fields and examples of Beyond 5G utilization are described. Capabilities required for Beyond 5G include ultra-fast and large capacity, ultra-low latency, ultra-security, resiliency and reliability, time synchronization accuracy, positioning and sensing, and autonomy.

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4.8.5 Shipbuilding (Ships)

4.8.5.1 Current situation and challenges

- Current situation

With the increase in maritime transport, efficiency is continually being improved through the application of ICT.

- The volume of marine transportation increases by about 4% every year, and the number of ships also continues to increase.
- There is a continuing shortage of labor due to the declining birthrate and the aging population and the departure of seafarers from the workforce.
- DX has progressed with the installation of sensors on ships, etc.
- Communications at sea are carried out using satellites, switching to land-based communication facilities upon entering the port.

- Challenges

For the shipping industry, improvements not only in ships but also in port facilities are needed. The challenge is to further increase efficiency and automation. Lack of effective communication means for overboard (underwater) sensors and underwater drones for navigational assistance and environmental monitoring.

- Insufficient port capacity (loading and unloading throughput, etc.) to handle the increase in cargo and transportation volumes

  ⇒ Since it is difficult to expand the number and scale of ports, the challenge is to increase operating time and efficiency.
- Shortage of manpower due to the aging of seafarers and the lack of people willing to take on the job

4.8.5.2 Future vision

Progress in the automation and efficiency of ships and port facilities will continue, enabling smooth transportation of goods. Automated driving of ships will also progress. The use of undersea communications for monitoring the vessel itself, the navigational environment, and the undersea environment will increase.

- Automation and acceleration of transport, loading, and unloading of cargo at ports
- Automation of navigation of ships (from offshore to onshore)
- Enhancement of seafarer training, adoption of work shifts centered on operations

4.8.5.3 Applications achievable with Beyond 5G

The application of ultra-low latency and highly reliable networks and the expansion of communication areas at sea and underwater will progress to enable the use of robots for the automation and optimization of ships and port facilities, automated navigation, as well as marine environment monitoring.

Application 1: Improve throughput of cargo loading/unloading at ports.

- Automated and remote operation of port cranes, use of robots to fully automate and save manpower for loading and unloading operations
- Automated driving of in-port transportation vehicles in narrow areas (unmanned operations)
- Automated driving of cargo vehicles that enable control of parking positions at a precision of 10 cm
- Automation of operations and enhanced navigation efficiency through the use of ship data (fleet operation center)

Application 2: Monitoring of the ship's internal and external navigation conditions and Monitoring of the marine environment

- Automation of operations and enhanced navigation efficiency through the use of ship data (fleet operation center)
- the external and undersea environment of a vessel using a radio-controlled undersea drone

4.8.5.4 Capabilities required in Beyond 5G

Capabilities required for Beyond 5G to achieve above mentioned applications are summarized in Table 4.8-6. Shipbuilding industry in Beyond 5G era is shown in Figure 4.8-5

Table 4.8-6 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Application 1		X	X	X		X	X		X	
Application 2		X	X	X	X	X	X	X	X	

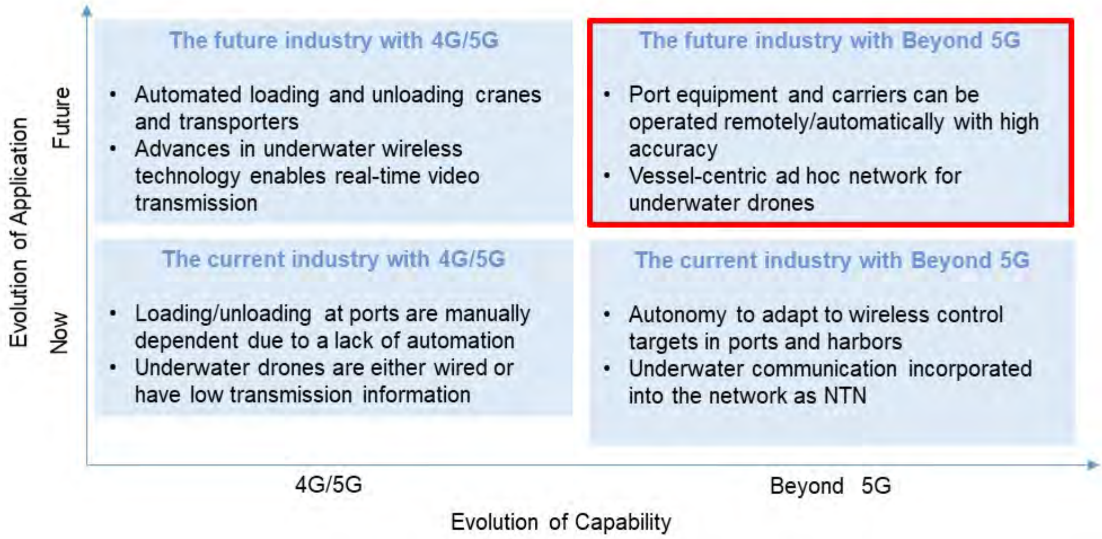

Figure 4.8-5 Shipbuilding industry in Beyond 5G era

4.8.5.5 Summary

This section examines the current status and issues in the shipbuilding and marine industries and presents expected future visions for these sectors and examples of Beyond 5G applications. Capabilities required for Beyond 5G include ultra-low latency, ultra-security, resiliency and reliability, positioning and sensing, universal coverage, and autonomy.

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4.9 Electronics, precision electronics and semiconductors

4.9.1 Electronics and precision electronics

4.9.1.1 Current situation and challenges

- As Beyond 5G becomes an essential infrastructure, the electronics and precision electronics industry must transform into a social infrastructure and platform industry.
- For Beyond 5G to become widespread as a communication function for different devices used in daily life and in business, it will be important to have a deep understanding of a wide range of industries and to establish agreements and actions toward appropriate social implementation.

As general-purpose technologies, Information and Communication Technology (ICT) have a very large impact on society, pointing to the need for a redefinition of all its aspects [1]. With the advancements in ICT, the electronics and precision electronics industry, which deals with electrical machinery, electrical equipment, and precision instruments, should transform from being an industry dealing with different devices and systems into a social infrastructure and platform industry.

The proper order of things is to use Beyond 5G to improve society and industry, rather than changing society and industry through Beyond 5G. Beyond 5G is not a goal, but a means, and it will change from being a convenient tool to have to being an ordinary part of the lifestyles and workstyles of people. In other words, it will serve as an essential infrastructure, along with electricity, water, gas, and roads. All consumer electronics, electrical equipment, machinery, and office equipment around us will be connected to each other via Beyond 5G.

All industries, including those where work has been traditionally carried out with analog processes, are increasingly using sophisticated cyber-physical systems (CPS) on a daily basis. An advanced and efficient network will be needed to connect with digital twins (DT), and Beyond 5G will serve as a neural network and sensory organ where electrical and precision equipment mediates communication between the DT of CPS.

Sensor information (real), AI analytics results of past data (cyber), and the combination of these will be used optimally in daily life and work. Electrical and precision equipment will become an integral part of information and communications. Therefore, a comprehensive and globally optimized approach must be taken, rather than adopting design concepts and operations for each device and system individually.

To do so, the electronic and precision equipment industry must nurture a deeper understanding of a wide range of other industries and establish agreements and actions toward appropriate social implementation, in addition to forming closer coordination among the areas and fields within the industry. In this regard, open Application Programming

Interfaces (APIs) and open Interfaces (I/Fs) for cross-industry/inter-industry collaboration, and common platforms for data analysis/processing and content handling will also be useful.

4.9.1.2 Future vision

- Beyond 5G will underpin the further evolution of people and society, as well as the expansion of industries.
- Collaboration between multiple products and systems will be inevitable, and cross-industry co-creation activities and collaboration between industries will advance.
- The relationship with users will also evolve, including a shift to future-oriented and user-centric design.

Until the 5G era, networks with high capacity, low latency, and multiple connectivity were needed to expand industries. In the Beyond 5G era, however, the new work styles and lifestyles in a super-aging society, or under the new normal brought about by the COVID-19 pandemic, point to the need to evolve into a sustainable society where everyone has the chance to reach their full potential. Therefore, Beyond 5G networks will not only support the expansion of industry, but also the further evolution of people and society, which in turn will lead to changes in market values.

In order for all devices and systems, from home appliances to industrial machines, to connect and collaborate via communication networks, it will be imperative to develop open I/Fs for control, to enable open access to data for effective and efficient utilization of the exchanged data, and to strengthen security and privacy to support safe and secure uptake of applications and usage scenarios.

As user needs change and diversify, individual companies and individual industries, as well as individual devices and systems, will likely become limited in their capabilities. As Beyond 5G will become commonly used in various aspects of society, cooperation between multiple products and systems will be inevitable, thereby leading to the advancement of cross-industry co-creation activities and collaboration between industries.

To meet the demands of such an era, the electronics and precision industry will need to transform not only to what the industry envisions for itself, but also to meet the essential needs of a wide range of users. Approaching new user needs and social demands by shifting to future-oriented and user-centric designs, regardless of the current industry segments and business conditions, will be imperative.

The relationship with users will go beyond the conventional supply-and-demand relationships, moving toward an era in which users and vendor companies and industries will create the future on close to equal terms and from the same standpoint. As diversity and inclusion and the aging society continue to evolve, electrical and precision equipment must not remain as products and systems that can only be understood and operated by experts but must be easily operable by the users themselves. Universal support and compatibility will also be an important factor toward the realization of a society that leaves no one behind [2].

4.9.1.3 Applications achievable with Beyond 5G

[Home appliances]

Beyond 5G is expected to play a more advanced role in living infrastructure by seamlessly connecting information on products that use electricity with product users and environmental information in kitchen appliances (refrigerators, Induction Heating (IH) cooking heaters, microwave ovens, rice cookers, etc.), household appliances (washing machines, vacuum cleaners, etc.), and Air conditioning ventilation and hot water supply equipment (air conditioners, ventilation fans, EcoCute heat pump, etc.).

There are two examples of the use of Beyond 5G for these home appliances: manufacturing and product functionality.

First, in terms of manufacturing, the content as a manufacturing industry conforms to the description in Section 4.10.3. Furthermore, it is desirable to be able to apply it to a system that supports the optimization of the global production system, including inventory management and transportation optimization.

On the other hand, issues and future visions in terms of product functions include realizing "health and comfort," "ease of use," and "energy saving." Since home appliances are devices that are mainly operated by humans in human living spaces, it is essential to link the situation in which they are installed and used with human information. Future demands in society include management of personal health and nutritional status information, support for operation (operation of the elderly and children, familiarity with equipment operation), user device usage (whether it can be used correctly and comfortably), environmental and energy conditions in homes, integrated management of buildings, streets, and outdoor environments and air conditioning, and realization of applications that perform appropriate equipment operation. To achieve these goals, Beyond 5G functions such as ultra-low latency that appropriately follows changes in the situation, ultra-fast and large capacity that transmit and receive information for accurate decisions, and ultra-massive connectivity for connecting a wide variety of devices to each other are required. Examples of utilization of individual devices are described below.

<u>Kitchen appliances</u>

- A function that supports the selection of optimal ingredients and cooking that minimizes food loss based on personal health, nutritional status, preferences, inventory, type, and freshness of food in the refrigerator.

- A function to monitor so that there is no risk of failure or burns such as over-burning during cooking, and a function to recommend including arrangements that will be completed at the specified time.
- In addition to connecting multiple diverse devices in real time and linking their status information, making appropriate decisions according to the user's situation and providing a universal interface that is easy for anyone to understand.

<u>Home appliances</u>

- Function to perform laundry and cleaning in daily life in consideration of user requests (short time, quietness, cleanliness, etc.)
- Support for work procedure arrangements (folding laundry, disposing of garbage, etc.)
- Linkage function with equipment and robots after understanding user requests, such as optimizing the division of duties between automated robots and humans that take into account the physical strength and muscle strength of the user.

<u>Air conditioner and Boiler</u>

- Control of health-related air environments (temperature, humidity, airflow, air purification, etc.) such as heat stroke, countermeasures against new infectious diseases, and heat shock
- Control that balances energy saving by considering power supply and demand and hourly electricity bills
- Comfortable air conditioning for better sleep and total indoor environment control that combines sound and light
- Control according to the needs of each site such as air conditioning in buildings such as offices, factories, schools, and hospitals
- Control of upspring and hot water storage from the viewpoint of energy storage, and control of water use in the event of a disaster
- Indoor and outdoor environmental information, real-time control according to user requests, integrated control of air conditioning, ventilation, hot water supply, lighting, etc.
- Energy conservation not only in residences but also in buildings and entire regions, and control linked to weather, power generation status, power storage status, etc.
- Support for cloud computing due to the decentralization of each function
- External linkage function and common interface due to the increase in the amount of information handled by air conditioning equipment

[Heavy electric equipment]

Robustness and resilience to disasters, obstacles, security, etc. are required for essential infrastructure in future society, including power equipment and systems, and ultra-security, resiliency and reliability in Beyond 5G are important. Various approaches to security have already been tried, on top of that, the application of quantum cryptography communication is to be considered effective in the future.

With the development of Beyond 5G and AI, it will be possible to analyze various data and information in real time and feed it back to equipment, systems, and services, increasing the possibility of real-time maintenance, security, repair, and restoration while ensuring the robustness and resilience of essential infrastructure. Smart system protection and control, smart maintenance is considered as example of these functions.

4.9.1.4 Capabilities required in Beyond 5G

- Beyond 5G will serve as a communications system that will organically utilize communications and computing resources by combining the quantitative expansion of 5G performance with distributed data processing.
- Full-scale use of AI will advance, and networks and AI will complement each other and evolve together.
- Measures must be implemented to reduce restrictions on users' use of services, and to optimize infrastructure, share equipment, and conserve power throughout society.

Initiatives to improve performance must be continued in regard to the three features offered by 5G; namely, enhanced Mobile Broadband (eMBB), Ultra Reliable Low Latency Communications (URLLC), and massive Machine Type Communications (mMTC).

In addition to the above three features, Beyond 5G will also enable ultra-low power consumption and ultra-security, resiliency and reliability, which are the key requirements for the infrastructures supporting Society 5.0. From the perspective of safety and security, support for security-by-design and cross-industry/inter-industry security safeguards will also be included.

For Beyond 5G utilization to penetrate all aspects of society, operations and contracts should be made more accessible to users who have not been able to fully utilize communications in the past, and democratization of communications, where users manage networks and services on their own, will also advance [3]. As a result, autonomy and scalability of devices and systems in the electronics and precision electronics industry will also serve as important functions.

Each component technology will also evolve. Operations will be automated and optimized as a complex social system that links and integrates not only the network aspects for wireless communications, but also for wired communications, including optical communications. The distributed data processing platform needed for optimal configuration as an essential infrastructure, including AI, will also evolve, along with the overall security for comprehensive protection of the entire system. Rather than evolving completely independent from each other, a coevolutionary and complementary relationship will be formed between AI and the network and its peripheral technologies [4].

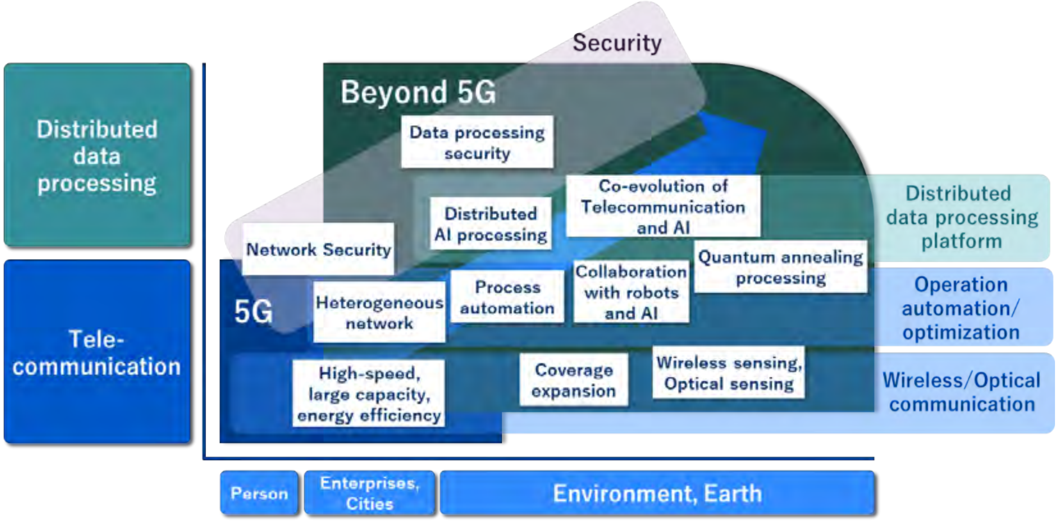

Figure 4.9-1 Direction of technological evolution toward Beyond 5G

The demand for devices and service formats with significantly evolved universal interfaces is likely to increase. Systems should work using manual-free, intuitive operations without complex procedures, and restrictions should be eliminated to enable device-free access to services anytime and anywhere. These and other functions that enable the use of the best communication services as necessary, regardless of age or disability and without worrying about contract formats and the device at hand, will be important in realizing a society that leaves no one behind and where everyone has the chance to fully exercise their individuality.

The requirements will evolve further from the pursuit of value centered on the development of people and industries up until the 5G era, to the contribution to a sustainable society, planet, and environment in the Beyond 5G era and onwards. The focus will change from services centered on human activities and industrial development to a society that coexists with the Earth and the environment through the use of ICT, and from network deployment by each company and organization to infrastructure optimization, equipment sharing, and energy conservation across the entire society. The ability to respond to these changes will be required in Beyond 5G.

The above discussions are summarized in the table and figure below.

Table 4.9-1 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Kitchen appliances	X	X	X		X					Universal interfaces
Home appliances	X	X	X		X					
Air conditioner, Boiler	X	X	X							
Heavy electric equipment		X	X	X						Robustness, Toughness

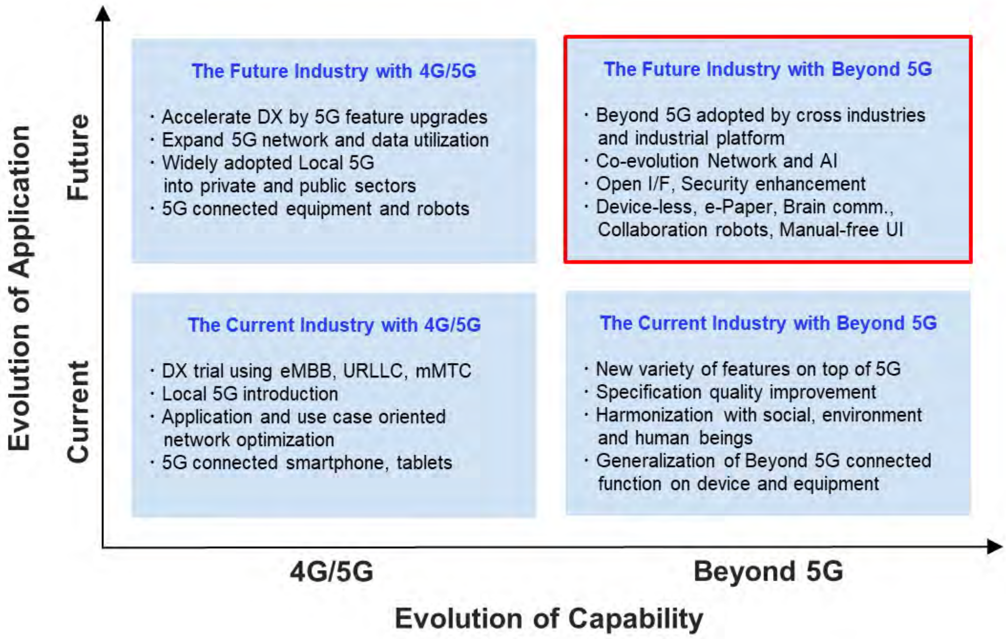

Figure 4.9-2 Electronics and precision electronics industry in Beyond 5G era

4.9.1.5 Summary

This section examined the current situation and future vision of Electronics and precision electronics industry and described the capabilities for Beyond 5G that are needed to the future vision. The required capabilities would be ultra-fast and large capacity, ultra-low latency, ultra-massive connectivity, ultra-security, resiliency and reliability, ultra-low power consumption, universal interfaces that can help user operation of equipment easily and robustness, toughness to keep operated for social essential infrastructures.

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4.9.2 Semiconductors

4.9.2.1 Current situation and challenges

- Current situation

Semiconductors are a vital material used not only in smartphones, PCs, and other communication devices, but also in automobiles, home appliances, robots, base stations, data centers, and devices from other industries.

Semiconductors are classified as Si semiconductors or compound semiconductors, and their uses include digital, analog, power, memory, communications, sensors, and optics. Suitable manufacturing methods have been established for each application.

Generally, manufacturing processes are divided into the front-end process, which is the wafer manufacturing process, and the back-end process, which is the package manufacturing process.

In the front-end process, miniaturization is advancing as described in Moore's law, and as things get smaller, the work hours and time required for manufacturing and the costs of manufacturing equipment increase.

Therefore, only companies with sufficient investment can manufacture at 10 nanometers or less, the current most advanced process, resulting in an increasing oligopoly.

The trend in the back-end process is to combine chiplets, or multiple chips, into a single package and make the LSI (chip) smaller to increase the yield and reduce the area. For memory, etc., chip layering is advancing, and the methods for achieving this are not limited to packaging technology. There are more methods using wafer and PCB technologies, making the boundaries between processes unclear.

- Challenges

Due to the COVID-19 pandemic, there is a supply shortage of semiconductors as of 2021.

Previously, there was a supply shortage due to factory stoppages in areas affected by natural disasters (earthquakes, floods, etc.), but factories were operating in other areas. Although it would take time and effort to achieve recovery, plans were established, and recovery would have been achievable with enough time.

The COVID-19 pandemic caused an unprecedented worldwide reduction in production output due to factory closures and reduced operating rates resulting from worldwide lockdowns. There were no alternatives available anywhere, and after 1 year the situation still had not resolved.

One major reason is the longer lead time in semiconductor manufacturing due to more complex manufacturing processes. It depends on the product, but the front-end process can take up to several months, and the back-end process can take about 1 month. There are plans for more production facilities in order to achieve recovery, but multiple companies are ordering semiconductor manufacturing equipment at around the same time, and as the orders increase, so do the delivery times. Additionally, there are secondary problems such as an inability to obtain semiconductors for use in the semiconductor manufacturing equipment, and as a result of this unresolvable situation, the production plans for automobiles, home appliances, etc., have been significantly weakened.

From another point of view, an increase in the world's population has increased the consumption of energy, and countries are making plans to reduce CO_2 and stop this increase. In order to achieve carbon neutrality, electric vehicles and energy consumption regulations for home appliances are being promoted. There are various ways to reduce energy consumption, such as changing the frequency and voltage according to the operating mode, only operating circuits as required, etc., and these are used to extend the battery life of smartphones, laptops, etc. This technology can also be applied to sets that are not battery powered, allowing the entire set to achieve low energy consumption.

Also, elements called power semiconductors are used for high power applications such as driving EV motors. In order to reduce the power consumption of these power semiconductors, Si semiconductors are being replaced with next-generation semiconductors (SiC, GaN, etc.).

- 5G initiatives

In order to resolve the aforementioned challenges, the following 5G initiatives are underway.

  - A shift to IoT for equipment in semiconductor factories; the introduction and use of transport robots.
  - The introduction and use of AI in supply chain control and at development sites.
  - The introduction and use of 3D methods in semiconductor processes and packaging technologies.
  - The development of manufacturing methods for reducing loss in next-generation semiconductors.

4.9.2.2 Future vision

- Laborsaving (5G) or automation (Beyond 5G) in semiconductor factories
- Laborsaving (5G) or automation (Beyond 5G) due to the use of AI in production plans, including for supply chains
- Shorter TAT (5G) and laborsaving (Beyond 5G) due to the use of AI at development sites
- End of the oligopoly due to advancements in semiconductor technology other than miniaturization (Beyond 5G)
- Development of next-generation semiconductors with zero loss (5G) and use of AI to further improve properties (Beyond 5G)
- Reduction in lead times in semiconductor manufacturing from several months to several days (Beyond 5G)
- Establishment of methods involving flying equipment or factories to avert disasters

(Beyond 5G)

4.9.2.3 Applications achievable with Beyond 5G

- Realization of remotely performed equipment calibration, repair, and installation in semiconductor factories; complete automation
- Laborsaving in supply chain control and at development sites
- Cheaper equipment for advanced semiconductor processes and shorter lead times
- Introduction and use of AI for reducing loss in next-generation semiconductors
- Worldwide cooperation to achieve the shortest development time of next generation semiconductor elements
- Manufacturing lead time shortened from several months to several days

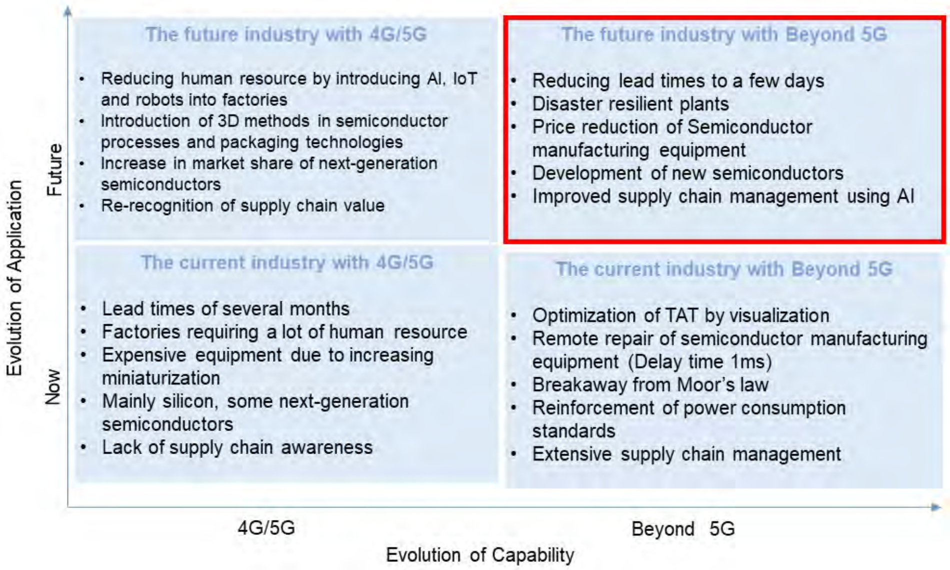

Figure 4.9-3 The semiconductor industry with Beyond 5G

4.9.2.4 Capabilities required in Beyond 5G

The following are the capabilities required for Beyond 5G based on current and future use cases in the semiconductor industry.

- In order to remotely perform equipment calibration, repair, and installation in semiconductor factories and achieve complete automation, ultra-fast and high capacity, ultra-low latency, ultra-security, resiliency and reliability, positioning and sensing capabilities are required. If many operations will be performed at the same time, it will also be necessary to have ultra-massive connectivity.
- In order to use AI and robots to achieve laborsaving in supply chain control and at development sites, ultra-fast and high capacity, ultra-low latency, positioning and sensing capabilities are required.

The capabilities required for Beyond 5G are shown for the aforementioned usage examples in Table 4.9-2.

Table 4.9-2 Usage examples of Beyond 5G and capabilities

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Fully autonomous semiconductor factories	X	X	X	X			X			
Labor savings in supply chains and at development sites	X	X	X				X			

4.9.2.5 Summary

This section examined the current situation and challenges of the semiconductor industry, the future vision, and usage examples of Beyond 5G. The capabilities required by Beyond 5G are ultra-fast and high capacity, ultra-low latency, ultra-massive connectivity, ultra-security, resiliency and reliability, positioning and sensing.

4.10 Agriculture, Fisheries, Food, Lifestyle-related

4.10.1 Agriculture and Fisheries

4.10.1.1 Current situation and challenges [1]

- Challenges
  - In the fields of agriculture and fisheries, labor shortages have become a serious issue in recent years due to the declining birthrate and aging population, as well as the declining population.
  - In the fields of agriculture and fisheries, there are many operations that rely on human resources or that can only be performed by skilled workers.
  - In order to enhance the sustainability of agriculture and rural areas, as well as fisheries and fishing villages, it is necessary to strengthen the production base, regardless of the size of the operation and the conditions of the rural and fishing village areas.

- Initiatives for ICT utilization [2]
  - In recent years, in order to realize Society5.0 in the fields of agriculture and fisheries, various efforts have been made to implement in society "smart agriculture" and "smart fisheries" that enable ultra-labor-saving and high-quality production by making full use of advanced technologies such as robots, AI, and the Internet of Things (IoT).
  - By introducing smart agriculture technology using robotics, tractors and smartphones, in a water-management system for a rice-paddy field for example, work can be automated, saving labor (work automation).
  - By using a business management application linked with location data, work records can be digitized and automated, so that workers can take charge of production activities even if they are not experienced (facilitating information sharing).
  - AI analysis of drone or satellite sensing data and weather data can be used to estimate factors such as produce growth or damage from disease or insects, enhancing the effects of advanced agriculture management (data utilization).
  - As a concrete example, since FY2019, a smart agriculture verification project has been underway, introducing smart agriculture technologies in a production environment and verifying their effects on agriculture management.

- Smart agriculture initiatives

The following are examples of current 5G smart agriculture demonstration projects.

a) Remote monitoring of agricultural equipment, etc.

- To implement practical smart agriculture incorporating technologies such as 5G, trials have been conducted using driverless tractors to perform agricultural work on agricultural land, and to ascertain the development of produce using sensors and cameras.
- By also incorporating Broadband Wireless Access (BWA) and other of the latest technologies besides 5G, one goal is to implement highly reliable networks with ultra-high speed and low latency, as required for fully-automatic, driverless operation using remote monitoring.
- To implement such a driverless system in society, a farmer would need to be able to monitor the vehicle and its surroundings remotely, and the low-latency and other features of 5G and Beyond 5G are promising for this type of communication.

b) Real-time remote monitoring

- To reduce the workload and manage livestock raising more efficiently, remote monitoring trials have been done in which image recognition was used to identify ear tags on cows in a barn, to locate particular cows and to transmit images of cows with low milking yields in real time.
- In this way, real-time monitoring is possible by transmitting images from high-definition cameras installed in agricultural settings or mobile cameras installed on robots or drones, with very high speed and low latency using 5G connections.

● Use cases of smart fisheries [3]

The following are examples of use cases, such as demonstration projects in the smart fishery industry using 5G at present.

a) improving the productivity of fisheries

- In coastal fishing, data from smart buoys at sea and real-time tidal current meters will enable the state of fish entering set-net nets to be monitored remotely. Based on this information, it is possible to predict the situation of the fishing sea up to seven days ahead and provide information to fishery operators using smartphones, etc., which can be used for deciding whether to go fishing or selectively catching fish.
- In offshore and deep-sea fisheries, efforts are being made to predict the formation of fishing grounds by analyzing data such as seawater temperature from artificial satellites and fish catch data using AI. In addition, the introduction of an automatic pole-and-line fishing machine to bonito fishing vessels is being demonstrated.

b) Improving the productivity of aquaculture

- In addition to the introduction of an automatic feeding system using ICT technology to remotely control the optimum amount of feed, efforts are being made to visualize aquaculture farms using IoT and underwater drone cameras.

4.10.1.2 Future vision [3]

- As technology advances, as in the case of Beyond 5G, it is expected that the three major features of 5G, (1) ultra-high-speed and large-capacity, (2) ultra-low latency, and (3) ultra-large number of simultaneous connections, will be further utilized to accelerate "smart agriculture" and "smart fisheries." In addition, cooperation with other industries, such as environmental measures including CO_2 countermeasures and natural disaster countermeasures systems, is also expected.
- In "smart agriculture" and "smart fisheries," it is expected that the use of Beyond 5G for real-time remote monitoring, remote guidance and support, and remote monitoring of agricultural machines, fishing boats, etc. using advanced technologies such as robots, AI, and IoT will further enhance the effect of productivity improvement through automation of work and utilization of data.
- Specifically, the real world, such as farms and fishing grounds, is mapped in cyberspace by CPS (Cyber Physical Systems), and as described above, the automatic operation of tractors on farms and the operational information of fishing vessels in fishing grounds can be monitored and controlled from cyberspace.

4.10.1.3 Applications achievable with Beyond 5G

- Self-Driving Tractors and Rice Transplanters on farms do not need same accuracy of self-driving cars in terms of traveling speed and obstacle recognition. However, the same level of communication capability is required, and Beyond 5G is expected as a technology that satisfies these requirements.
- For use cases requiring ultra-low-latency control, such as crop-dusting using drones, faster and safer drone flight control is possible by using a combination of Local Beyond 5G and edge-computing technologies.
- Data from various sensors such as for temperature, humidity, and rainfall spread across cultivated fields can be gathered using IoT technology such as Low-Power Wide Area (LPWA) or Beyond 5G technology, managed in cyber-space, and used for agriculture management and other purposes.
- By analyzing this data from various perspectives using AI technology, it can be used in overall management of agricultural work to maximize yield, such as automating watering or drainage, opening or closing green houses, or determining when to apply agricultural chemicals.
- By using the latest AR and VR technologies though Beyond 5G, instruction or support could also be given from a remote location, and they could be used to start new cultivation in regions where cultivation has been abandoned or overseas, or to support such efforts.

- Data from smart buoys and real-time tide meters floating on the sea can be used to determine the amount of fish caught and the types of fish caught in fixed fishing nets.
- At present, it is difficult to accurately identify the type of fish using video information from underwater drones, etc. due to the resolution of the image. However, it is expected that the recognition accuracy will improve in the future due to the expansion of communication capacity.
- In this way, the utilization of Beyond 5G in "smart agriculture" and "smart agriculture" is expected not only to further improve production but also to lead to the maintenance and revitalization of communities, such as the promotion of settlement through the improvement of living environments in underpopulated areas.
- In the future, when utilizing Beyond 5G in agriculture (rural areas) and fisheries (fishing villages), it is important to take into account the state of development of the utilization environment and the cost of introduction, and to provide more concrete examples of utilization at the site, including local Beyond 5G.

The evolution of Beyond 5G technology and industry is shown in Figure 4.10-1.

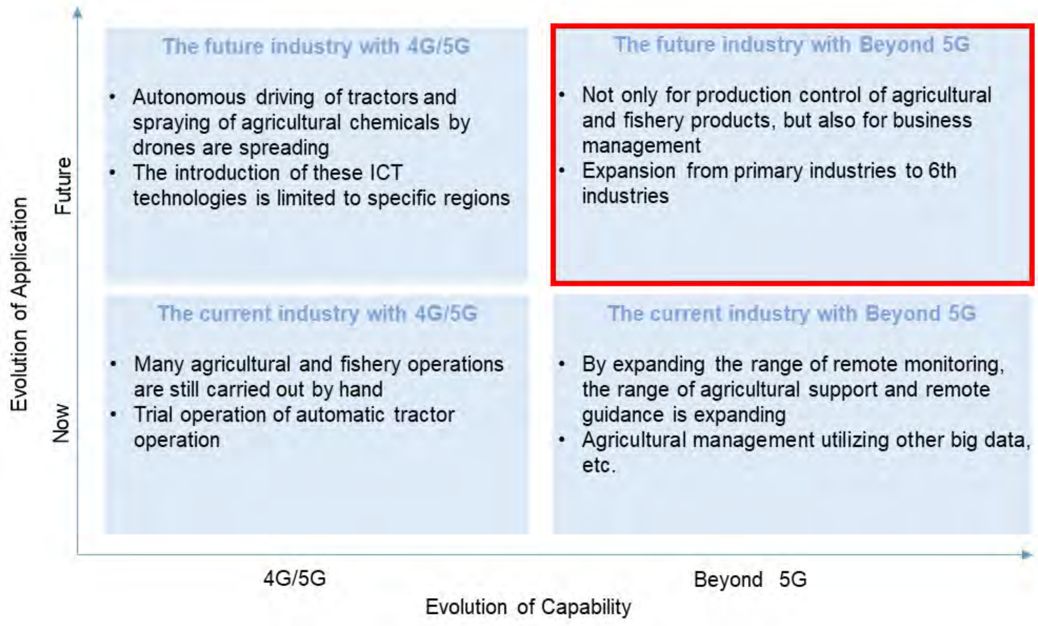

Figure 4.10-1 Agriculture / Fisheries industry in Beyond 5G era

4.10.1.4 Capabilities required in Beyond 5G

Based on the current and future use cases in smart agriculture and smart fisheries, the following are the capabilities required for Beyond 5G.

- For remote monitoring and automatic operation of agricultural machines such as automatic tractors and automatic rice transplanters, from the viewpoint of running speed and obstacle recognition, it is considered that the same level of communication performance is required, although the capability to the automatic operation level of the automobile is not required. The Beyond 5G capabilities for these technologies are related to ultra-low latency and positioning and sensing.

- With regard to remote monitoring technology for cattle barns in the livestock industry, in order to identify the position of cows and transmit images of cows in real time, ultra-fast and large capacity may be required as a Beyond 5G capability, and in some cases, universal coverage may be required to make it easier for radio waves to reach.
- In the smart fishery, in the coastal fishery, it is necessary to remotely grasp the situation of fish entering the set-net from smart buoys on the sea or real-time tide meters. Therefore, as a capability of Beyond 5G, smart buoys and tide meters are required to have ultra-low power consumption because they may be connected simultaneously and installed in remote sea areas. In addition, it is necessary to be able to grasp the position of smart buoys and tide meters, and it is necessary to have positioning and sensing functions. It is also assumed that universal coverage will be required as a capability, since places where radio waves are hard to reach.
- On the other hand, in aquaculture in the smart fishery, it is necessary to use underwater drones to visualize aquaculture areas. For this reason, in terms of Beyond 5G capabilities, the following will be important: Simultaneous connection of a large number of underwater drones due to the possibility of multiple connections, ultra-security, resiliency and reliability to prevent equipment failure, ultra-low power consumption to enable long-term remote operation, positioning and sensing to enable location identification, and Coverage expansion to make it easier for radio waves to reach.

Table 4.10-1 shows the correspondence between the above application examples and the capabilities required for Beyond 5G.

Table 4.10-1 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Remote monitoring of agricultural machinery (Tractors, etc.)		X					X			
Remote monitoring	X							X		
Smart buoy and real-time tidal current meter			X		X		X	X		
Underwater drone			X	X	X		X	X		

4.10.1.5 Summary

In this section, the current status and challenges of the agriculture, livestock, and fisheries industries are surveyed, and the expected future image of these fields and examples of Beyond 5G utilization are shown. The capabilities required for Beyond 5G include ultra-fast and large capacity, ultra-low latency, ultra-massive connectivity, ultra-security, resiliency and reliability, ultra-low power consumption, positioning and sensing, and universal coverage.

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4.10.2 Food

4.10.2.1 Current situation and challenges

- Classification by food production industry

The word "foods" includes a wide range of types and varieties in daily life. Here we classify the type of food according to industries producing these foods. For example, rice is a primary product produced by agriculture, while packs of sliced mochi (rice cakes) are processed from glutinous rice in a factory, so they are a secondary product. Food products are not all produced by agriculture, but also by the livestock and fisheries industries, which each also produce primary and secondary products, classified as shown in the table below.

Table 4.10-2 Food product classifications

	Agriculture	Livestock (incl. poultry)	Fisheries
Primary products	Grain, vegetables, mushrooms, fruit, pulses, etc.	Beef, pork, poultry, etc.	Fish, shellfish, seaweed, etc.
Secondary products	Cut mochi packs, frozen vegetables, canned tomatoes, tofu, natto, bread, noodles, etc.	Ham, sausage, bacon, roast pork, etc.	Canned mackerel, tuna, and shellfish, dried fish and seaweed, etc.

  - Primary food products include products from primary industries, which are mainly agriculture, livestock (including poultry) and fisheries. The current state and issues of these industries are as indicated in the previous section (Section 4.10.1), and productivity is expected to increase with introduction of 5G and Beyond 5G in the future.
  - On the other hand, most secondary food products are produced in facilities such as food processing factories. These are a type of manufacturing business, and food processing is particularly amenable to smart factory applications. Below, we discuss the current state and issues of regular manufacturing industries (and food processing in particular), and expectations for introduction of 5G and Beyond 5G

- Issues surrounding manufacturing (and food processing in particular) [1]
  - With the recent low birthrate and aging of Japan's population, the manufacturing industry workforce has tended to shrink gradually each year, and a corresponding decline in Japan's manufacturing productivity has been unstoppable.
  - To counter this decline in labor productivity due to a shrinking and aging workforce, manufacturing industries have worked to increase productivity more than before, but even more improvements are needed.

- Particularly in food processing production environments, stable production-line operation is needed to maintain the quality of food products and to avoid production-line stoppages due to mechanical or other faults.

- Current initiatives involving use of ICT
  - In recent years, there have been initiatives using ICT for product, process and market innovation, contributing to increasing productivity with limited resources, and developing new production methods. In particular, initiatives using IoT or AI to ascertain the operating state of all kinds of equipment or the actions of workers in real time have been active.

Table 4.10-3 Initiatives using ICT in manufacturing industries

	Content of ICT-based initiatives
Product innovation	・Customized products based on innovative production, using big data, AI or robotics. ・Converting products to services by using IoT to remotely monitor the operation of the company's products, or to propose new products.
Process innovation	・Increase manufacturing process efficiency using technology such as robotics, and remote operation and control. ・Reduce work errors by using sensing with technology such as IoT to manage production and provide guidance for work.
Market innovation	・Gather and analyze marketing information including feedback and analysis using big data and AI.

Source: MIC (2020) "Study of changes brought to economy and society by 5th Generation Mobile Communication Systems"

- Initiatives in the manufacturing industry (food processing industry) [2]

a) Internal factory monitoring [3]

  - Video from high-definition cameras installed in a factory can be transmitted at very high speed and low latency using 5G, to enable real-time monitoring of the state of facilities and machinery.
  - IoT has been used to measure and visualize data regarding operational state, but such visualization is advancing with additional information such as camera video of people's movements.
  - More accurate and detailed monitoring is possible by transmitting higher-resolution video (4K, 8K, etc.) using the ultra-high speed and capacity of 5G. Feedback control can also be more accurate utilizing the ultra-low latency feature of 5G.
  - With analysis using AI technology, it is possible to increase worker efficiency, and also to automatically detect product flaws or inconsistent processing in the production line.

- Using edge computing closer to the factory site, the ultra-low latency of 5G can be used to perform real-time detection, providing immediate feedback.

b) Work support [4]

- Provide support for interaction between people and the production systems for a production line in a factory through 5G using a PC, a tablet, or technologies such as VR and AR, according to content of the work.
- For example, AR goggles can be used to perform work smoothly using supplementary information, or for remote guidance or communication.
- With existing communication schemes (Wi-Fi, etc.), performance has been inadequate in terms of speed and latency, so by introducing systems with higher response rates using features of 5G, they can be used to provide work support and improve quality.

c) Automation of equipment [5]

- Process automation (PA) technology has evolved in a somewhat different form than factory automation (FA) technology, which has focused on automation (automatic control), monitoring or optimization of production processes, streamlining such processes, reducing energy consumption, or maintaining safety in a factory.
- By switching to wireless communication using 5G features with these FA and PA technologies, it will be possible to gather high-volume data from production lines using IoT technology, or to perform real-time remote control of production equipment.
- In critical domains where FA or PA technology could not be applied due to accuracy or latency with existing technologies (Wi-Fi, etc.), it may be possible to apply them using the performance of 5G.
- It will also be possible to meet high-performance requirements in a factory by using edge computing linked with communication on the “edge”, closer to robots and other related equipment built into the production facility.
- By using Hybrid 5G, which uses Local 5G for the private network inside a factory and the public 5G network to link between factories or enterprises, many driverless transport vehicles could operate more intelligently. Entire supply chains could also be optimized by using Hybrid 5G to combine internal factory information with information on the public network, implementing smart production that can handle fluctuation in demand with more flexibility.

4.10.2.2 Future vision [6]

- As technologies like Beyond 5G advance further, by utilizing the features of 5G: (1) ultra-fast and large capacity, (2) ultra-low latency, and (3) ultra-massive connectivity; we can expect food-processing smart-factories to accelerate, improving productivity and promoting environmental measures such as reducing CO_2 emissions.

- With Beyond 5G, introduction of wireless technology will reach a new stage, with many devices being monitored simultaneously on video, increasing maintainability and facilitating collection and analysis of data from production lines, and contributing to increased operation rates and productivity.
- In particular, a production line, which is in the real world, is mapped to a cyber-physical system (CPS) in cyberspace, making it possible to monitor and control actions of the production line and workers.

4.10.2.3 Applications achievable with Beyond 5G

- Edge computing technology is used for parts that require high-speed, low-latency data analysis, such as vibration analysis for stable operation of production lines.
- Data from sensors and sequencers installed in the plant are collected by IoT technology such as LPWA (Low Power Wide Area) and local Beyond 5G in the plant. The collected data is managed in cyberspace and used for production control.
- TSN (Time-Sensitive Network) technology, which can control production line equipment with very little time error, is important for the automation of equipment for the introduction of FA and PA. Combining these technologies with Beyond 5G is expected to improve production.
- Using the latest AR and VR technology and using it through Local Beyond 5G, technical guidance and support will be possible from remote locations.
- In this way, use of Beyond 5G in food processing smart factories, can further increase productivity for food products and also be used for managing inventory of materials for the manufacturing processes and the products themselves. By combining AI and big data, it can also be applied for managing distribution to retail outlets and even for marketing.
- As an example, Beyond 5G technology could be used to address food waste, which has been a societal issue in recent years. By continually managing inventory at food stores, if a store has extra inventory that it has not sold as closing time approaches it could be sent to another store that has already sold out, or data such as the weather, temperature or customer traffic could be used to determine the optimal production amounts for the next day, to minimize food waste.

Figure 4.10-2 Food Processing Industry in Beyond 5G era

4.10.2.4 Capabilities required in Beyond 5G

Based on the current and future use cases of smart factories in the food industry, especially in the food-processing manufacturing industry, the following capabilities are required for Beyond 5G.

- In order to monitor the condition of facilities and equipment in a factory in real time, it is assumed that images from high-precision cameras are used. In this case, as the capability of the Beyond 5G, ultra-fast and large capacity and ultra-low latency are required because the communication of a large amount of image information is required. These cameras also require ultra-low power consumption because they have to operate for long periods of time throughout the factory. In addition, it is thought that a positioning and sensing function is also necessary in order to grasp where the relevant facilities and equipment are located in the factory.
- When using PCs, tablets, VR/AR technology, etc. to provide work support in a manufacturing line in a factory, it is necessary to communicate image information for AR/VR at ultra-fast and large capacity and ultra-low latency. In addition, since the glasses used for AR/VR must be ultra-low power consumption and it is necessary to accurately grasp the positional information of the facilities and equipment to be supported, the function of positioning and sensing is also considered to be important.
- Smart factories need to promote factory automation (FA), which aims to automate production processes, monitor and optimize them, and process automation (PA), which aims to streamline manufacturing processes and reduce energy consumption.

For this reason, ultra-fast and large capacity and ultra-low latency are required as Beyond 5G capabilities for monitoring and the like. In addition, time synchronization accuracy is required for the control of production lines and equipment, and ultra-low power consumption is required for long-term operation. Also, it is thought that positioning and sensing will be required in order to grasp the location information of the equipment.

Table 4.10-4 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Factory monitoring (High Precision Camera)	X	X			X		X			
Work support (AR/VR, etc.)	X	X			X		X			
Facility automation (FA/PA, etc.)	X	X			X	X	X			

4.10.2.5 Summary

In this section, the present state and challenges of the food industry, especially the food processing industry as a manufacturing industry, are surveyed, and the future image expected in these fields and examples of the utilization of Beyond 5G are shown. The capabilities required for Beyond 5G include ultra-fast and large capacity, ultra-low latency, ultra-low power consumption, time synchronization accuracy, and positioning and sensing.

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4.10.3 Living and Cultural Goods

4.10.3.1 Current Status and Challenges

- Living and Cultural Goods
  - Living and cultural supplies refers mainly to non-food products consumed or used in the home and include the products shown below, according to Japan standard product classifications by the Ministry of Internal Affairs and Communications (June, 1990 revision) [1].
  - Many of these are manufactured goods from manufacturing industries, and within those industries, are related to non-food-production industries such as textiles, chemicals, furniture and equipment.
  - As such, the discussion below includes manufacturing current conditions, issues and expectations for 5G and Beyond 5G not included earlier (in section 4.10.2) regarding smart factories for food processing.

Table 4.10-5 Living and cultural supplies classifications

Classification	Items
Living and cultural supplies	Kitchen utensils and tableware (except silverware, plated ware and similar metal ware)
	Apparel (except footwear and apparel accessories)
	Apparel accessories
	Footwear
	Jewelry, personal adornments and silverware
	Household textile articles
	Furniture
	Appliances and equipment for cooling, heating, cooking, boiling (using a main heat supply other than electricity) and sanitary equipment
	Other household equipment and utensils
	Medical supplies and related products
	Drugs and related commodities
	Cosmetics, dentifrices, soaps, household synthetic detergents and household chemical products
	Recreation equipment and toys
	Musical instruments
	Sports and athletic goods (except footwear and uniforms)
	Printed products, film, records and other recorded materials (except programs)
	Stationary, paper products, office supplies and photographic supplies
	Works of art, collectors' pieces and antiques
	Other living and cultural supplies

- Challenges
  - In these manufacturing industries, with the recent shrinking and aging population, the workforce has tended to decrease each year and a decline in the domestic productivity in these industries persists.
  - To counter this declining labor productivity due to the shrinking and aging workforce, these industries will need to increase productivity even more.
  - For production of products like clothing in particular, items suited to the size or style of individuals are required, so small numbers of many types of product must be produced in a short amount of time.

- Initiatives for ICT utilization
  - As in Section 4.10.2, these manufacturing industries are contributing to increasing productivity and new production methods with limited resources through innovation in products, processes and marketing using ICT.
  - In recent years, initiatives to produce small quantities of many types suited to the diverse needs of customers, utilizing AI, are particularly active.

- Initiatives in the Household and Cultural Goods Manufacturing Industry [2]

As indicated earlier in Section 4.10.2, initiatives are already taking shape in these industries, such as factory monitoring using 5G, work support using AR and VR, automating equipment using features of 5G in factory automation (FA) and process automation (PA), and hybrid 5G networks combining Local 5G within a factory with 5G public networks between factories or between enterprises.

- Factory internal monitoring
- Work support
- Automation of equipment, etc.

4.10.3.2 Future vision [3]

- As technologies advance, with Beyond 5G, by further utilizing the features of 5G: (1) ultra-fast and large capacity, (2) ultra-low latency, and (3) ultra-massive connectivity; smart factories will accelerate, making productivity-increasing effects even greater and also acting as countermeasures against CO_2 and other environmental issues.
- With Beyond 5G, introduction of wireless technology will reach a new stage, with many devices being monitored simultaneously with video to increase maintainability and facilitate collection and analysis of data from production lines, contributing to increased utilization rates and productivity.

- In particular, a production line, which is in the real world, is mapped to a cyber-physical system (CPS) in cyberspace, making it possible to monitor and control actions of the production line and workers.

4.10.3.3 Applications achievable with Beyond 5G

- Edge computing technology is used for parts that require high-speed, low-latency data analysis, such as vibration analysis for stable operation of production lines.
- Data from sensors and sequencers installed in the plant are collected by IoT technology such as LPWA (Low Power Wide Area) and local Beyond 5G in the plant. The collected data is managed in cyberspace and used for production control.
- TSN (Time-Sensitive Network) technology, which can control production line equipment with very little time error, is important for the automation of equipment for the introduction of FA and PA. Combining these technologies with Beyond 5G is expected to improve production.
- Using the latest AR and VR technology and using it through Local Beyond 5G, technical guidance and support will be possible from remote locations.
- In this way, use of Beyond 5G in smart factories can further increase productivity for lifestyle related products and also be used for managing inventory of materials for the manufacturing processes and the products being produced. By combining AI and big data, it can also be applied for managing distribution to retail outlets and even marketing.

Figure 4.10-3 Living and cultural goods manufacturing in Beyond 5G era

4.10.3.4 4. Capabilities required in Beyond 5G

Based on the current and future use cases of smart factories in the manufacturing industry of daily necessities and cultural goods, the following are the capabilities required for Beyond 5G.

- In order to monitor the condition of facilities and equipment in a factory in real time, it is assumed that images from high-precision cameras are used. For this reason, as in the previous section, ultra-fast and large capacity, ultra-low latency, ultra-low power consumption, positioning and sensing, etc. are considered to be required as the capabilities of Beyond 5G.
- As in the previous section, Beyond 5G capabilities such as ultra-fast and large-capacity, ultra-low latency, ultra-low power consumption, and "positioning and sensing are considered to be necessary for providing work support using PCs, tablets, VR/AR technology, etc. in manufacturing lines in factories.
- When factory automation (FA) and process automation (PA) are promoted in smart factories, as in the previous section, ultra-fast and large capacity, ultra-low latency, ultra-low power consumption, time synchronization accuracy, and positioning and sensing are considered to be required as Beyond 5G capabilities.

Table 4.10-6 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Factory monitoring (High Precision Camera)	X	X			X		X			
Work support (AR/VR, etc.)	X	X			X		X	X		
Facility automation (FA/PA, etc.)	X	X			X	X	X	X		

4.10.3.5 Summary

In this section, we have surveyed the current status and challenges of the consumer and cultural goods-related industries, especially the manufacturing industry, and presented the expected future image of these industries and examples of Beyond 5G utilization. The capabilities required for Beyond 5G include ultra-fast and large capacity, ultra-low latency, ultra-low power consumption, time synchronization accuracy, and positioning and sensing.

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4.11 The retail, wholesale, and distribution sectors

The retail, wholesale, and distribution sectors include a wide range of industries as shown below.

Retail industry, wholesale industry, wholesale food, wholesale clothing, wholesale fisheries, department stores, super stores, convenience stores, pharmacies, electronics stores, home centers, discount stores, book stores, sporting goods stores, second-hand stores, auto supply stores, etc. Also, there are integrated trading companies that handle a wide range of products and services focusing on import/export trade or the sale of goods domestically and specialist trading companies that specialize in specific sectors. However, even if a product is the exact same or similar, the sales methods could be different, such as mail orders, outlets, etc., and these also form a large market. Additionally, online sales, where products from a wide range of sectors and industries can be purchased over the internet, is becoming a very large market compared to direct sales.

4.11.1 Current situation and challenges

The current main challenges for the retail, wholesale, and distribution sectors are as follows.

- Products do not sell (consumer needs change with the times)
  - It is harder to sell products and goods easily. High quality products and similar products with a low price are both getting better in all categories. This is because new products are constantly being developed and sold. Also, as the quality improves, the products can be used longer after purchase. Therefore, consumers do not need to purchase replacement products or goods frequently, and it is becoming more common to use a single item for a long time.
  - Another cause is more rapid changes in trends. With the widespread use of the internet, consumers who purchase products and goods are able to collect more information. Consumers are sensitive to trends, and the trend cycle continues to get shorter as popular products quickly change.
  - It is a major challenge for businesses to respond to needs that change with the times. Currently, there is a shift from the generation where products and goods would be purchased and owned to one where sharing is the norm. Consumers who are concerned with purchasing expensive goods are trending toward sharing products, goods, and superior services relatively cheaply over the internet. Subscription services are a good example. The services provided can be used freely at a set price.

- Purchases over the internet, such as through online shopping and EC websites

- As in Europe, the United States, and China, online stores and EC websites are experiencing an increasing growth rate. Even in Japan's retail industry, there is an increasing trend toward gathering customers and introducing products/goods and selling them over the internet.
- The change in the timing of the purchase of products and goods is making it more difficult for physical stores to respond to actual buyer motives through showrooms. Even if physical stores are able to attract customers, the customers can look for a website selling the same item for cheaper in order to make the actual purchase, and the customer could be taken by another company.

✧

- Initiatives for SDGs
  - Elimination of plastic/plastic bags
    Across Japan, every year 30.5 billion plastic shopping bags are used, which is about 300 bags per person. The production of these bags requires about 420,000 kiloliters of crude oil. [1]
  - Fair trade
    This is the buying and selling of goods at a fair price by retailers so that the producers can have a dignified and better life. There is a possibility that the production of cheap products uses environmentally harmful processes or labor that ignores human rights. Products with a fair trade mark, and the sharing of the meaning of this mark with consumers, allows consumers to contribute to SDGs and society through their purchasing.
  - Food loss
    A major social problem is the disposal of edible food by stores and consumers resulting from the sale of a wide variety and large quantity of food products. Also, a large quantity of food products are disposed of due to the passage of best before and use by dates.
  - Various challenges in supply chains
    In the retail, wholesale, and distribution industries, the manufacture of products and goods, wholesale, distribution, and sales are linked by the supply chain. For example, products and goods are not only shipped to retailers, but also supermarkets, convenience stores, and many other types of businesses. Therefore, a major challenge in the shipping industry in the supply chain is handling de-carbonization and carbon neutrality.

In addition to the aforementioned challenges, the style of work in the retail industry is also greatly changing due to COVID-19. Even within the retail industry, various initiatives are being taken according to the business model in order to adapt to the current and future COVID-19 environments. Supermarkets and drug stores that sell daily goods take measures against the three Cs for the current style of living with COVID-19, as it is important for them to protect both consumers and employees. In this way, the promotion of DX through labor saving, ICT, and AI is becoming more urgent.

4.11.2 Future vision

ICT is being used to solve current challenges. There are diverse expectations for a future where new communication technologies are used for such initiatives, but this section covers the following expectations for the realization of Society 5.0.

- Depopulation and shrinking industry due to an aging society and related solutions
  Depopulation due to aging is rapidly progressing across Japan and in regional cities. Therefore, the retail industry will be unable to get sales, and stores, supermarkets, drug stores, etc., required for daily life will be unable to stay in business.

- The effects on the living environment resulting from regional differences in population decline and related solutions
  The aim is to achieve the Vision for a Digital Garden City Nation [2] across regions with disparities in population decline to establish a living environment that has similar convenience to a metro or city area regardless of where someone lives and a regional society that uses the natural abundance of the region.

- Data logistics and collaboration in order to sustainably develop industry
  In order to handle the sale of products and goods over the internet in Japan's markets and to solve various social challenges, large corporations are not only implementing their own industry-specific forms of management, but they are also cooperating with other companies and across industries to establish infrastructure for data sharing and logistics to develop social/community-based services through the sale of products and goods.

- Contribution to social implementation models for the formation of social infrastructure for industries
  Industries greatly involved in daily life must be present at the individual level and the community/regional level, and their growth is being promoted for models of social implementation in industries that will form the social infrastructure in the future.

- Industry contributions to SDGs
  Industries make many contributions through their measures and responses, such as by reducing food loss and waste, starting with the participation of primary industries

that precede the manufacturing of products and goods and spanning across the manufacturing, shipping, transport, and distribution of products and goods prior to sale; the sale of products and goods; as well as after sales have taken place. Notably, many industries are involved in a supply chain. Therefore, it is necessary to use advanced technology such as next-generation networks and AI in measures for carbon neutrality [3].

For example, in order to reduce the daily CO_2 emissions for the distribution (trucks, etc.) of products to all convenience stores across Japan, companies are taking measures to understand and reduce their own greenhouse gas emissions as well as those of others. [4]

4.11.3 Applications achievable with Beyond 5G

- Use of ICT in traditional sales
  - Shift from physical stores to virtual stores such as online stores and EC
  - Delivery, inventory, and sale of products based on precise, advanced sales projections
  - Coordination of transport to ensure accurate delivery of products and goods
  - Linking of systems to expand supply chains
  - Use of display robots to cover chronic labor shortages
  - Optimizations for long work hours
  - Sophistication of register payments, ordering tasks, inventory tasks, shift creation, and sales promotion

- Use of ICT due to COVID-19
  - Customer flow management and analysis (including temperature measurements on entering the store)
  - Avoiding congestion with IoT technology
  - Expansion of online supermarkets
  - Sharing-based delivery services

- Shift to digital services
  - Support for social media, etc.
  - Support for new purchasing methods (internet, smartphones, etc.)
  - Provision of services (experiences) that add value to the sale of products or goods

- Consumption and sharing
  - Value of products and goods when used (consumed) after purchase
  - Value of products and goods when shared after consumption

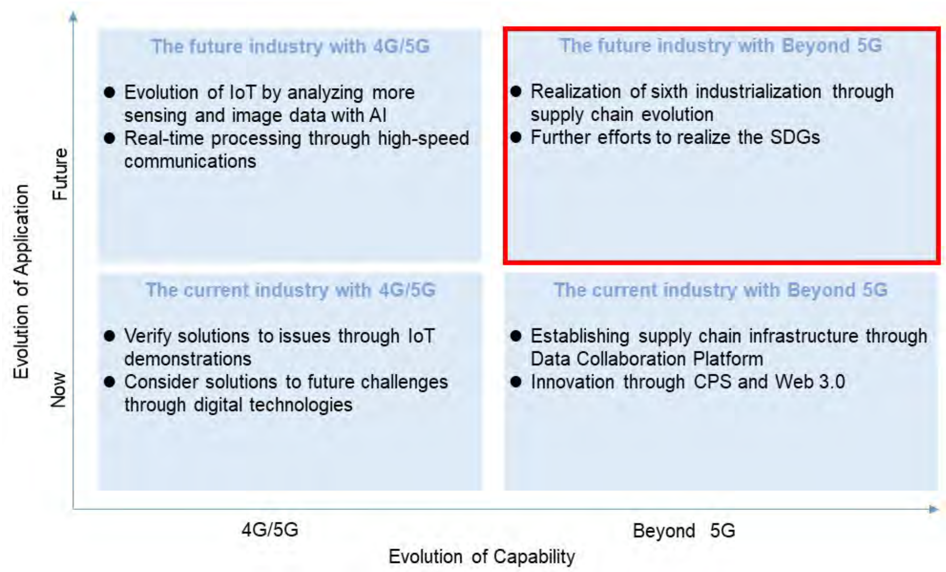

Figure 4.11-1 The retail, wholesale, and distribution sectors with Beyond 5G

4.11.4 Capabilities required in Beyond 5G

The following network capabilities are required in order to achieve retail, wholesale, and distribution industries as described below.

- Ultra-fast and Large capacity, ultra-low latency
  Delivery by highly autonomous drones
  High-volume media transfers such as movies and images
  Autonomous stores (Holoportation, concierge)
  Data logistics and collaboration for joint transport (reducing CO_2 emissions)

- Ultra-massive connectivity
  Spatial sensing for entire regions
  Autonomous stores (products and goods)

- Ultra-security, resiliency and reliability
  Personal information
  Data logistics and collaboration across sectors and corporations
  Autonomous stores (payments)

- Ability to be expanded
  Measures for energy conservation
  Environmentally-friendly transport vehicles
  AGVs (autonomous guided vehicles)

CPS (Cyber Physical System), DTC (Digital Twin Computing)

Linking municipal Oss

Table 4.11-1 Usage examples of Beyond 5G and capabilities

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Use of ICT in sales	X	X	X	X	X		X		X	Trusted Data
Use of ICT due to COVID-19	X	X	X				X	X	X	Trusted Network
Shift to digital services		X		X			X			Trusted Network Data
Consumption and sharing				X			X	X	X	Trusted Network Data

4.11.5 Summary

This section examined the current situation and challenges of retail, wholesale, and distribution sectors; the future vision; and usage examples of Beyond 5G. The performance requirements of Beyond 5G were shown in the previous table. The requirements are single requirements or a combination of numerous requirements based on the application or service to be realized or a linking (like Beyond 5G/MEC) of application services focusing on the cloud.

However, the use of data will be a vital theme in the expansion of industry, and a shift to DX with the use of AI will be encouraged. Therefore, a series of initiatives for securing economic security, such as Trusted Networks and Trusted Data (web), will be an important requirement for Beyond 5G. [5]

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4.12 Services, Public Services, Corporate Services

4.12.1 Healthcare

Medicine and public health are important components of social services. With the support of health care providers, medical systems, delivery systems, and medical technology, we can receive safe and advanced medical services. In this section, we delineate our vision for the future by taking into account the current state of healthcare and its challenges, and discuss the use cases achievable with Beyond 5G, as well as the requirements for those use cases.

4.12.1.1 Current situation and challenges

The environment surrounding medicine and healthcare, such as the declining birthrate and aging population and the coronavirus pandemic, is changing year by year, and the situation in 2030 is likely to be significantly different from the current situation. Moreover, problems and issues will likely arise from the changes in the environment. The Japanese government has established the Headquarters for Healthcare and Medical Strategy Promotion to compile health and medical strategies [1]. This section highlights three of the healthcare issues that Japan and other countries around the world may face in the future.

<u>1. Harmony with a super-aging society</u>

Japan's population aging rate was 28.8% in 2020, which is high compared with other countries, such as those in advanced (18.3%) and developing regions (7.4%). In the future, the aging of the populations in developing regions as well as in advanced regions is foreseen to rapidly accelerate, rising to 28.2% in advanced regions and 16.4% in developing regions by 2060 [2]. Japan, which has a high population aging rate compared with other countries, will likely face the following four challenges ahead.

First is the increase in cost of healthcare, with per capita medical expenses increasing with age after adulthood and rapidly so after reaching 65 years of age. Second is the manpower shortage in the healthcare system. With the surge in demand for medical services, the number of needed healthcare professionals is seen to increase to a maximum of 10.7 million by 2040, which is about one-fifth of the entire workforce [3]. Third is the regional disparities in the healthcare system. The aging of the population in sparsely populated areas is increasing, with those aged 65 or older at 36.6%, along with the increase of the population in medically underserved areas [4]. And fourth is the expanding in the difference between the average lifespan and the healthy lifespan. According to the abridged life table for 2020, the average lifespan of Japanese people is increasing year by year to 81.64 years for men and 87.74 years for women, therefore it will also be important to extend the healthy lifespan, i.e., the period that a person can expect to live in full health without hampered by disabling illnesses [5].

Japan, which is foreseen to be among the first to be faced with these challenges, is looked up to by the rest of the world to provide healthcare using the world's best technologies under healthcare policy, to be the first in achieving harmony with a super-aging society, and to fulfill the role of presenting the world with solutions to these challenges.

2. Response to unknown diseases

Coronavirus disease 2019 (COVID-19), which was first reported in December 2019, has quickly spread worldwide. In response, countries around the world have taken measures and travel restrictions to prevent the spread of the disease. These measures have brought about major changes in our daily lives. Infectious diseases have been recorded for thousands of years before Christ, and killing countless people, for example Pestilence in the middle ages of Europe, and the great influenza epidemic in the early 20th century [6]. After the 18th century, although the emergence of vaccines and antibiotics has enabled significant progress in methods for preventing and treating infections, at least 30 emerging infections have been detected since 1970. Vaccines for COVID-19 have been developed, and the numbers of new infected individuals appear to be decreasing as vaccinations progress in each country. However, there is a high likelihood for unknown infections to occur in the future, pointing to the need for putting systems and measures in place to respond and resolve them promptly when they occur, such as 1. Establish network and database for fast Pathogen identification and share the Pathogen information, e.g. genetic information, 2. Establish platform for the seamless development of medicine and vaccine with using AI and robotics, and 3. Preparing diagnostic tool with high sensitivity and easy to use at clinical practice [7][8].

3. Advancement of pharmaceutical and medical device development technologies

Research and development in the medical field is accelerating worldwide, and further innovations should come about through the use of digital technology. In Japan it has been pointed out that basic research is not always leading to practical application, the Japan Agency for Medical Research and Development (AMED) was established in 2015 to centralize research and development in the medical field carried out by the Ministry of Health, Labor and Welfare, the Ministry of Education, Culture, Sports, Science and Technology, and the Ministry of Economy, Trade and Industry [9]. This has led to the creation of a system to promote coherent research and development activities, from basic research to practical application, through which many results have been reported. Hence, the pharmaceutical and medical device industry, which is a knowledge-intensive industry, has potential to grow as an industry. Japan must, therefore, systematically work towards achieving the world's highest medical technology standards and take the lead in the industry’s global market expansion. From another aspect, it is also important to organize that who and how to cover the installation and operation costs when the advanced medical technology is rolled out.

We have thus far discussed the challenges that await us in the light of the international and domestic situations in the medical field. As a forerunner in finding solutions, Japan should take steps beyond industrial boundaries to address these challenges.

4.12.1.2 Future vision

On the basis of the current state of healthcare and the issues listed in section 4.12.1.1, we envisioned the five future images for healthcare aimed at making our lives more enriched. They are summarized in Figure 4.12-1.

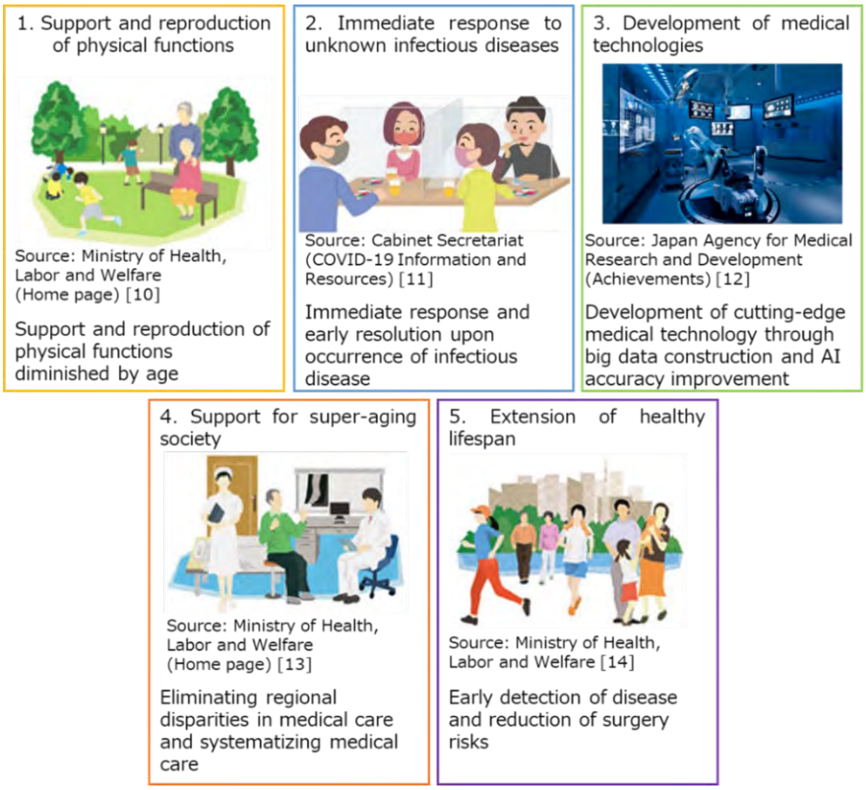

Figure 4.12-1 Five future visions for healthcare

1. Support and reproduction of physical functions and abilities

Age-related deterioration and loss of physical and sensory functions, namely, the five senses (sight, hearing, smell, taste, and touch), motor sensation, and sense of balance, affect daily living, reduce the quality of life, and could also diminish healthy life expectancy. Research on medical technologies, namely, on regenerative medicine to restore lost physical functions is ongoing. For example, clinical trials of retinal disease treatments, self-transfusion of platelet, and immune cell therapy using induced pluripotent stem (IPS) cells are on their way [15]. Support and reproduction of physical functions using robotics, mechatronics, and AI by leveraging communication technologies are also possible other than from the perspective of regenerative medicine. In the future, it will be possible to extend healthy lifespan through support and reproduction of physical functions.

2. Immediate response to unknown infectious diseases

Given the importance of rapid implementation of measures upon the discovery of unknown infections, frameworks and systems to implement these measures as introduced in section 4.12.1.1 must be prepared and created in advance. In addition, for example, monitoring social activity and health condition are also important. For the monitoring, to reduce person-to-person contact, a system to analyze information on infection and health conditions and provide the analyzed information in real-time, in addition to location information, should be established in advance. In the future, it will be possible to minimize the impact of unknown infections on our daily lives through the prompt implementation of measures to curb their spread and the prompt development of vaccines.

3. Development of medical technologies

The development of information and communication technologies (ICT) has made a significant contribution to the development of medical technologies. For example, genome analysis, which comprehensively analyzes the genetic information of living organisms, involves the processing of a large amount of information, calling for the use of information processing technologies. Cancer and intractable diseases will hopefully be overcome in the near future through genome analysis [16][17]. Further, the creation of big data and the improvement of AI accuracy resulting from the expansion of communication platforms. And using the latest technologies, medical database is constructed in cyberspace to realize digital twins, and they will likely lead to the development of state-of-the-art medical technologies that leverage these advances.

4. Construction of a medical and nursing care system to support a super-aging society

With the advent of a super-aging society, some patients may not be able to reach hospitals due to their physical conditions and amid the regional disparities in healthcare. The introduction of ICT should help resolve these issues. One of examples is the Personal Healthcare Record (PHR), which centrally manages medical history and information, such as individual medical records held by each medical institution. Recently, since smart phones are widely used and progress of cloud computing, PHR is used for variety of medical services. For example, AMED developed PHR system for preventing disease, and connecting medial service and nursing care service. In the future, it will be possible to receive more individually tailored medical care through the introduction of ICT into medical technologies.

5. Extension of healthy lifespan

As human lifespans continue to lengthen, extending the healthy life expectancy will become crucial. Daily health management is one of the important factors in extending the healthy lifespan. Lifestyle-related diseases, such as cancer and diabetes, account for 60% of the causes of mortality among Japanese [18]. Initiatives to prevent cancer and diabetes, must, therefore, be taken as part of daily life. Likewise, regularly evaluating your health conditions is also very important, wherein people should make sure to discover and deal promptly with any physical anomalies. Also, minimally invasive treatment, which reduces the burden on the patient's body in case of necessity treatment from a different perspective, is also an important consideration. The probability of contracting chronic disease increases with age, while the risks from medical treatment, such as surgery also increase, requiring the development of medical technologies that minimize the burden on the body. In the future, it will be possible to prevent and promptly detect diseases through the use of daily health management systems, as well as to perform minimally invasive treatments that are physically harmless.

4.12.1.3 Applications achievable with Beyond 5G

In this section, we discuss eight applications that are achievable through the use of Beyond 5G in future medical technology as shown in Figure 4.12-2, in order to achieve the future healthcare depicted in section 4.12.1.2. We also discuss the requirements for medical and communication technologies that underpin the realization of these future visions.

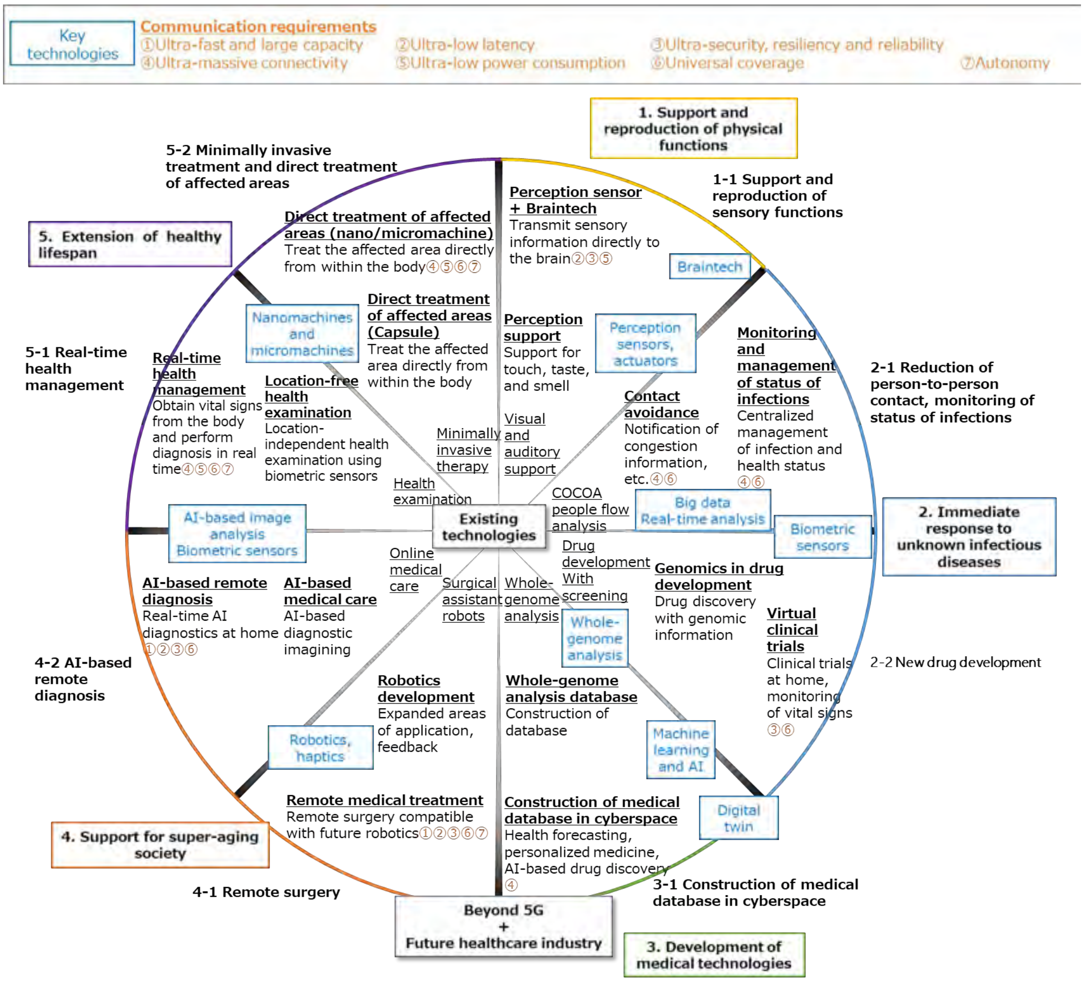

Figure 4.12-2 Future visions and requirements for medical and communication technologies that underpin the realization of the future visions

1-1. Support and reproduction of sensory functions

Examples of familiar medical devices for supporting sensory functions are eyeglasses and hearing aids for supporting vision and hearing. In the future, medical devices will also likely reproduce the senses of touch, taste, and smell, in addition to sight and hearing. Research and development of artificial skin sensors, for example, is being carried out as a component technology for these future medical devices. Development of wearable devices that generate appropriate electrical signals in response to skin sensation has been reported [19]. Likewise, there is a need for a way to transmit digital signals from sensors to humans. For example, for tactile sensation, this can be done by reproducing pressure and transmitting it to humans using actuators. In addition, it is expected that the interaction between tactile sensation and other sensory functions, such as visual sense realized by AR/VR and haptics technology which reproduces tactile sensation. Furthermore, as a future means of transmission, a method will be developed to transmit sensory information directly to the brain. The Brain-

Machine Interface (BMI) is being studied as a technology for reading brain signals and stimulating the brain [20]. U.S. government has driven the research of BMI from the 1970s, and recent years, it has been improved rapidly with the evolution of neuroscience, information science, and industrial technology. In 2020, Neuralink developed a coin-shaped device that can be planted in the human head, and detects the electric field generated by the nerve cells. Therefore, the mechanism for transmitting digital sensory signals from sensors to humans using the BMI can be considered as an application format for medical devices in future that reproduce sensory functions. Communication technologies for connecting various perception sensors to the BMI, therefore, play an important role; and since the sensory function is necessary for determining physical abnormalities and hazards, ultra-security, resiliency and reliability, ultra-low latency are required for such technologies. Furthermore, for convenience, these medical devices should be able to operate continually for at least one day on a single charge, while maintaining constant data transmission and reception. Communication devices, therefore, must operate at ultra-low power consumption.

2-1. Reduction of person-to-person contact and monitoring of status of infections

Reduction of person-to-person contact is a way to curb the spread of unknown diseases and infections once they are discovered and signs of their spread appear. During the COVID-19 pandemic, two ICT-based solutions became widely used in Japan. The first is a mobile phone application for checking close contact with COVID-19 positive users. The app uses proximity communication function (Bluetooth) to detect contact within 1 meter for more than 15 minutes with other users and sends a notification of possible contact with a positive user if the other user has been registered with the system as having tested positive to COVID-19 [19]. The other is the collection of information about the flow of people and the amount of people in downtown areas provided using big data on mobile phone location information. The quantitative data provided helped the national and local governments decide on policies and also influenced our awareness of our individual behavior.

These technologies are widely used, and in the future, they are seen to further evolve to enable analysis of information on infection and health conditions and provision of the analyzed information in real-time. For example, real-time analysis of actual congestion status in certain areas, establishments, and transportation facilities and provision of results to users will enable the implementation of contact-avoidance measures, such as regulation of entry, in accordance with the situation, and can be used to prompt specific behaviors depending on our specific situations. Further, adding physiological and morbidity information to the location information will widen the range of uses. For example, during the spread of infectious diseases, people may have to recuperate at home or at hotels due to lack of patient beds in hospitals. Using biometric sensors to obtain real-time vital signs, such as heart rate, and blood-oxygen level from patients and transmitting the information to medical facilities will enable quick responses to change in their medical conditions. Further, adding morbidity information will enable verification and analysis of the status and history of infection in each region, as well as providing centralized support to affected persons, including the management of their health status and the determination of their need for admission. Realizing these use cases will require communication technologies that enable the acquisition of highly accurate location information from mobile phones to analyze accurate congestion status, while ensuring a high level of security for handling personal information. Further, managing vital information in real time will require providing reliable communication coverage to all rooms of the hotels and homes where patients recuperate.

2-2. New drug development

While vaccine development usually takes several years. On the other hand vaccines for COVID-19 were developed in a short period of less than a year. mRNA vaccines have attracted attention and can be designed immediately once genomic information of the virus is analyzed, and fabrication process is proceeded [22]. Therefore, considering the conventional vaccine design process which requires large number of screening repeatedly to clarify effectiveness of the design samples, genomic-based drug development, which specifies the design of drug and vaccine against the target bacillus and virus, significantly reduce the period and cost of the development and is expected to be developed more effective drug and vaccine with the logical development process based on genomic information [23]. Clinical trials are an important process for vaccine development, but for the vaccine by U.S. company Pfizer, trials began in April 2020 and approval was received in December of the same year. One of the reasons behind the shortened clinical trial period was the large amount of financial input and the ability to simultaneously carry out the three-stage trials. A large financial support, however, is not always available, such as when the spread of infections is only regional in scope. In order to proceed clinical trials with shorter period and lower cost, virtual clinical trials will be conducted, where everything from recruitment of participants to completion of the trials will be carried out online. By eliminating geographic and time constraints when recruiting participants for clinical trials, more people can participate from a wider area, even across national borders. Further, although restrictions may be imposed on travel and behavior during outbreak of infectious diseases, carrying them out completely online will ensure that the trials can proceed regardless of the restrictions. Because examinations and medications are performed at home, responding to change in physical condition will be one of the concerns of clinical trial participants. The institutions administering the clinical trials can provide prompt support by detecting the change immediately and issuing notifications through remote online medical examinations and constant monitoring of vital signs by having participants wear biometric sensors during the clinical trial period. Also, monitoring of vital signs will enable the accumulation of a larger amount of information than that obtained from regular examinations conducted during ordinary clinical trials. It can also be used as a means to follow up on the occurrence of adverse reactions and the sustainability of the effects. Although virtual trials have various promising effects, they require communication technologies that enable constant connections between biometric sensors and clinical research institutions, while ensuring a high level of security to achieve real-time monitoring of vital information. Reliable communication coverage must also be provided over the areas where participants in the study stay and perform their activities in order to monitor the vital information anytime.

3-1. Construction of a medical database in cyberspace

Advances in DNA sequencing technology have reduced the time required for genome analysis, and medical genomics has been applied in some areas of clinical practice [24]. Moreover, as a private service, genetic testing has become more accessible, making it possible to learn about one's genetic predisposition to certain diseases.

The genetic data analyzed using reports and papers from research institutes can be linked to clinical cases and health information. However, the data for whole-genome analyses conducted by research institutes for diabetes, cancer, cardiovascular disease, and other cases are retained by each research institute separately [22]. The voluminous results from whole-genome analyses accumulated by each research institute have significantly contributed to the promotion of research and development. Therefore, a whole-genome sequencing and analysis plan was formulated in view of the future importance of creating an integrated database for managing whole-genome sequence data [23]. AI will be instrumental in linking the management of big data from whole-genome analysis results with clinical cases and health information. Moreover, the accuracy of the database will also be improved by using biometric sensors to obtain daily vital information and appropriately incorporating it as health information. In the future, whole-genome analysis will be carried out for everyone who wants it, and the analysis results will be linked with clinical cases and daily health information in real time. This will lead to the creation of a medical database as a digital twin in cyberspace, enabling the prediction of future health conditions and the provision of personalized medicine. At the same time, using AI to manage and analyze medical information in cyberspace will make it possible to constantly update the integrated database and apply it for industrial uses such as developing therapies and drugs for cancer and lifestyle-related diseases. Building an integrated database in cyberspace will require a highly secure network for linking human body sensors, whole-genome analysis results, and medical information such as individual clinical cases and health information.

4-1. Remote medical surgery

Although the common practice is for medical practitioners to perform direct patient surgeries, surgical assistant robots are now being commercialized to provide minimally invasive surgeries [27]. Moreover, remote surgery, which combines robotics and communications technology, is also being studied as one of the use cases for 5G. Meanwhile, enhancement of robotics is being considered for the future, enabling wider application areas, higher resolution images, and use of haptics to provide tactile feedback to medical practitioners. Furthermore, the operation of mobile surgery rooms using vehicles and aircraft equipped with surgical assistant robots will enable moving the surgery environment to where the patient is, and surgery is started immediately. Expansion of communications technologies will be imperative in enabling these future robotics and medical technologies. In particular, high-capacity communication is required for the real-time transmission of high-resolution images, such as 8K images, and ultra-low latency is required to enable interactive communication for providing tactile feedback in response to the operations of the medical practitioner. Also, providing a surgery environment at anywhere people visit with using the mobile surgery rooms equipped on vehicles and aircraft will also necessitate expansion of the high-capacity communication coverage. As the future technology, autonomous robotic surgery was reported recently [28]. In this report, it is demonstrated that a surgical robot automatically performs laparoscopic surgery for a large animal autonomously. For the fusion of communications technologies and autonomous robotic surgery, high-capacity communication is required for the real-time transmission of the information captured by large number of cameras and sensors, they are the key information for the autonomous robotics. In addition, autonomous network is also required for the tight connection between devices.

4-2. AI-based remote diagnosis

In 2020, the spread of COVID-19 has led to enhancement of the convenience of online medical care, providing a diagnosis for patient at-home by doctors over the telephone and the Internet a common practice [29]. Currently, online medical care is basically through examination by doctors for diagnosis and prescribing a drug, but in the future, diagnosis will likely be conducted using images of affected parts, voice data for auscultation, and vital information, such as blood pressure and heart rate. There are various approaches to AI-based diagnostics. In particular, since AI is highly compatible with image analysis technology, AI-based image diagnostic technology can be harmonized with dermatology, and AI-based diagnostics using radiographic images, for example, has advanced. In the future, AI-based diagnostics will be applied in familiar areas such as for chest X-rays and electrocardiograms, as well as for audio and vital information. The evolution and fusion of online medical care and AI diagnostics will enable the acquisition of various medical images and vital information from outside medical institutions, such as from home and ambulances. At the same time, transmission of the acquired vital information to medical institutions and AI servers will also enable real-time, automated AI-based diagnostics regardless of location or time. For this use case as well, large amounts of data must be transmitted within a short period of time under highly urgent situations. Expanding the high-capacity communication coverage will also be necessary to provide medical examination environment at anywhere people visit.

5-1. Real-time health management

Health management is carried out through regular health examination and comprehensive medical checkups at medical institutions. While more than 60% of adults are reported to be taking medical examinations, many people do not undergo checkups citing lack of time, money, or necessity [30]. Wearable devices are now equipped with biometric sensors that measure pulse rate and other vital signs. This enables us to acquire a wider range of information continuously with less hassle. Further ahead, vital information is measured inside the body by small ingestible devices which equips multiple cameras to monitor 360 degree view. In this case, these devices and cameras are tightly connected autonomously to synthesize video images. As the future innovative technology, nanomachies and micromachies which are the extremely small devices, having size of several nanometer to several micrometer may be used as biometric sensors. Injecting a microscopic device into the body to diagnose inside the body [31] will make it possible to obtain substances in a body fluid, such as blood in addition to the vital information obtained by wearable devices. The acquired vital information will then be transmitted to medical institutions to carry out real-time health management using AI-based diagnostics. For example, when a physical abnormality is detected, a notification will be sent immediately to a doctor and the doctor will inform and diagnosis the patient. Communication technologies will be crucial in controlling the myriad devices injected into the body, in managing the acquired vital information, and in transmitting it to medical institutions and AI servers. For example, devices are usually distributed evenly on different parts of the body, but if abnormal areas are detected, the devices can be concentrated on those areas to try to find out the affected part and improve accuracy of the information. When this happens, controlling the myriad devices injected into the body will require massive simultaneous connectivity. There will also be a need to construct an autonomous communication network for coordination via interconnections between the devices and functions. Furthermore, once injected, the devices must continue to operate within the body for a long span. Enabling long-term operations will, therefore, necessitate ultra-low power consumption and operations based on energy harvesting within the body, as well as the use of external power supplies via communication technologies. The in-vivo environment must also be additionally factored into the communication coverage. For example, water, which makes up about two-thirds of the body of adults needs to be taken into account for the study of communication environment within the body.

5-2. Minimally invasive treatment and direct treatment of affected areas

Currently, treatments using laparoscopes is becoming prevalent as examples of minimally invasive treatments. Using laparoscopes, however, requires puncturing a hole, albeit small, to enable inserting medical devices into the body. In order to carry out treatment without injuring the body and to further reduce effects of the treatment on the body, small ingestible devices such as capsule endoscopes will be equipped with treatment and medication functions, enabling direct treatment and administration of drugs to affected areas from within the body. Devices will also be further miniaturized and replaced with nanomachines and micromachines. These miniaturized machines will also be applied for in-vivo treatment and medication, and combining them with functions for diagnosis introduced in real-time health management will enable autonomously performing medical activities, from diagnosis to treatment, within the body, without patients being conscious about the ongoing activities. Unlike with the control of nanomachines and micromachines for the purpose of health management, devices that have completed drug administration are released out of the body, and devices that have been newly filled with drugs are injected into the body, resulting in a device swap. Therefore, management of the replacement of other devices will increasingly become more important, along with autonomous device exploration for each device and the establishment of interconnections among devices.

4.12.1.4 Capabilities required in Beyond 5G

In section 4.12.1.3, we looked into the specific future applications achievable with the fusion of medical and communications technologies. In this section, we look into the performance requirements for Beyond 5G with each application in mind.

(a) Ultra-fast and large capacity

(Requiring applications : 4-1. Remote medical surgery, 4-2. AI-based remote diagnosis)

Ultra-fast and large capacity will be required for real-time transmission of high-definition video in remote treatments and AI-based telemedicine. For example, medical robots are operated while watching 3D images, but in the future the images will be enhanced to 8K. Moreover, because ultra-low latency will also be required for remote surgery, the transmission of uncompressed images or images compressed at a low compression rate will likely be necessary considering the amount of delay incurred for video compression. A transmission speed of several tens of Gbps will be required for transmitting 8K images without compression.

(b) Ultra-massive connectivity, positioning sensing

(Requiring applications : 2-1. Support and reproduction of sensory functions, 3-1. Construction of a medical database in cyberspace, 5-1. Real-time health management, 5-2. Minimally invasive treatment and direct treatment of affected areas)

When a large number of ultra-microscopic devices are injected into the body, such as nanomachines and micromachines, ultra-massive connectivity will be imperative because they need to be controlled from and exchange information with the outside of the body. For example, if several to several tens of devices are injected into the body while assuming passenger capacity in trains, it will be necessary to connect simultaneously with devices at approximately several million to tens of several million devices/km2.

Improving the accuracy of positioning will also be critical when using mobile phone positioning information for infection prevention measures. For example, in the case of COVID-19, data suggest that maintaining a distance of two meters between people is a basic principle in preventing the spread of infection. Therefore, a positioning accuracy of a few meters in the horizontal direction will be required, especially in crowded indoor and outdoor environments

(c) Ultra-low power consumption

(Requiring applications : 1-1. Reduction of person-to-person contact and monitoring of status of infections, 3-1. Construction of a medical database in cyberspace, 5-1. Real-time health management, 5-2. Minimally invasive treatment and direct treatment of affected areas)

Nanomachines and micromachines must continue to operate for a long span in the body once they are injected into the body, therefore, power supply will be a critical factor. For this, wireless technology will be used to control and power devices inside the body from the outside. Further, operation based on energy harvesting will also be necessary, for example, through supplementation of power through heat and vibration, which requires implementing a mechanism for operating within the range of the amount of power that can be supplied.

(d) Ultra-security, resiliency and reliability

(Requiring applications : 1-1. Reduction of person-to-person contact and monitoring of status of infections, 2-2. New drug development, 4-1. Remote medical surgery, 4-2. AI-based remote diagnosis)

Virtual clinical trials, real-time AI-based diagnostics, and remote surgery that require remote monitoring of vital signs in real time will necessitate high levels of safety and reliability in communications. In particular, for remote surgery, high reliability will be required because it involves human life, for example 10^{-7} will be needed. In addition, a highly secure network will be essential in building medical databases in cyberspace because it involves the handling of various personal information, such as genome analysis data.

(e) Autonomy

(Requiring applications : 4-1. Remote medical surgery, 5-1. Real-time health management, 5-2. Minimally invasive treatment and direct treatment of affected areas)

Use of nanomachines and micromachines will entail collaboration with a large number of devices, pointing to the need for methods to enable centralized control by outside of the body, as well as collaborate with each other. Therefore, autonomous communication control of devices will be necessary because communication networks are established by individual devices and functions probing and interconnecting with nearby devices and functions.

(f) Universal coverage

(Requiring applications : 2-1. Support and reproduction of sensory functions, 2-2. New drug development, 4-1. Remote medical surgery, 4-2. AI-based remote diagnosis, 5-1. Real-time health management, 5-2. Minimally invasive treatment and direct treatment of affected areas)

The in-vivo environment will be added as a new area within the communication coverage. Establishing communications between devices within the body or with devices outside the body will entail establishing a communication environment by taking water, which makes up about two-thirds of the body of adults, into account. For example, a model for radio wave propagation that takes the body's internal environment into consideration must be developed.

Table 4.12-1 summarizes the capabilities required in Beyond 5G for healthcare.

Table 4.12-1 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
1-1 Support and reproduction of sensory functions		X		X	X					
2-1 Reduction of person-to-person contact, monitoring of status of infections, and health management			X					X		
2-2 New drug development (Virtual clinical trials)				X				X		
3-1 Construction of medical database in cyberspace			X							
4-1 Remote medical treatment	several tens of Gbps	X		10^{-7}				X	X	
4-2 AI-based remote diagnosis	X	X		X				X		
5-1 Real-time health management			X		X			X	X	
5-2 Minimally invasive treatment and direct treatment of affected areas			10^6 - 10^7 devices/km^2		X			X	X	

4.12.1.5 Summary

In this section, we created a picture of our vision for the future of healthcare by considering the current state of healthcare and its challenges. We also introduced the applications based on Beyond 5G that should be achieved to realize the future vision, examined their communication requirements, and showed that a high level of performance is required; namely, ultra-fast and large capacity, ultra-low latency, ultra-massive connectivity, positioning and sensing, ultra-low power consumption, ultra-security, resiliency and reliability, autonomy, and universal coverage. Medical and public health are essential to our lives. The realization of these applications that combine medical and communications technologies will bring about a future where we can enjoy a richer, healthier, and longer life.

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4.12.2 Government and Education

The future vision for government and education is universal and not specific to any country. However, the current progress of digital transformation of administrative systems, as well as the status of their usage, their operation methods, and their legal frameworks vary from country to country. Below we describe the current challenges and future visions for government and education using the example of Japan's administrative systems.

Since the early 2000s, Japan has been promoting e-government and e-municipalities through various policies, including the e-Japan Strategy (2001) and the IT Reform Strategy (2006). However, the adequacy of the current system to support the changes in people’s lifestyles brought about by the COVID-19 pandemic that started in 2020 has been put into question. To address this issue, Japan is promoting a new “Priority Policy Program for the Realization of a Digital Society” as it aims for a “people-friendly digitization that leaves no one behind” [1].

Since 2019, GIGA school program is improving the school ICT environments in Japan. One device per one student with a high-speed network in schools has been realized. In future, ICT is expected for minimization of any education gap, on-line support of extracurricular activities and more professional on-line guidance.

4.12.2.1 Current situation and challenges

(1) Government

Below we present problems and issues from the three perspectives of system configuration, system users, and system operators in regard to the current national and local government administrative systems.

<u>1. Issues related to administrative system configuration</u>

The current national and local government service systems have been individually constructed for specific jurisdictions and purposes and are individually optimized systems [2]. For example, service systems for family registry, basic resident registry, children, nursing care, welfare, and provincial taxation are built for each city and town. Municipalities also sometimes offer their own customized services. On the other hand, systems related to services for the Basic Resident Registry Network, pensions, Hello Work employment service, and national taxation are provided through nationwide-level systems. These siloed systems for specific jurisdictions and purposes lead to a high cost for components and systems for the government as a whole. Meanwhile, although electronic applications have already been introduced for several services, there are currently various systems for different purposes. For example, the systems vary depending on the purpose, such as application for administrative procedures (eGov), Mynaportal, subsidy application system (jGrants), and tax payment systems for national taxes (e-Tax) and local taxes (eLTAX).

2. Issues from the perspective of users of administrative services

From the perspective of the convenience of national and local government systems, since administrative systems are different for each jurisdiction and purpose, users need to process applications separately for each system, putting a heavy burden on the users. In particular, depending on the service (e.g., applications during emergencies), administrative offices may become crowded with applying users, pointing to the need for widely adopting the use of paperless procedures and electronic applications. Furthermore, the cost for users should be reduced by digitalizing regulations and practices (e.g., registration of official seals) for administrative procedures.

On the other hand, although national and local governments possess various data that include personal information, the private sector cannot efficiently make use of these data. Because the location, standards, and formats of the data, as well as the methods for their utilization and the way in which personal information is handled are not necessarily the same.

3. Issues from the perspective of operators of administrative systems

From the standpoint of the national and local governments that operate the administrative systems, it is desirable to increase operational efficiency and reduce operational costs because of the wide variety of operations being handled [3]. For example, in handling user inquiries, response operations should be downsized through the enhancement of FAQs and the application of automated AI-based response to inquiries. Also, face-to-face AI should be adopted to reduce the workload in face-to-face reception desks. Further, there is a need to reduce face-to-face operations and improve operational efficiency through digitalization by accelerating the implementation of electronic applications for users. Meanwhile, from the perspective of government employees' workstyle, reforms such as telework should be instituted through the development and integration of communication systems leveraging mobile networks.

(2) Education

Education sector covers a wide range from so-called school education to corporate education. This section mainly focuses the school education and lists up the problem.

1. Enhancement of education environment through ICT

The improvement of school ICT environment has been quickly promoted under COVID-19. However, the education environment outside of school campus such as home study is not enough. Continuous support from school campus to home through ICT is expected. For on-line learning, two-way communication and hybrid learning using both on-line and off-line are expected to use more effectively.

2. Knowledge sharing in the education sector

Teachers as well as student needs more support through ICT. Especially, know-how of teachers will be widely re-used through ICT.

3. Introduce of ICT to other activities than learning

On-line communication among schools will be activated through ICT to support practical learning and to make up of the instructor shortage for extracurricular activities

4.12.2.2 Future vision

(1) Government

In light of the above issues, the government is promoting a new “Priority Policy Program for the Realization of a Digital Society" aimed at a “people-friendly digitization that leaves no one behind,” along with the establishment of the Digital Agency to do away with the compartmentalization of government and to carry out regulatory reform [4]. The following are the administrative systems that will enable "people-friendly digitization that leaves no one behind.”

1. Thorough improvement of UI and UX and implementation of national services

User-oriented systems that facilitate processing of related administrative procedures are needed in place of the current separate systems for different uses and providers. Specifically, implementing the following initiatives should improve administrative system services.

- Use of smartphones or tablets to enable system users to easily complete procedures anytime, anywhere
- Completion of procedures in one-stop in accordance with the user's life stage (change of address, death, inheritance, etc.)
- Provision of services that are linked with semi-public services (education, health/medical care, nursing care, etc.)

2. Common platform for the digital society

The Individual Number Card (My Number Card) should be widely adopted as a personal ID for using services, along with expanding the services where it can be used. Further, common platforms for the digital society should be developed and widely adopted, for example, to enable real-time data synchronization and cross-referencing among government agencies, use of digital signatures, and creation of a new administrative certification system.

3. Data distribution and utilization

A data strategy is needed to ensure safe, secure, and effective use of the various data held by the government. For example, anyone should be able to use data anytime safely and securely. This environment will be made possible through the creation of databases for standardization and common rules for managing data in a distributed manner while ensuring the reliability of the data, as well as through the establishment of an open data infrastructure for the utilization of data held by the government.

4. Elimination of the digital divide

Accessibility should be provided in a way that prevents disparities in ICT use opportunities to arise due to user age, disability and other physical and mental conditions, and economic factors. Likewise, administrative systems should be made accessible anytime, anywhere, without geographic restrictions, through mobile devices and other means.

(2) Education

In future, it is expected to prepare an environment in which everyone can receive education equally and freely, regardless of their circumstances.

4.12.2.3 Applications achievable with Beyond 5G

(1) Government

There are many use cases for the future images of the administrative system described above where the system itself is achievable even with 4G and 5G networks. However, further advancements, such as UX improvement and the elimination of the digital divide, will only be made possible with the use of Beyond 5G.

1. Integrated administrative services

For the services provided by the administrative systems, enabling the filing of a variety of applications and notifications in one-stop in accordance with user scenarios, such as birth, death, marriage, change of address, etc., is advantageous from the perspective of the user. Furthermore, by centralizing the "private touch points," users will be able to access the administrative systems from a single location without thinking about the individual systems. To achieve this, administrative systems should be developed with the following in mind: (1) creation of an infrastructure for providing common functions across the country, such as government cloud and government network, 2) streamlining of system development through the unification and standardization of service systems in local public entities, and (3) creation of a framework that provides individual systems as services (SaaS) and that can be used as an API collaboration tool to streamline system-to-system collaboration.

2. User-friendly UX

A user-friendly UX will enable users to access administrative services anytime, anywhere. The services will be made available regardless of the above-mentioned user conditions or economic factors, without geographic restrictions, and in a safe and secure manner. In particular, users will have stress-free access to administrative services even during disasters and emergencies, or during heavy communication traffic on devices.

3. Collaborative services with government

Providing the functions of the administrative system as API and making administrative services accessible to systems from other industries will enable linkage of services across industries and businesses. For example, coordination with semi-public sectors, such as medical and educational institutions, and collaboration with private services, such as integration of moving procedures with public infrastructure contracts, will be made possible. On the other hand, various data (e.g., weather, river, traffic, etc.) from government and relevant institutions will be provided as open data and utilized for services by other agencies, leading to further enhancement of the services.

(2) Education

There are many use cases for the future images of the education sector where the system itself is achievable even with 4G and 5G networks. However, the introduction of more high-level learning method and the hybrid learning method with coexistence of on-line and off-line learning will only be made possible with the use of Beyond 5G.

1. Remote instruction and on-line communication

It is possible to more realistically convey the instructor's know-how in club activities and practical skills. In addition to oral instruction, it is possible to directly convey sensations even remotely. Especially the club activities connecting remote locations, such as ensembles and choruses, are possible.

2. Hybrid class

Both students who participate remotely and students who participate in the actual classroom can take classes without stress. The instructor can proceed with the lesson without being conscious of both students. In addition, an environment has been realized without any problem even if students and instructors speak different languages.

4.12.2.4 Capabilities required in Beyond 5G

Table 4.12-2 indicates the required capability to achieve the above applications envisioned for the government and education sectors and this section describes the roles of Beyond 5G networks in terms of the network requirements

Table 4.12-2 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Integrated administrative services	x		x	x				x		
User-friendly UX		x	x	x						
Collaborative services	x			x						
Remote instruction and on-line communication	x	x		x			x	x		
Hybrid class	x	x		x				x		

(a) Ultra-massive connectivity

For users to enjoy administrative services even during disasters and emergencies or during heavy communication traffic on devices, administrative systems must provide ultra-massive connectivity. Also, networks that are capable of accommodating a large number of devices for collecting various data held by government and relevant institutions will be crucial in ensuring openness of data. Storing such data in large amounts and in real time will require the use of private networks (equivalent to Local 5G), as well as public networks, by local public entities.

(b) Ultra-fast and large capacity, ultra-low latency

Communication infrastructures with sufficient capacity to ensure that the quality of communications over mobile networks will not deteriorate will be needed also during heavy communication traffic, such as during disasters and emergencies, as mentioned above. Also, improving UX for administrative services will entail the use of different devices (TV, speakers, etc.) and different UIs (e.g., holographic-type communications), especially for users who are not adept at using smartphones. Even for such cases, high capacity, ultra-low latency network infrastructures that can ensure sufficient communication capacity and real-time capability will be needed.

(c) Ultra-security, resiliency and reliability

A high level of security is necessary because of the need to handle data that include personal information. Also, for collaborative services, including data linkage with semi-public and private sectors, a function for linking IDs that indicate user identity and service eligibility must be included in security functions.

(d) Universal coverage

The regional digital divide should be eliminated, i.e., a wide coverage that includes heterogeneous radio and device collaboration should be provided to enable users of administrative services to have access to the services using mobile communications anytime and anywhere, not only through the city office (face-to-face) or from home (online).

Figure 4.12-3 shows the government and education sectors in Beyond 5G era

Figure 4.12-3 Government and education sectors in Beyond 5G era

4.12.2.5 Summary

This section examined the current situation and future vision of Government and Education sectors and described the capabilities for Beyond 5G that are needed to the future vision. The required capabilities would be ultra-massive connectivity, ultra-fast and large capacity, ultra-low latency, ultra-security, resiliency and reliability and universal coverage.

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4.13 Restaurant

4.13.1 Current situation and Challenges

- Challenges
  - The COVID-19 pandemic, which began in early 2020, continues to this day. The fifth wave peaked around August 2021, when the Tokyo Olympic Games were being held, and was nearly over by around October of the same year. However, toward the beginning of 2022, the sixth wave spread, and the seventh wave of the Omicron variant BA5, which started around July of the same year, became more widespread than expected.
  - Every time a state of emergency has been declared, the restaurant industry has been forced to ask for business operating with reduced hours and voluntary suspension of business, which has dealt a heavy blow to its business.
  - With the end of the fifth wave in 2021, the business operating with reduced hours of restaurants was lifted in various places. In order to be able to resume business operations during the COVID-19 pandemic, efforts were made to turn around the economy during the pandemic, such as a trial of a system in which only customers who present a vaccine passport or vaccination certificate or have a negative PCR test can enter the store.
  - Around October 2022, a national travel support campaign was launched as a measure to stimulate tourism demand. In addition to discounts for travel and accommodation, regional coupons that can be used at restaurants in each region have been issued, and efforts are being made to revitalize the local restaurant industry.
  - For a long time, the top issues for restaurant businesses have been: (1) rising cost of ingredients, (2) decreasing spending per customer, and (3) deterioration of facilities and equipment. With decreasing spending per customer, increases in various expenses are putting pressure on profits, which is currently an issue. To deal with this, increasing sales is the first priority, even while reigning-in expenses [1].
  - Restaurant sales are determined by four main elements: (1) guest seating, (2) guest turn-around rates, (3) spending per customer, and (4) number of days operating, expressed as (sales = seats × turn-around × spending × days-operating). To increase sales amid COVID-19, all four of these elements must be increased [1].

- Current initiatives using ICT
  - To increase sales at restaurants as described above, ICT has been used in various initiatives As an example, to increase (2) guest turn-around rates, some

establishments have placed tablet terminals at tables so that customers entering can place their orders smoothly, without having to call a server. Many stores are also using smartphone payment, which has become more common recently.

- For (1) guest seating, which is a physical issue determined by the premises, an increasing number of businesses are providing take-out to external customers "virtually," in addition to serving customers in on premises. There are also initiatives to increase sales with direct home delivery, accepting orders for take-out products through the internet, and collaborating with food delivery services to deliver them by motorbike or car.
- Furthermore, in order to reduce the time required for cooking, some stores have introduced cooking robots and serving robots to automate some of the cooking processes, such as boiling noodles, and have introduced robots to serve cooked noodles to customers' tables.
- Many restaurants (particularly restaurant chains) have their own smartphone applications and use current 5G technology to enable ordering or reservations through the internet.
- Other possible initiatives using current ICT in restaurants include increasing efficiency in procuring and using ingredients for food products, or measures to reduce food waste as described earlier.

4.13.2 Future vision [3]

- As technology advances, as in the case of Beyond 5G, it is expected that the restaurant industry will accelerate the provision of various services by taking advantage of the three major features of 5G: (1) ultra-high-speed and large-capacity, (2) ultra-low latency, and (3) ultra-large number of simultaneous connections.
- Advanced technologies such as robotics, IoT and AI can also be expected to be effective for increasing sales in the restaurant industry, by making food preparation more efficient, and reducing personnel and other costs.
- Considering the space required for current food preparation robots, which produce only a small number of products, improvement to enable production of more types of products in small quantity would be promising. Using Local Beyond 5G, table-setting robots could automatically move to customer tables and deliver items that customers have ordered.

4.13.3 Applications achievable with Beyond 5G

- Many serving robots are currently controlled using conventional technology (Wi-Fi). To meet these requirements, it is necessary to be able to recognize when a child or the like crosses in front of the table during serving and stop suddenly, or to recognize the position and shape of the table in centimeters. In the future, it is expected that the recognition accuracy of positioning, etc. will be further improved.

- IoT technology could also be used to detect which tables are occupied, receive orders from customers, and continually monitor inventory of the various ingredients being used. Also, take-out products ordered through the internet have conventionally been delivered by motorbike or car by collaborating with meal delivery services, but in the future, meal delivery services could switch to using drones.
- Using Beyond 5G, such restaurant state data could be mapped into cyberspace in a cyber-physical system (CPS), to enable central monitoring of data such as the operating state of robots in each store, inventory of ingredients, the state of orders from the internet, the status of deliveries by delivery services.
- By using AI to analyze the information collected from each store using IoT technology and Beyond 5G, it will be possible to reduce food loss and use the marketing information obtained to make business decisions.
- As advanced technologies such as Beyond 5G, robotics, AI and IoT are used increasingly in the restaurant industry, the appearance of unstaffed restaurants may not be too far in the future, similar to how unstaffed convenience stores have begun to appear recently on a trial basis.

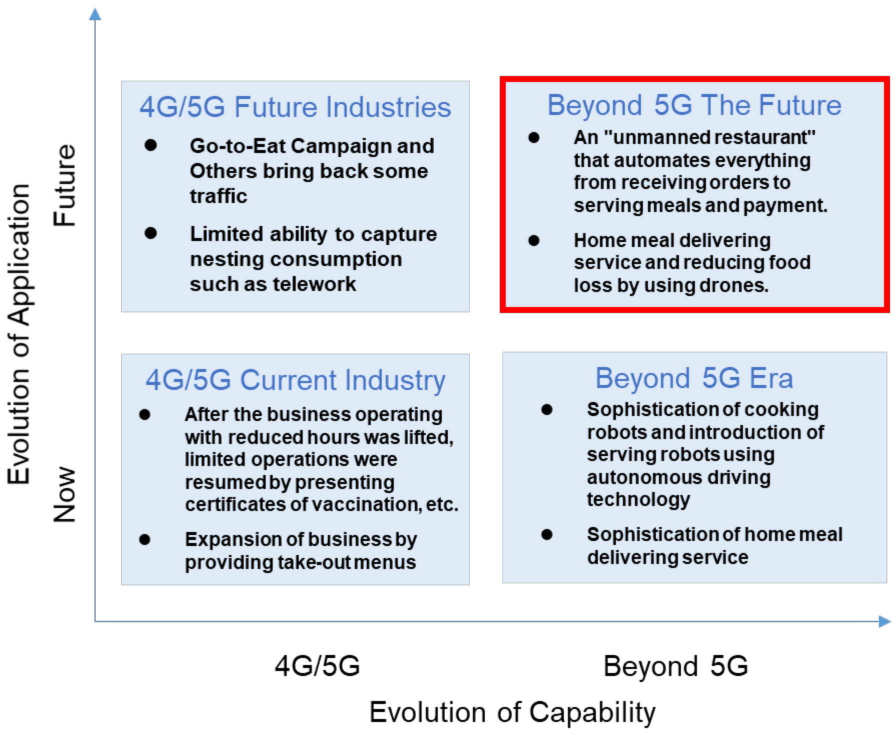

Figure 4.13-1 Restaurant Industry in Beyond 5G era

4.13.4 Capabilities required in Beyond 5G

Based on the current and future use cases in the restaurant industry, the following are the capabilities required for Beyond 5G.

- In restaurants in the future, it is thought that cooking robots, serving robots, and the like will become more and more popular from the viewpoint of reducing labor costs. In order for a cooking robot or a serving robot to recognize a surrounding situation, it is necessary to communicate a large amount of image information with a low delay and to confirm positional information. Therefore, ultra-fast and large capacity, ultra-low latency, positioning and sensing, etc. are required as the capabilities of Beyond 5G. In addition, it is thought that ultra-low power consumption will also be an important requirement, especially for serving robots, since they need to operate automatically for a long time.
- Drones are expected to be used for home meal delivering service in the future. In this case, as the capability of the Beyond 5G, it is necessary to have ultra-fast and large capacity, ultra-low latency, and ultra-security, resiliency and reliability with less danger of accidents and drops over the urban area, corresponding to the operation at Level 4, so that the flight of the drone can be smoothly carried out. In order to be able to fly for a long period of time, drones must consume as little electricity as possible, and they must also have a positioning and sensing function in order to grasp the location information of the flight path. In addition, in some cases, there is a possibility of flying to mountainous areas where radio waves are difficult to reach, and it is considered that "coverage expansion" may also be necessary.
- In the future, an unmanned restaurant is assumed. In such restaurants, the aforementioned serving robots and cooking robots are considered to be in operation during normal business hours. For this reason, it is assumed that ultra-fast and large capacity, ultra-low latency, ultra-low power consumption, positioning and sensing, etc. will become important as capabilities of Beyond 5G, as with serving robots and cooking robots. In addition, ultra-security, resiliency and reliability is also considered to be important in order to operate unmanned restaurants safely and continuously.

Table 4.13-1 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Cooking robots Serving robots	X	X			X		X			
Food delivery service (by drones)	X	X		X	X		X	X		
Unmanned restaurant	X	X		X	X		X			

4.13.5 Summary

In this section, the current situation and issues of the restaurant industry are surveyed, and the future image expected in these fields and examples of Beyond 5G utilization are shown. The capabilities required for Beyond 5G include ultra-fast and large capacity, ultra-low latency, ultra-security, resiliency and reliability, ultra-low power consumption, positioning and sensing, and universal coverage.

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4.14 Entertainment, and Leisure

4.14.1 Current situation and challenges

COVID-19 has made it more difficult for people to gather at real locations. As a result, opportunities for entertainment and leisure activities in virtual space have increased sharply [1]. This trend toward digitalization of entertainment has not been limited to conventional fields like movies, music and games, expanding into various new areas such as sports, travel, amusement facilities, toys and so on [2]. Especially in recent years, entertainment in the "metaverse," which is a constructed 3D virtual space, has been gaining a lot of attention. For example, on Fortnite, the rapper Travis Scott held a music event in the virtual space, attracting more than 27 million viewers [3]. With the evolution of 3D display device technologies such as VR, the spread of entertainment in the virtual space is expected to increase. In addition, due to the increasing participation of professional sports teams and the expansion of related businesses, the eSports market is expected to grow to $1.6 billion USD in 2023 [4].

On the other hand, COVID-19 has had a big impact on content production. In the video production sphere, there is a problem that video production cannot be performed due to the travel restrictions caused by COVID-19. To overcome such a situation, recently technical innovations such as virtual production technology[*1] and volumetric capture technology[*2] have been developed to enable virtual content production to continue even in such circumstances.

At present, the usage of online content is led by younger generations. However, it is expected to expand for broader generations in the future. Text and image content used to be the mainstream in social networks, but in recent years, the number of video posts and the amount of live content has increased significantly. It is expected that the content carried by future social networks will continue to evolve [5]. These factors are expected to lead to further growth in entertainment-related markets. At the same time, there are many problems to be solved in a communication network, such as dealing with an increase of communication traffic and the demand for low delay applications.

*1: Virtual Production is a general term for new video production technology that synthesizes live-action video and computer graphics (CG) in real time. With "In-Camera VFX," one form of Virtual Production, a 3DCG image linked with the movement of the camera is projected as a background on an LED display installed in the studio behind the performer.

*2: A technology that converts the real world into 3D digital data and reproduces it by using high-quality images. This is a so called free-viewpoint technology that enables a user to interact with the content by moving their viewpoint.

4.14.2 Future vision

The entertainment industry is expected to further change people's lifestyles and drive progress in the future. In association with device and telecommunication technology evolution, a range of new service experiences will be provided one-after-another. Here, we introduce five visions that may be important in the entertainment industry in the future.

1. Ultimate immersive experience

Further improvement of experience quality is required when providing entertainment in a virtual space. In particular, by providing an ultimate immersive experience and sense of unity that fully stimulates the five senses, it is expected to be possible to create experience value that has never been experienced before and provide applications that surprise and impress people. To achieve this, it is necessary to develop spatial information transmission technology that transmits the entire space with ultra-high sound quality and ultra-high image quality, and spatial reproduction technology that reproduces not only visual and audio but also tactile, olfactory and taste sensations. In order to further enhance the sense of immersion, it is expected that an ultimate immersive experience and sense of unity will draw the user into the world of the content by using ultra-low latency communication technology which enables real time interactive communication with a virtual space. For example, live music, watching sports, remote live events, online games, remote amusement parks, online travel, and many other applications are expected to provide an emotional experience. In addition, there is a demand to provide real-time entertainment content even in mobile scenarios such as in vehicles, trains, ships, aircraft and so on.

2. Integration of virtual and real

Entertainment is expected to change from being enjoyed only in a virtual space to being enjoyed by combining virtual and real spaces. The seamless fusion of the virtual and real worlds, through either a real-time reflection of the real world in the virtual space or a superposition of the virtual space on the physical space of the real world, will allow provision of new experiences to users.

A typical example is a navigation application using AR technology. Other services are virtual sports events and virtual sessions with famous musicians. In order to realize such services, technologies that enable capturing the real world accurately and reflecting the captured image in the virtual space are required. In addition, the evolution of interaction devices linking the physical and real worlds is also required.

3. Integration of entertainment and social networks

The future social network is expected to evolve from traditional text-based, image-based and video-centric content to the ultimate immersive experience and the convergence of the virtual and real worlds. In virtual spaces such as the metaverse, it is expected that entertainment will be integrated with social interaction, rather than just providing entertainment content. In a place where entertainment and social interaction are fused, social networks are established in the virtual space where people can play games with their friends, enjoy live events with families, communicate with other users and so on.

4. Content creator assistance

In the field of content production, professionals used to produce content using special equipment. However, in recent years, with the evolution of devices and AI and the development of SNS, it has become easier to create and provide content, and anyone can easily become a creator of high-definition content such as music, video and games. This trend is expected to accelerate in the future. In a world where anyone can easily become a creator, it is necessary to create a new environment that supports content creators. Further advances in virtual production technology and AI cloud-based video production workflow technology are expected to provide the value that creators want. In particular, in the social entertainment space where entertainment and social interaction are fused, it is expected that content will be utilized as a bridge between content creators and people who enjoy the content, and that content will become more hyper-personalized, such as through creating content targeting specific people.

5. Borderless service provision

So far, rich services have been available mainly in the limited locations that have good telecommunication infrastructure. Future entertainment should be widely served to as many people as possible. Instead of allowing a limited number of people to benefit from the service, we need to make it easy and affordable for people all over the world to enjoy high-quality entertainment services anytime and anywhere.

4.14.3 Applications achievable with Beyond 5G

In this section, we introduce some examples of use cases that are expected to be realized by Beyond 5G in order to realize the future vision outlined in Section 4.14.2. Note that these are just some of examples and it is expected to add more use case examples in the future.

1. Interactive Live Music

One of the usages of metaverse is live music entertainment where artists and audiences can interact each other in virtual space. By reflecting artists captured by such as volumetric capture technology in real time for virtual space, audiences can enjoy live event anywhere with viewpoint freedom. By connecting audiences in real time, the enthusiasm and unity of sense can be shared in virtual space as more immersive entertainment experience. To realize such experience, it is expected for Beyond 5G communications to able to connect a very large number of users simultaneously in virtual space to provide real-time interactive experiences.

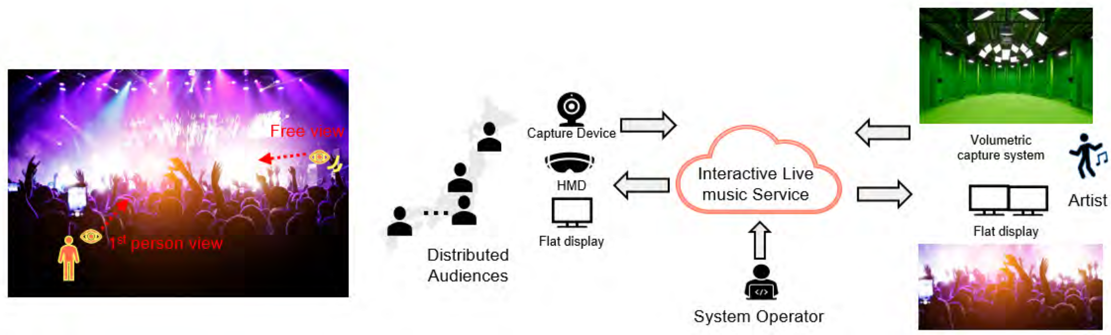

Figure 4.14-1 Interactive Live Music use case

2. AR navigation

AR navigation use case can be considered as the one of important use case for an integration of the entertainment and social. For example, in tourism applications, it can be expected to realize the application where the travel information is reproduced in virtual space and linked to physical world. Tourists can obtain the necessary information based on the location by AR glass in real time. By seamlessly superimposing information acquired in virtual space over physical space, information can be provided more intuitively. In addition, it is also expected to provide new experiences by linking with location-based gaming through AR glass. People in physical space can interact with users nearby in virtual space easily. Use cases such as AR navigation requires advanced information processing such as digital twins, which is the main use case for Beyond 5G. Network should support end to end communication to enable processing from capturing physical world to mapping calculated information virtually to physical world again.

3. Virtual Sports

Recently virtual sports where people can enjoy sports in virtual world have gained popularity. For example, in virtual cycling, people can enjoy a realistic cycling experience by pedaling on the stationary bicycle located in the room with screen displayed the scenery of the course. Depending on the condition of the course in the virtual space, it can also provide a more realistic experience by giving feedback such as load to the bicycle pedal. In the future, such virtual sports service may enable the new experiences like competing with famous athletes in the virtual space while staying at home. To enable these use cases, it will require not only high-quality information transmission but also interaction with wearable devices worn on the body to enable real-time interaction with virtual space. In addition, because latency will be critical in sports application, Beyond 5G communication is required to support low latency communication to realize comfortable experience.

4. **Virtual Production**

From the perspective of supporting content production side, it is necessary to stimulate the creativity of creators and create an environment where anyone can easily produce entertainment content. One example is virtual production. Virtual production is the new camera technique that produces video content by simultaneously photographing and synthesizing the virtual space of the background video and the real subject. This technology can help to make high quality video contents easily without going to the location. Building the environment to support contents creators will become more important in the future. In order to create a highly flexible contents creation environment, Beyond 5G communication can support to realize by, e.g., replacing wired cable to wireless.

4.14.4 Capabilities required in Beyond 5G

We describe the requirements for Beyond 5G communication in order to realize these visions for the entertainment industry of the future. The evolution of the entertainment industry is shown in Figure 4.14-2, and the future vision and required technology for the industry are shown in Figure 4.14-3. Finally, the requirements for Beyond 5G is shown in the Table 4.14-1.

For information transmission, it is necessary to meet the requirements for high-definition data communication such as 4K/8K/large screen, high-definition, high sensitivity, high brightness/high dynamic range, and high frame rate. In addition, it is necessary to support new technologies such as volumetric capture and 3D resynthesis, which convert the real world into 3D digital data and reproduce them with high image quality. At the same time, by interacting in the virtual and real spaces in real time, for example, in a remote live event use cases such as live music and watching sports, it is expected that the ultimate sense of presence will be provided for users. In such a use case, as a performance requirement for Beyond 5G communication, large capacity communication at a raw data rate of about 48 - 200 Gbps and a low delay time, such as MTP (Motion To Photon) 10 msec and TTP (Time To Present) 70 msec, are required for end-to-end communication [6]. In addition, smaller devices such as AR devices have hardware limitations, so they need to be more closely integrated with the network side. For example, it is necessary to support the architectures such as cloud rendering and split rendering where the processing load on the device side is partly done by the network side. It is also necessary to realize these high-speed, large-capacity and low-delay communications requirements simultaneously. In the initial stage of network deployment, a limited area is assumed to provide such beyond 5G wireless communication. Along with the further development of the wireless communication infrastructure, the network deployment is expected to expand in order to support for example mobility uses case such as high-speed trains and airplanes.

For interactive viewing, communication for multi-modal real-time interaction would be required. To integrate virtual and real spaces in particular, data from many sensors needs to be collected and reflected in the virtual space in real time. In particular, use cases such as virtual sports require communication performance that can adequately track human reaction in time. Because a large number of sensor devices need to communicate in low latency, in addition to conventional communication between base stations and devices, short-range, highly-reliable low-latency communication directly between devices is promising. For Beyond 5G communication systems, there may also be demand for functions beyond communication, such as sensing or location functions. In particular, it will be necessary to capture more data, such as data on human emotions and tactile information, which have not been available much in the past, and reflect them into the virtual space.

There is also a requirement to expand coverage to the whole world, to correct economic disparity by improving communication connectivity and access to good-quality content. With advances in technologies such as satellite communications, it should be possible to provide low-cost, high-grade communications coverage. As business in the virtual space expands, it will also be important to support security requirements. Therefore high-security and resilient communications must be provided [7].

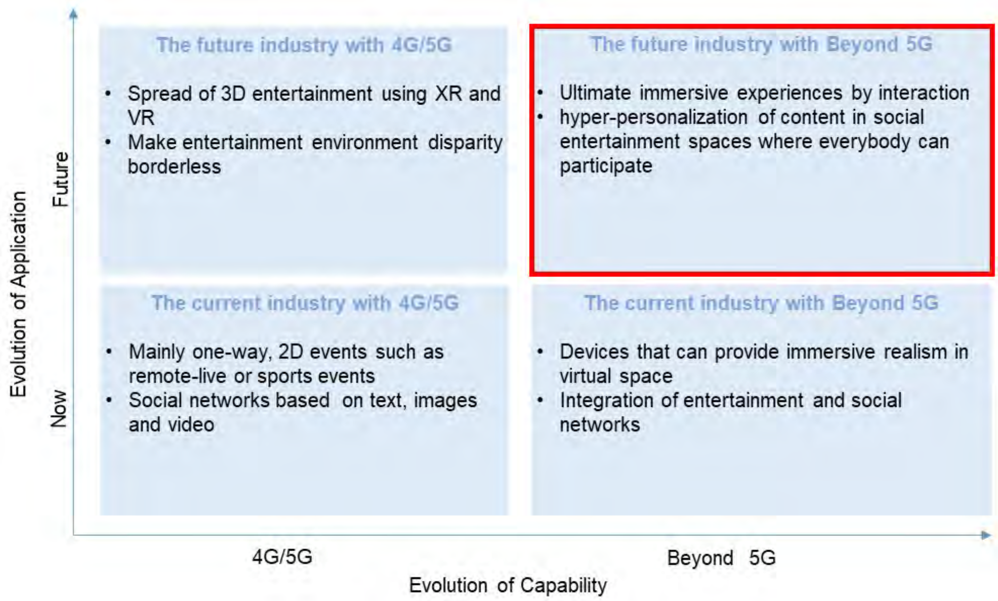

Figure 4.14-2 Entertainment industry in Beyond 5G era

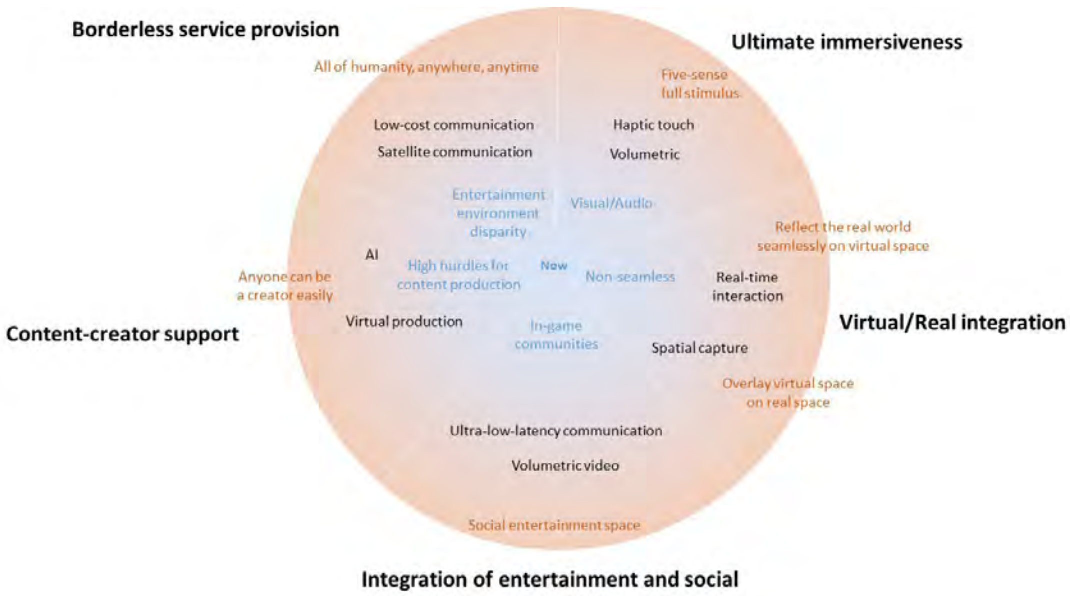

Figure 4.14-3 Future vision for the entertainment industry and required technology

Table 4.14-1 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Interactive Live Music	48-200Gbps	MTP ≦10ms, TTP ≦70ms	Max. Audiences >1.2 mil		X	X	X			6DoF free view
AR Navigation	X	X	X		X	X	X			Cloud/Split rendering
Virtual Sports	X	≦20ms			X	X	X			
Virtual Production	X	X				X	X			

4.14.5 Summary

In this section, we introduced the current situation and challenges in the entertainment and leisure field and show the future vision we expect. We also introduced some examples of future use cases using Beyond 5G communication and listed up the communication requirements. The use case examples presented in this section show that advanced communication technology is necessary to support e.g., ultra-fast and large capacity, ultra-low latency, ultra-massive connectivity and ultra-low power consumption. In addition, it is required to support new functionalities such as time synchronization accuracy, high accuracy positioning and sensing.

The entertainment and leisure sector are the essential for enriching our lives. Therefore, further development with Beyond 5G communication is expected to realize future visions in this field.

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4.15 Academic and other

4.15.1 Space

4.15.1.1 Current situation and challenges

Space utilization has been prioritized for research and development purposes by the national government and for specific industries. Its use for the general public is only for specific application such as satellite broadcasting. In 2022, 5G standard specifications aimed at the integration of terrestrial and satellite networks was formulated for the first time, and it is expected that further studies will be made toward deeper cooperation among them. In addition, the number of emerging countries and new companies aiming for space development is increasing, further new initiatives in the space industry are needed to contribute to the solution of social problems through utilization of space and space development technologies.

Since future use cases in space utilization are related to various industries, they are wide-ranging, and the time it takes to realize them will vary from a few years to decades. Therefore, we have broadly categorized use cases from the two perspectives of (1) “protecting life on Earth from space,” which is the most recent and relatively familiar perspective and is already being carried out in some industries, and (2) “expanding the living sphere and area of activity to space,” which is an extension of technological development for (1). The future vision and applications are discussed in the following sections.

4.15.1.2 Future vision

- Protecting life on Earth from space

During the occurrence of large-scale disasters, current mobile communication systems (4G/5G) use satellite communications to directly communicate with the mobile backhaul and user terminals to mitigate damage caused by ground disasters. Data from observation satellites are also used for national security, weather forecasting, and climate change countermeasures. They have become essential for protecting our lives; hence, space utilization has become increasingly important in recent years.

Satellites are also being used to collect geospatial data as the basis for automated driving and ship navigation, which will likely become more widespread in the future. There is large potential for space utilization in the area of national security, such as for monitoring the conditions of oceans using location, time, and positioning information. In addition, IoT and sensor technologies are becoming more sophisticated, pointing to the increasing potential of more efficient, human-independent activities, such as infrastructure maintenance and management, land conservation management, and resource exploration through monitoring of conditions from space.

- Expanding the life sphere and area of activity into space

Since private spacecraft took off into space in 2020, space development has accelerated and space has become more accessible. In the future, space will be one of the activity areas for us on Earth, just like cyberspace. Earth, space, and cyberspace will be seamlessly connected, and the area where human beings can freely operate through remote control will expand.

4.15.1.3 Applications achievable with Beyond 5G

In this section, use cases of each of the above two perspectives, (1)"protecting life on Earth from space" and (2)"expanding the life sphere and area of activity into space," are shown. Note that a) and b) correspond to (1) and c), d), and e) correspond to (2).

a) Smart communication infrastructures utilizing space

In Japan, the demand for broadcast communications between residential areas has been increasing since 2020 as urban and other residential areas have become more scattered due to the serious aging and decline of the population. On the other hand, it has become more difficult to maintain roads, bridges, and other social infrastructures necessary for living safely and securely in rural areas, remote islands, and mountainous regions, making it more urgent to realize smart cities using networks integrating space and ground systems.

In the suburbs, there is a need to improve productivity in the agricultural, forestry, and fishery industries and to maintain infrastructures such as water and sewerage systems and electric power transmission networks. These call for the development of wide-area robotics network systems that integrate information systems via local or central AI processing with stable, high-speed communication networks between robots and sensors deployed across wide areas. Enhancing resilience and eliminating the digital divide (information gap) are crucial to ensure the continued autonomy and independence of systems during failures or disasters, highlighting the importance of communication environments over air and space.

In the current cellular networks, satellite communications are also used in areas where ground communication networks are not yet established, such as in remote areas and islands, as well as for moving objects (ships, aircraft, mobile devices, etc.). They are also used as network platforms for inflight Wi-Fi and communications. The following use cases are achievable upon the realization of communications infrastructures covering land, sea, and air through the spatial and aerial coverage provided by Beyond 5G non-terrestrial network (NTN).

- Seamless, end-to-end service coverage expansion across cities, including automated driving support, traffic control, and logistics management systems for automated logistics and unmanned taxis

- Provision of wide-area robotics and automation systems for primary industries, such as agriculture, forestry, and fisheries, through surveillance and tracing using various land and sea IoT sensors, and by utilizing the collected data and AI
- Provision of broadband and network connectivity services to meet temporary connection demands, such as for disaster recovery, construction sites, and events
- Provision of backhaul and backbone lines to regional 5G areas and Local 5G areas, and enabling smart communications through provision of services for remote work, distance education, telemedicine, wide-area living information, and alternative broadcasting services
- Automation and smart operations for security and defense and for natural disaster predictions through the use of IoT sensors mounted on aerial drones and NTN

In the future, once high-capacity, high-speed communications using terahertz waves and space-based optical communications are realized, all sorts of information will be available anytime, anywhere through network infrastructures that seamlessly connect land, sea, air, and space, and that are integrated with the terrestrial networks of various industries. For example, GPS information on the cloud currently provides real-time information on passable routes and traffic-avoidance routes. In the future, GPS information on the cloud, information on in-vehicle and drone cameras, and accident and construction information will be combined to obtain traffic-avoidance routes. It may also be possible to control not only unmanned logistics systems but also all cars, either in groups or individually, to find the best possible routes to each final destination, and to use integrated information for automated driving to save resources and reduce CO_2 emissions.

Smart communications infrastructures may also become applicable to new areas, whether on land, sea, or air. For example, constructing global or regional HAPS networks solely via HAPS within NTN will possibly enable mission-critical control for early warning systems and robotics applications with extremely high response speed requirements, such as over extremely low-latency networks utilizing radio communication at speeds 1.5 times faster (ca. 300,000 km/s) than transmission over land and submarine optical fibers (ca. 200,000 km/s).

Beyond 5G technology evolution and the evolution of the communications infrastructure are shown in Figure 4.15-1

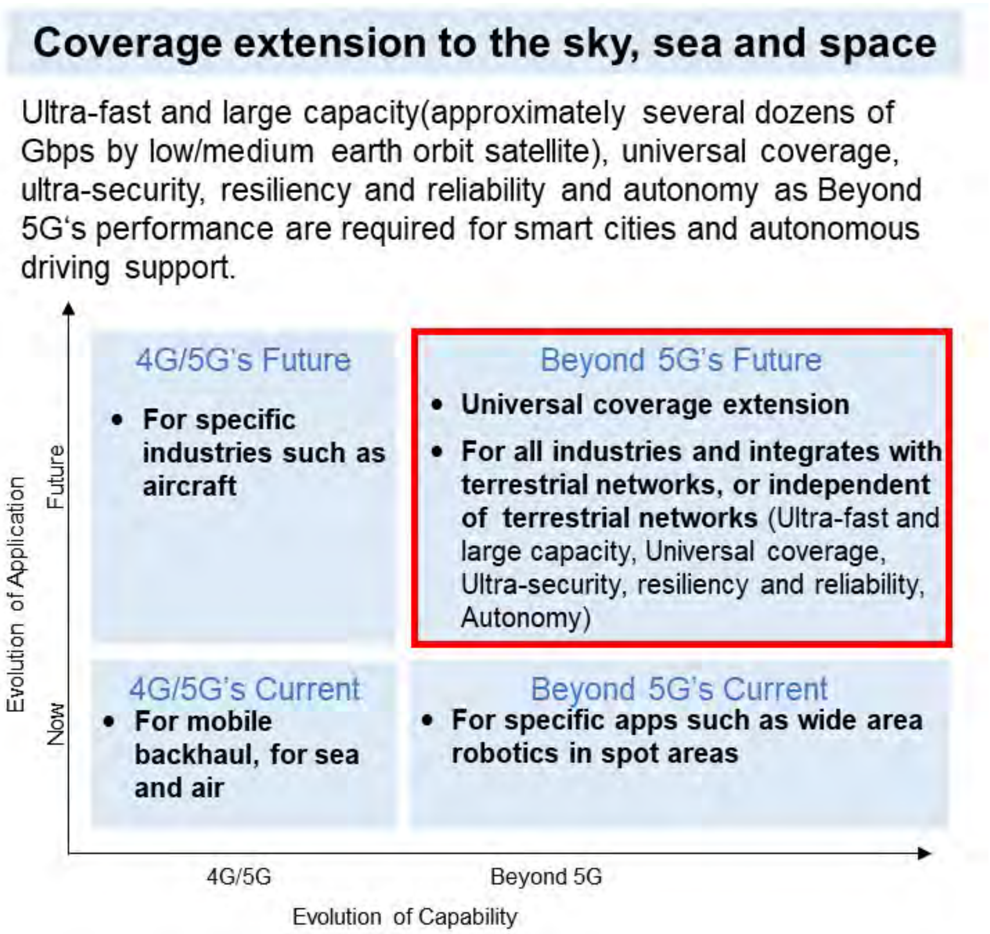

Figure 4.15-1 Space industry in Beyond 5G era (1)

b) Use of space-generated data in a secure, resilient environment

In response to the needs for monitoring the worsening and more frequent natural disasters and volcanic activities around the world, for ensuring national security due to intensified regional conflicts, and for mitigating the effects of global-scale extreme weather events and climate changes, the demand for observing and monitoring the earth from space has sharply increased, and the utilization of satellite images and data is expanding. For example, satellite images and data are already being used for production and management of agricultural and fishery products, for herbivore-damage and theft countermeasures, and in insurance examination. Supercomputer analysis of weather observation satellite data will contribute to improving the accuracy of weather forecasts, making them essential and intricately linked to our daily lives.

In the future, use of data generated by observations from space, such as aerial data, weather data, and the position and movement of people and things as viewed from space (hereinafter, space-generated data) will be imperative. As the major premise for their use, ultra-security, resiliency, and scalability of Beyond 5G will be required for establishing the platform for utilizing space-generated data in a secure and resilient environment.

- Enhanced security through quantum cryptography

  In anticipation of the current encryption technology becoming compromised, development of quantum-resistant encryption technologies that cannot be decoded by quantum computers as well as of photon-based quantum cryptography are underway. In the future, quantum encryption keys will be distributed via NTN optical communications to improve the security of inter-continental and mobile telecommunications, which are difficult to secure via on-ground networks. Quantum cryptography technologies will also likely improve the security of inter-satellite networks. [1]

- Platform for utilization of space-generated data

  At present, in order to utilize space sensing information and various IoT sensing data from land, sea, or air, past data collected through separate dedicated networks are provided mainly to enterprises after AI processing on ground-based supercomputers and terrestrial clouds. In the future, these data will be provided along with AI functions that have been generalized and made public via clouds with reduced data collection times and improved security, enabling individuals to utilize data at close to real-time accessibility.

  Likewise, data centers can be built in outer space, which is less affected by ground disasters, and the large amount of raw, space-generated data can be simultaneously analyzed and evaluated on the spot by AI processing, thereby significantly reducing the amount of data sent to the earth, making real-time use of space-generated data possible. Also, if data platforms can be securely offered through the cloud using quantum cryptography, Beyond 5G can be used to deliver data that must be securely delivered to the earth in real time, including non-space-generated data, such as data linked to personal information and data related to national security. Therefore, individuals may have direct access to data centers in outer space and access information tailored to their needs.

The need to mitigate risks of pandemics (such as COVID-19) brought about by the globalization of the economy and the increase in population mobility has led to the rapid entrenchment of the "new normal." As a result, the demands for communications and data platforms that enable individuals to use information necessary for remote work, telemedicine, and online education, anytime and anywhere, are increased. If avatars can be developed for guaranteeing reliable personal authentication by combining the smart communications infrastructures described above with these data-utilization platforms, they can be used for telework, for example, in providing a work environment to workers whose activities are limited by various constraints. It will also become possible to live without the restrictions of real time or space, via cyberspace. This will enable the building of a truly inclusive world that is not bound by gender, age, nationality, language, and the presence of handicaps, as well as the generation of new benefits. And people may get the value they need to maintain and develop their lives with avatars alone.

Beyond 5G technology evolution and changes in the space-generated data utilization infrastructure are shown in Figure 4.15-2

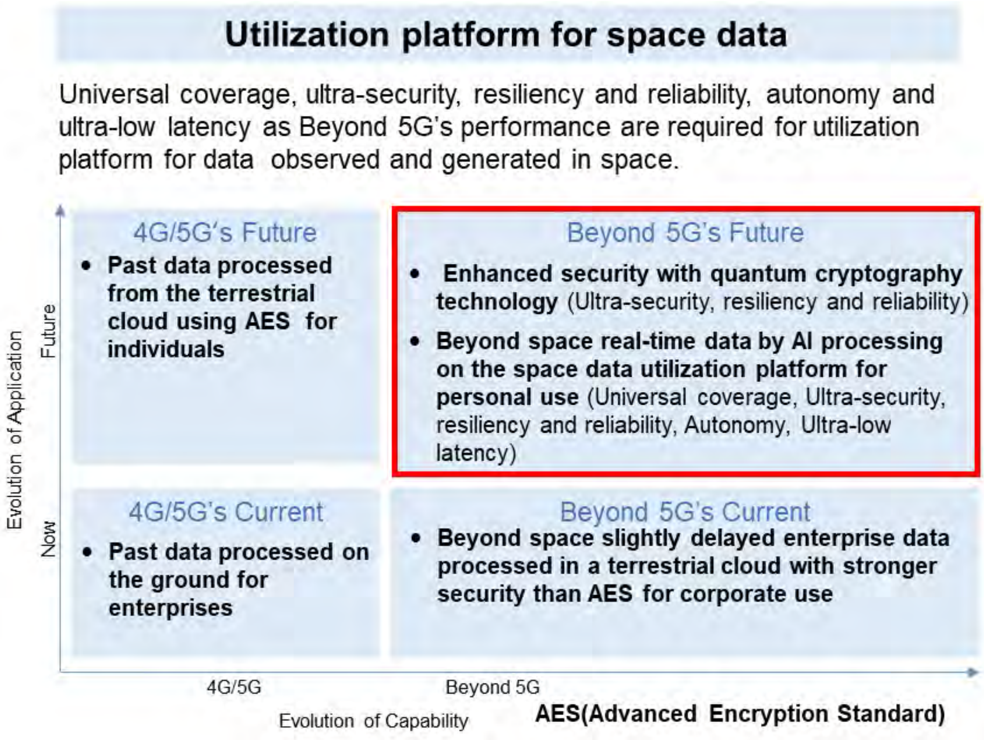

Figure 4.15-2 Space industry in Beyond 5G era (2)

c) Use of outer space and cyberspace as new areas of activity

Once Beyond 5G communication technologies become established, they will not only improve convenience on ground and real spaces but will also make it possible to merge them with outer space and cyberspace. They will likely lead to a future where outer space and cyberspace will serve as additional spheres of human activity, wherein they are considered as mere extensions of the scope of human life activities. Bidirectional projection of outer space and cyberspace will enable synchronization of outer space and ground activities in cyberspace, making it possible to conduct space activities without delay. This section examines the possible methods for using outer space or cyberspace from a ground perspective.

- Space environment utilization and manned activities

  A prime example of space environment utilization achieved with the current industry and communication technologies are the research and experiments conducted at the International Space Station (ISS). The ISS serves as a unique demonstration platform that takes advantage of a special environment characterized by vacuum, zero-gravity, and high radiation, but despite its use and availability, it still cannot be said that outer space has become a commonly used area of activity. If we can build airports or accommodation facilities in outer space and use them as transit stations to final destinations for overseas travel, and if we can travel seamlessly back and forth between outer space and the earth using space elevators, then outer space will feel closer. Sophistication of technologies in the space industry can, in fact, make these a reality.

  What can we achieve, therefore, with the improvement of communication technologies and the establishment of Beyond 5G communications? For example, if high-volume diagnostic image data can be instantly transferred to ground medical teams, telemedicine can be provided not only on the earth but also to space, making it possible to conduct medical activities from the ground to astronauts who are stationed at the ISS and the Lunar Gateway. Physical time delays can be predicted and corrected in cyberspace, pointing to potential applications in remote surgery. Also, if space flight becomes commonly accessible to the general public, workstations from space hotels under a seamless communication environment will become a potential reality. Improvements in robot technologies as well as in communication technologies will enable performing ISS maintenance operations, which are currently carried out by astronauts, remotely from the ground or through autonomous robot functions. Further, it will increase the possibility of carrying out emergency repairs to infrastructure, which could not be done by astronauts. It will also be possible to develop and operate infrastructures such as emergency evacuation sites (safe haven) and back-up facilities in orbit to protect human life, using the same analogy as storing species of organisms in space environments, which are free from ground disasters.

- Space debris measurements

  Conservation of the space environment must be considered to ensure safety and comfort in outer space. One of the biggest challenges is the buildup of space debris, which must be addressed in the development stage by designing structures to generate less debris, operations to avoid collisions with debris, and de-orbiting and removal of debris after decommissioning. The current options being studied include monitoring, tracking, capturing, and removing debris by bringing it back and releasing it into the atmosphere, which requires proactive operations to deal with individual objects. Another option being proposed is to change the orbit of debris using laser brooms.

What will the advancement of communication technologies and the availability of Beyond 5G communications bring about? Results of experiments to detect debris and other obstacles flying at high speeds beyond 8 km/s using ground radars indicate that by accurately predicting the trajectory of obstacles in cyberspace and notifying spacecraft in danger of collision, spacecraft can efficiently and effectively orbit while avoiding collisions. Globally linking outer space with cyberspace will make it possible to maintain the safety and high availability of many orbiting infrastructures.

- In-orbit services and autonomous operation

Currently, there are two major orbiting infrastructures: manned bases (ISS, etc.) and satellites. As mentioned above, the ISS is being maintained by astronauts, but because satellites are unmanned, they are generally decommissioned after equipment failure or reaching their design life. Sophistication of technologies in the space industry, however, will make it possible to repair satellites and upgrade services by replacing equipment and to extend their life through in-orbit refueling.

Likewise, advancement of satellite functions and satellite autonomy will enable the use of Beyond 5G communications in outer space to operate NTN and other information and communications networks automatically and autonomously for various space infrastructures, including satellites. Combining with in-orbit services will lead to the establishment of resilient space infrastructures and communication networks that are independent of ground infrastructures.

- Building new in-orbit infrastructures

At the end of 2020, a memorandum of understanding was concluded on Japan's participation in the U.S.-led Artemis lunar exploration program. Japan's contributions to the construction of the Gateway, which will serve as the relay hub for manned lunar exploration, have drawn attention. In particular, Japan has leveraged the knowhow from the development and operations of the Japanese Experiment Module (“Kibo”) and the Space Station cargo spacecraft (“Kounotori"). Japanese companies, including start-ups, have already begun developing landers and rovers for lunar exploration and are promoting their development through public-private partnerships.

These developments are believed to pave the way for the construction of infrastructures not only for space but also for the earth. For example, factories and plants can be built in space and operated remotely for waste disposal and resource recovery, thereby contributing to reduction in the environmental impact on the planet. Various measures have been hammered out to achieve carbon neutrality on the earth, but in the future, we may find ways to do this through space utilization. In addition, if we can build a power energy network for solar power generated and transmitted from orbit, we will be able to provide a stable supply of natural energy, independent of weather conditions and disasters.

There is a need, however, to consider environmental protection in space as well as on the earth. Aside from the removal of space debris described above, in-situ resource utilization (ISRU) is another goal of the space industry. For example, the industry aims to carry out "local production for local consumption" of resources by using sintered materials and waterless concrete from the sand-like particles known as "lunar regolith" found on the moon surface, as building materials for the lunar base. In the future, digital twin and robot technologies will be used to automatically and remotely process and assemble these building materials, which will require synchronizing operations with cyberspace and reflecting them in production planning. Likewise, systems must be capable of rapid response to failures, as well as efficient, waste-free, and reliable operations. These will all be possible in the future with the application of high-speed, high-capacity Beyond 5G communications.

Beyond 5G technology evolution and the expansion of its area of activity are shown in Figure 4.15-3.

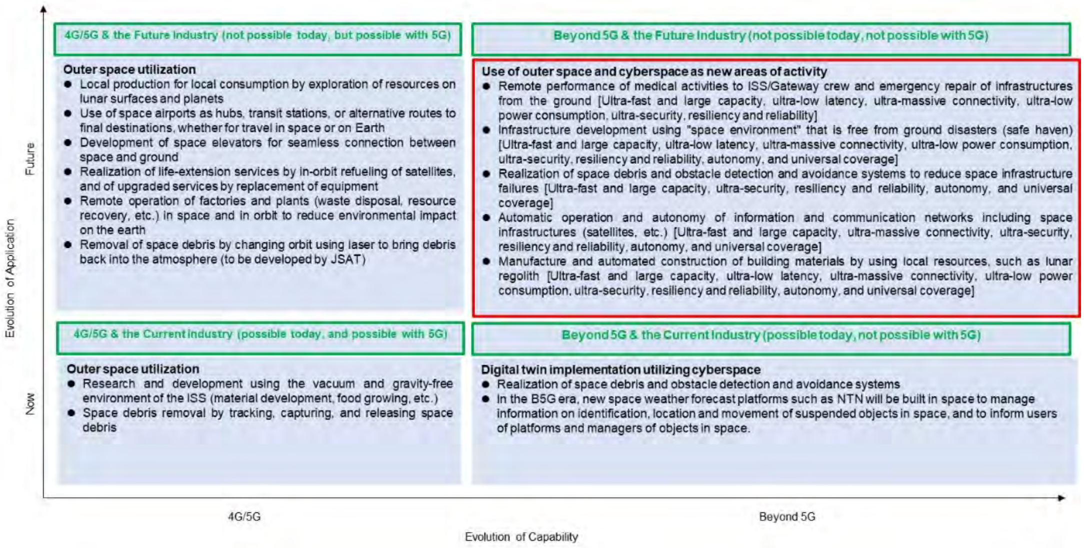

Figure 4.15-3 Space industry in Beyond 5G era (3)

d) Controlling space vehicle networks in a world where information is always available, without "being aware of communications"

In our world today where 90% of mobile device owners use smartphones, users have to download large apps over Wi-Fi and sign up for unlimited data pricing plans to watch videos frequently, i.e., we are in an era where users need to "be aware of communications." The uptake of Beyond 5G will enable ultra-fast and large capacity, ultra-low latency, and ultra-low power consumption communications, eliminating the need for many users to “be aware of communications.”

Now, we are using satellites to provide communication environments for remote areas, insular regions, and mobile objects. Beyond 5G communications, however, will make it possible to seamlessly connect land, sea, air, and space to enable access to all information from anywhere, anytime.

Stratospheric platforms will be able to monitor and receive radio waves from outer space and send signals to ground users, thereby playing a role in seamless communication between space and the ground. On the other hand, there is a need to improve the transmission capability of Beyond 5G infrastructures through the use of space technology for diamond semiconductors, which are predicted to increase power output and efficiency.

In addition, if a local Beyond 5G communications environment can be established separately for the moon, Mars, deep space, and Earth, and then connect them through Beyond 5G communications and cyberspace, deep space and Earth can be seamlessly connected, and their information can be used without the need to be aware of the distance between them.

Beyond 5G technology evolution and spacecraft network control are shown in Figure 4.15-4.

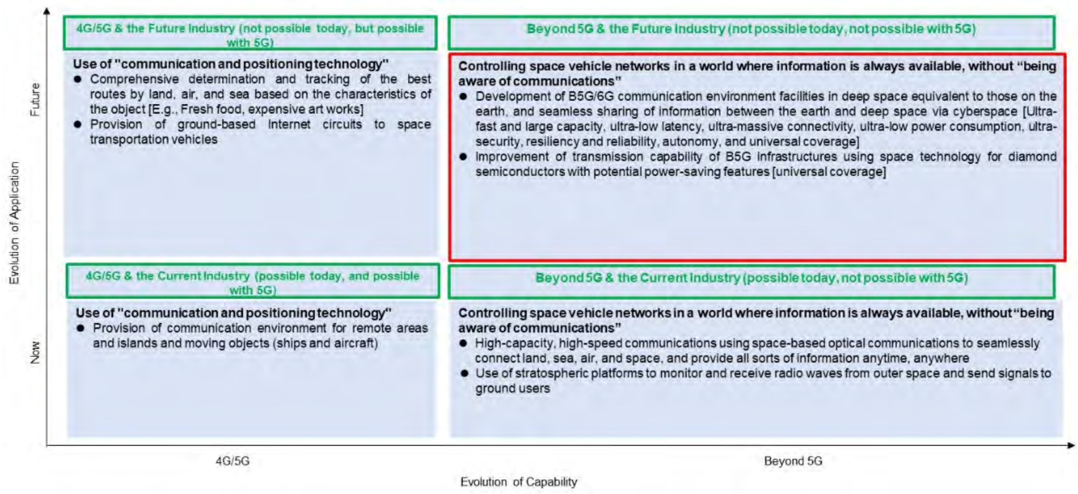

Figure 4.15-4 Space industry in Beyond 5G era (4)

e) Contribution to human activities from outer space and cyberspace

In cyberspace where there are no borders, it is said that the significance of GDP indicators varies, and people’s sense of values are not limited to pursuing wealth, but rather focused on qualitative abundance and contributions to the world. Space, which is without borders like cyberspace, can also be used similarly, wherein communication between people with different cultural and religious values via space and cyberspace will lead to the creation of unprecedented new values and to the building of a society that supports diverse ways of living.

- Measures against disasters

  Japan, which experiences many disasters, is in the midst of efforts to understand the ground situation from space using IoT and sensor technologies. From a communications perspective, however, the only measure that has been taken so far is to mitigate damage from disasters by adopting redundant network configurations. In the future, global climate change diagnosis and prediction accuracy will also improve. In particular, environments that enable the use of Beyond 5G will pave the way for conducting real-time, high-frequency, and high-resolution fixed-point observations for the whole world from space. For example, by running a weather prediction model on orbit, high-precision predictions can be made in a timely manner. Likewise, by obtaining GPS location information on orbit, it will be possible to provide pin-point evacuation advisories to personal devices at the appropriate timing from space. The ability to communicate directly with space also provides the advantage of not being affected by damage of ground base stations.

- Countermeasures in agriculture and fisheries

  This section delves into the contribution of the space industry to agriculture and fisheries from a similar perspective as the disaster countermeasures mentioned above. Currently, observation satellite data are used to control the production of agricultural products, which are also monitored from the air to prevent damage from wildlife. Further, the promotion of DX in the agriculture and fishery industries will lead to the resolution of the food loss problem through the monitoring of production status of agricultural products throughout Japan, and, eventually, throughout the world, and by capturing domestic and international demand information to predict the supply-demand balance. Future use of Beyond 5G will improve both the quality and quantity of observation data from space, making it possible to precisely predict the damage and growing conditions of agricultural crops and to implement proactive countermeasures. Accumulating continuous observation data on sea surface temperature and other factors via satellites will enable contributions to ecosystem-friendly fishing practices by understanding the migration of marine habitats and the signs of ecological changes caused by these differences.

- Contributions to education and to economic activities through entertainment

  Current examples of utilization of space for education include live broadcasts from the ISS and astronomical observation from space through astronomical observation satellites. Elements of entertainment are provided not only through Earth orbit tours for some wealthy people, but the general public can also enjoy visual space travel via VR, and there are also facilities for experiencing zero-gravity environments.

The application of Beyond 5G communications in this domain will enable ordinary users to enjoy space travel by sending their avatars to virtual outer spaces. Development of avatar technologies that can also transmit tactile signals will enable experience of activities that are different from traveling on Earth. Also, in terms of benefits here on Earth rather than on outer space, educational contents independent of location or time constraints will become widely used, potentially leading to the elimination of the digital divide in the educational environment. Haptics will also enable taking musical instrument lessons and playing music virtually. Thus, the establishment of Beyond 5G communications will likely lead to the creation of a society that merges the real and virtual realms to enable diverse lifestyles under completely different concepts of time and place.

Beyond 5G technology evolution and its contribution to human activities are shown in Figure 4.15-5.

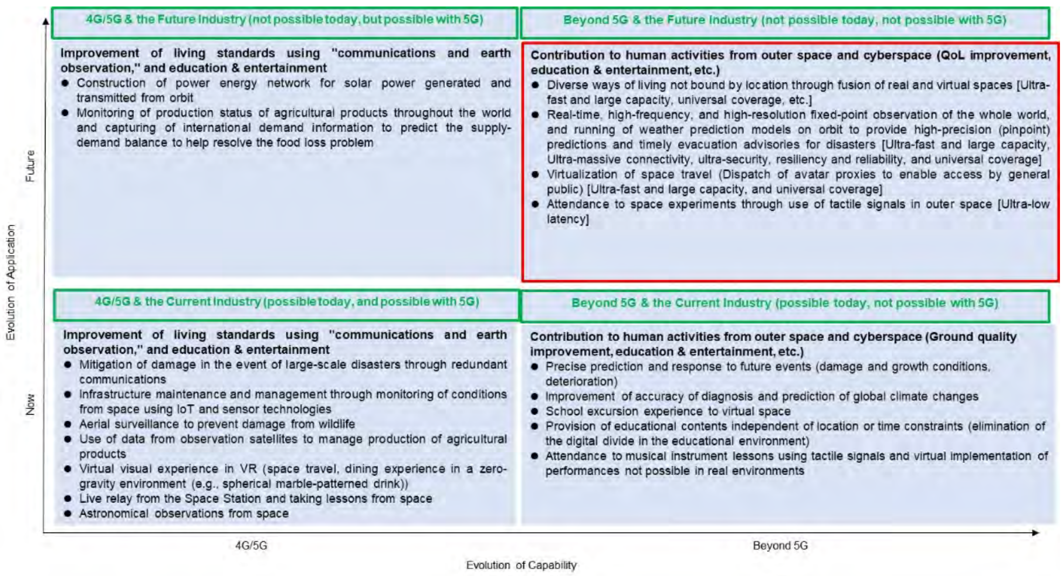

Figure 4.15-5 Space industry in Beyond 5G era (5)

4.15.1.4 Capabilities required in Beyond 5G

It is essential to develop technologies to achieve the Ultra-fast and large capacity, Ultra-low latency, and Ultra-massive connectivity required for Beyond 5G. The following is an overview of the elements required for Beyond 5G and the necessary technologies to achieve them.

(a) Ultra-fast and large capacity

Extending the ground network into outer space entails ultra-fast and large capacity communications between space and the ground. In Beyond 5G, the frequency bands used in 5G (3.7 GHz, 4.5 GHz, 28 GHz, etc.) will be expanded to include higher frequencies in the millimeter and terahertz waves, and optical technologies will be used to enable wide-band communications. Higher frequencies in turn require technologies for miniaturization and high integration. In addition, high-speed (wide-band) signal processing and parallel signal processing technologies for large-capacity signals will be indispensable technologies for increasing speed, pointing to the potential of MIMO technologies using multiple antennas.

(b) Ultra-low latency

A physical, one-way propagation delay of around 120 msec occurs in network connections with geostationary orbit satellites. When connecting to systems that do not allow transmission delay, the delay can be reduced to around a few msec by utilizing ultra-low-altitude satellites (orbit altitude of around 200 km) or HAPS (altitude of around 20 km). Optimal networks that meet the latency requirements of users and use cases must be built by combining with space communications.

(c) Ultra-massive connectivity

In the Beyond 5G world, more people and things will need to be connected. The major advantage of operating from space is the ability to connect many users at the same time or to receive data from many sensors, using one antenna coverage. Technologies for distributed processing or for distributed networks using multi-hop communications during massive connections will also be useful in terms of the feasibility of using satellites with limited resources. More efficient networks can be built by combining the ultra-wide coverage of geostationary satellites with the short-range communications of low-orbit satellites.

(d) Ultra-low power consumption

Increase in power consumption is inevitable due to the increase in speed and capacity. For satellites in orbit, power consumption of devices must be reduced because waste heat is a major issue. In addition to compound semiconductors such as GaN and InP, which are widely used as current communication technologies, new semiconductor materials must be developed, such as diamond semiconductors, which have potential to provide higher power, higher efficiency, and higher reliability. Likewise, there is also a need to aim for parallel signal processing, lower operating frequency, and lower power consumption in order to achieve larger capacity in the future.

(e) Ultra-security, resiliency and reliability

Demands for data security and resilience are foreseen to increase even more in Beyond 5G. Security and resilience of data servers can be ensured by placing them in outer space, or these demands can be met by applying quantum cryptography communications to space communications.

(f) Autonomy

Future satellite operations, such as constellation of multiple low-orbit satellites, will become increasingly complex, making it impossible for operators on the ground to decide and operate everything. Optimal operation timing and service provision to users must be carried out autonomously by utilizing AI and other means. Satellites may also be operated in such a way that they can independently carry out sensing of the state of communication lines and autonomously set the optimum communication parameters.

(g) Universal coverage

There is a trade-off between the antenna coverage and the communication capacity (communication power) for communications from HAPS at altitudes of about 20 km, from low-orbit satellites at altitudes of several hundred km, and from geostationary orbits at altitudes of 36,000 km.

Mapping the differences in orbit altitude with the network hierarchy and combining with digital beamforming technology will make it possible to expand the network more flexibly and broadly.

The above use cases and the correspondence of required Beyond 5G capability are shown in Table 4.15-1.

Table 4.15-1 Capabilities required in Beyond 5G

	Ultra-fast and large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consumption	Time synchronization accuracy	Positioning and sensing	Universal coverage	Autonomy	Others
Smart communication infrastructures utilizing space	X Millimeter wave, terahertz wave, high integration, multiple antenna MIMO			X				X *	X AI utilization	*Map the difference in orbital altitude (HAPS, low-orbit satellites, geostationary satellites, etc) to the network hierarchy and combine it with digital beamforming technology
Use of space-generated data		X ultra-low-altitude satellites, HAPS		X quantum-resistant Cryptography				X *	X AI utilization	
Use of outer space as new areas of activity	X			X	X					
Controlling space vehicle networks in a world where information is always available	X	X	X	X					X	
Contribution to human activities from outer space and cyberspace	X	X						X		

4.15.1.5 Summary

This section examined the current situation and future vision of space industry and described the capabilities for Beyond 5G that are needed to the future vision. The required capabilities would be ultra-fast and large capacity, universal coverage, ultra-security, resiliency and reliability, autonomy, ultra-low latency, ultra-low power consumption, ultra-massive connectivity.

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4.15.2 HAPS

High Altitude Platform Station (HAPS) is seen as one of the promising Beyond 5G technologies in the "Future technology trends toward 2030 and beyond" published by ITU-R, an organization that develops international standards for wireless communications [1]. In this section, we delineate our vision for the future by taking into account the current state of HAPS and its challenges, and discuss use cases achievable with Beyond 5G, as well as the requirements for those use cases.

4.15.2.1 Current situation and challenges

HAPS uses unmanned aircraft and airships that continuously fly in the stratosphere at an altitude of about 20 km as base stations and can provide stable mobile communications and Internet access in place of fixed lines in areas where communication networks are not available, such as mountainous areas and isolated islands, and in developing countries.

Examples of HAPS backhaul connections include not only HAPS-to-ground gateway communications, but also HAPS-to-HAPS and HAPS-to-satellite communications, which will enable deploying HAPS in areas where it is difficult to deploy ground gateways. Also, since the atmosphere between HAPS-to-HAPS and HAPS-to-satellite is thin and has no shielding, it provides the advantage of enabling stable links even with high-frequency signals and optics. Therefore, it is also important to promote collaboration between HAPS and non-terrestrial network systems with different altitude such as satellites.

Various companies both in Japan and overseas have recently started conducting communications tests in the stratosphere. However, we believe that the following institutional issues must be addressed to promote the widespread use of HAPS in the future [2].

1. Development of aviation regulations for HAPS

   International rules for HAPS, which are unmanned aircraft, are not yet in place, making it imperative to develop international and national aviation regulations for flying in the stratosphere. In Japan, experimental introduction in special zones will be an effective way to do this.

2. Establishment of common criteria for aircrafts

   There are no common criteria for various aircrafts in each country even for test flights in the stratosphere, making the process for obtaining flight permits unpredictable. There is a strong need for aviation authorities in each country to develop common criteria for various aircrafts.

3. Additional identification of frequencies for HAPS

   The current Radio Regulations allow HAPS to use only the 2.1 GHz frequency band as an IMT base station. However, use of additional frequency bands (694-960 MHz, 1710-1885 MHz, and 2500-2690 MHz) for HAPS is being considered for discussion at World Radiocommunication Conference 2023 (WRC-23).

4. Establishment of international framework for interference coordination with neighboring countries

   Radio interference to neighboring countries must be addressed around national borders because HAPS creates an ultra-wide coverage from the stratosphere. An international framework for coordinating radio interference with neighboring countries should be developed.

4.15.2.2 Future vision

HAPS will enable effective deployment of base stations not only to areas that are not connected and difficult to connect (such as rural areas), which are not amenable to deployment of conventional ground base stations, but also to unexplored areas in the mobile industry, including the air and sea. This means having three-dimensional coverage being extended in the vertical direction as well as in the traditional horizontal direction, enabling a world where the Internet can be accessed by all people in any location. This will also lead to the creation and nurturing of new domestic industries, including transformation from other industries using HAPS.

Moreover, HAPS can be used as a means to solve social issues such as the increase in natural disasters, the continuing digital divide (information gap), and the unabated CO_2 emissions. Specifically, HAPS will enable the provision of networks that are resistant to natural disasters, elimination of the digital divide through ultra-wide coverage, and carbon reduction through the use of the solar planes. These benefits will provide solutions that will contribute to the achievement of the SDGs, such as building resilient infrastructures, correcting information disparities, and addressing climate change with the use of clean energy.

4.15.2.3 Applications achievable with Beyond 5G

We propose the following four use cases as the main use cases utilizing HAPS, which will be realized by Beyond 5G [3] [4].

1. Connecting the unconnected

   More than 40% of the world's population mainly in remote rural areas are unable to access the Internet. HAPS will provide ultra-wide coverage from approximately 20 km above the air with a delay equal to that of ground IMT base stations, enabling efficient expansion of coverage to unconnected or difficult-to-connect areas.

2. Emergency communications and disaster recovery

   The impact of many natural disasters occurring throughout the year around the world is significant, often causing destruction of terrestrial communication systems and hindering essential emergency communications. Since HAPS is located in the stratosphere and can move freely regardless of air traffic or weather, they are not affected by natural disasters on the ground and can support rescue and recovery activities in the event of disasters.

3. Connectivity for urban air mobility

   Urban air mobility (UAM), which includes flying vehicles and drones, will likely become the new system for transporting passengers and goods in cities with dense populations in the near future. HAPS will provide three-dimensional coverage for these air mobility systems from the air, supporting remotely piloted aircraft systems (RPAS) and, eventually, enabling the realization of autonomous flight.

4. Internet of things (IoT)

   Provision of communication services for things such as sensors, home appliances, machinery, and cars that have not been connected to the Internet until now will lead to the creation of new industries and businesses. Since HAPS can provide ultra-wide coverage, they can help create a world where everything is connected, anytime, anywhere.

4.15.2.4 Capabilities required in Beyond 5G

To provide "sustainable and ultra-wide coverage communications" needed to realize the above use cases, Beyond 5G will require the following new capabilities and specifications. In addition to these, the same terminals as those used in ground-based IMT must be usable (i.e., device affordability is addressed), and the amount of delay must be equivalent to that stipulated in IMT-2020 (5G) for enhanced Mobile Broadband (eMBB).

- Maximum horizontal coverage

  This refers to the maximum radius of the area (in km/BS) that can be covered by a single base station. A single base station should be able to cover areas with a radius of several tens to hundreds of kilometers.
- Maximum vertical coverage

  This refers to the maximum altitude of the area (in km/BS) that a single base station can cover. A single base station should be able to cover a few kilometers above the ground that cannot be covered by a ground base station.

- Carbon neutrality

  This refers to the capability to provide zero CO_2 emissions during operation.

Beyond 5G Capabilities required by each of the above use cases are mapped into Table 4.15-2.

Table 4.15-2 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Connecting the unconnected								A radius of several tens to hundreds of km		Carbon neutrality
Emergency communications and disaster recovery								A radius of several tens to hundreds of km		Carbon neutrality
Connectivity for urban air mobility								A few km above the ground、A radius of several tens to hundreds of km		Carbon neutrality
IoT								A radius of several tens to hundreds of km		Carbon neutrality

4.15.2.5 Summary

In this section, we created a picture of our vision for the future of HAPS by taking into account its current state and its challenges. We also introduced the use cases utilizing HAPS as one of the Beyond 5G technologies, toward the realization of the future vision. We then described the corresponding new capabilities and requirements for Beyond 5G. The required capabilities would be universal coverage and carbon neutrality. The need to address the various social challenges pointed out in the SDGs has highlighted the potential of technologies that can provide sustainable and ultra-wide coverage communications, such as HAPS.

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4.15.3 Society

4.15.3.1 Current situation and challenges

We focus on two major social issues and examine how Beyond 5G should be used in the "Ideal Society in 2030."

- Global social issues

The 17 global goals outlined in the Sustainable Development Goals (SDGs) are representative of the global social issues. SDGs can be interpreted differently depending on where people live and how they work, but according to the outcome document for the adoption of the development agenda, “Transforming our World: the 2030 Agenda for Sustainable Development” [1], it is essential to harmonize the three aspects of economy, society, and the environment in order to achieve these goals. Further development of communication technologies offered by Beyond 5G is needed to solve social issues through the achievement of the SDGs.

- Social issues in Japan

We focus on two of the biggest social issues facing Japan: (1) population problems due to the aging and declining population and (2) environmental issues such as decarbonization and mitigation of damage from natural disasters and climate change.

With regard to population problems due to the aging and declining population [2][3], Japan has the highest proportion of the population aged 65 or older in the world [4]. An aging and declining population brings about a variety of issues, including decline in productivity due to lack of workers, economic impacts of fiscal deterioration associated with decline in regional vitality, and increase in the burden placed on the current generations by social welfare for pensions and medical and nursing care costs for the elderly [5]. These in turn lead to a wide range of other problems. With regard to environmental issues, many devastating natural disasters have occurred in recent years due to climate changes [6]. Moreover, Japan is a country that is prone to earthquakes, tsunamis, and volcanic disasters, as shown by the Great East Japan Earthquake in March 2011, the Great Hanshin Earthquake in January 1995, and the Mount Ontake Volcanic Eruption in 2014 [7]. Mt. Fuji, the highest mountain in Japan, is also an active volcano, and it continues to warrant attention [8].

- Population problem

The population problem, which is exemplified by the aging and declining population, leads to exacerbation of social and economic issues, such as reduction in economic scale due to decrease in domestic demand, shortage of labor, decline in international competitiveness, financial crisis, and collapse of social security system due to rising medical and nursing care costs. The population problem goes beyond these national-level issues and also relates to the question of how individuals can live a meaningful long life, referred to as the “100-year life” [9].

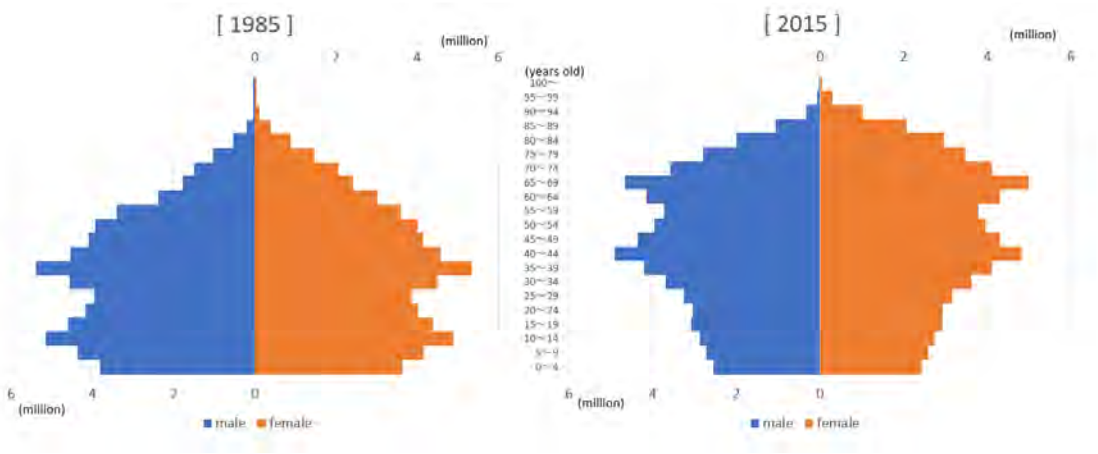

Figure 4.15-6 Japan’s population in 1985 and 2015
("Population Census" from Statistics Bureau of Japan） [10]

- Environmental issues

Environmental issues include global warming, which is driven by an increase in the concentration of carbon dioxide in the atmosphere due to the large consumption of fossil fuels by humans, occurrence of disasters resulting from climate change, and pollution of the atmosphere, ocean, and soil caused by various human activities. These problems threaten the long-term survival of the human race.

4.15.3.2 Future vision

- <u>Measures for aging and declining population</u>

As the 1985 and 2015 population pyramid shows, the aging and decline of the population in Japan has advanced considerably. According to the Annual Report on the Declining Birthrate [2] and the Annual Report on the Ageing Society [3] issued by the Cabinet Office, the government is directly addressing the structural problem of the declining birthrate and the aging population by aiming to realize a “Society with the Dynamic Engagement of All Citizens” through the “New Three Arrows;” namely, “a robust economy that gives hope,” “dream-weaving childcare supports,” and “social security that provides reassurance.”

- <u>Measures for natural disasters</u>

In regard to natural disasters, measures must be taken against their causes, such as global warming and environmental destruction, but the increase in occurrence of natural disasters will likely continue into the 2030s. The goal for 2030 should be to have the ability to “predict, detect, and evacuate from disasters in advance,” “confirm safety and obtain relief supplies and necessary information immediately after a disaster," and "find missing people quickly," which are all necessary in securing lives and property in the event of natural disasters and in providing prompt support during emergencies.

4.15.3.3 Applications achievable with Beyond 5G

- Measures for aging and declining population

Solving the labor shortage caused by the declining birthrate and the aging population necessitates reinforcing the workforce by promoting employment of the people who are unable to work even though they want to, as well as improving productivity and reducing labor demand by promoting automation using AI and IoT. T For example, technologies are expected to supplement the capabilities lost due to aging and disabilities, to create the working environment for anyone raising children without anxiety, to solve the language barrier faced by foreign workers, and to enable workers who are physically unable to stay in Japan to work in Japan without having to travel to Japan. Moreover, natural disasters include the damages by winds, floods and earthquakes. There is a strong demand in the future telecommunications industry for mechanisms that can quickly restore the means of communication in response to the accompanying communication failures.

In efforts to realize a society in which the elderly can have continued hope for the future by having long life expectancy, various health management services through wearable devices and smartphone apps, and IoT services for watching over and protecting the elderly and infants are now being provided. Taking measures to support vulnerable populations with limited mobility as an example, we see that although demonstration experiments for self-driving buses are being actively pursued, buses mainly provide a means of traveling to designated locations. In the 2030s, society should have personal mobility and infrastructure systems that are tailored to diverse individual needs, such as for daily walks and going where one wants to, for the sheer enjoyment of movement. These initiatives will not only support the vulnerable populations with limited mobility but will also lead to the advancement of monitoring services, provide support for people living alone, and nurture motivation for life. The use of Beyond 5G will surely play an important role in realizing this kind of society.

In 2020, the COVID-19 pandemic became a major trigger for promoting remote work and online classes following restrictions in movement to control infections. However, further improvements are needed through the evolution of communication technologies. For example, the evolution into low-latency, high-image-quality remote work and online classes through the use of augmented reality technology or by combining with robotics and the realization of ultra-safe and reliable online voting will help pave the way for "Society with the Dynamic Engagement of All Citizens".

These advances in communications technologies will realize use cases such as "enhanced remote work," "expanded personal mobility and infrastructure systems," "low-latency, high-image-quality remote control systems," which will help solve the issues brought about by the population problem.

- <u>Measures for natural disasters</u>

Examples of current countermeasures include monitoring by IoT devices using surveillance cameras and sensors, as well as notification services using emergency warning emails and weather forecasting apps. For rescue efforts during natural disasters, which will likely intensify in the future, further improvement of predictive and sensing technologies, low-power consumption technologies, and stable power supplies through energy harvesting will be needed, which in turn point to the need for acquiring more accurate information. In the future world of Beyond 5G, the evolution of these technologies will lead to the realization of personalized disaster notification services including useful information such as suggestions of evacuation sites and evacuation routes, and means of transportation, in accordance with unique individual attributes, such as age, gender, disability, and cultural backgrounds.

Communication satellites, HAPS, and other technologies that will provide communications from outer space and over the air are examples of Beyond 5G applications in the prediction of disasters, such as landslides and tsunamis, through collection of information on mountainous regions, oceans, and other uninhabited areas, and in rescue operations for people in remote areas, such as mountains, islands, and oceans (fishing and shipping activities) and for people in inaccessible areas, such as large-scale-disaster areas. Distributed network topology technologies and management systems for autonomously providing priority communications to disaster areas are also important from the perspective of maintaining traffic balance and preventing gaps in coverage areas in the event of disasters.

When mobility and other necessary services are not readily available during disasters, or when individual devices cannot be used due to emergency restrictions, there should be a system that will provide immediate information, such as optimal evacuation routes, through signaling devices or digital signage. As examples of emergency digital signage, local bus bulletin boards and vending machines can be used as emergency information boards during disasters. Further, use of VR training systems based on the latest regional images to simulate various disaster sites during regular evacuation drills will provide a steady grasp of information on optimal evacuation routes depending on the disaster situation, enabling calm actions in the event of emergencies.

These advances in communications technologies will realize use cases such as “simultaneous distribution of personalized emergency bulletins based on individual attributes, location, and situation,” “communications system that enables users to exchange information without worrying about power supplies or being out-of-service even during disasters,” and “system for providing notifications on optimal evacuation routes during disasters.” These use cases will help solve the challenges in efforts to mitigate damage caused by natural disasters.

4.15.3.4 Capabilities required in Beyond 5G

The following are the most important requirements for Beyond 5G to achieve the use cases for solving the social issues mentioned above.

- <u>Aging and declining population</u>
  - Enhanced Remote Work
    - ➢ Ultra-low latency, ultra-security, resiliency and reliability
  - Expanded personal mobility and infrastructure system
    - ➢ Ultra-fast and large capacity, ultra-low latency, and autonomy
  - Remote control system
    - ➢ Ultra-fast and large capacity, ultra-low latency

- <u>Natural disasters</u>
  - Personalized emergency bulletins based on individual attributes, location, and situation
    - ➢ Universal coverage
  - Communications system that enables users to exchange information without worrying about power supplies or being out-of-service even during disasters
    - ➢ Ultra-security, resiliency and reliability, autonomy, and universal coverage
  - System for providing notifications on optimal evacuation routes during disasters
    - ➢ Ultra-fast and large capacity, ultra-security, resiliency and reliability, autonomy

The above mentioned capabilities are shown in Table 4.15-3. Also, the measures for aging and declining population issue in Beyond 5G era are represented in Figure 4.15-7 and the measures for natural disasters issue in Beyond 5G era are represented in Figure 4.15-8.

Table 4.15-3 Capabilities required in Beyond 5G

	Ultra-fast & large capacity	Ultra-low latency	Ultra-massive connectivity	Ultra-security, resiliency & reliability	Ultra-low power consump-tion	Time synchroni-zation accuracy	Positioning & sensing	Universal coverage	Autonomy	Others
Enhanced Remote Work		X		X						
Expanded personal mobility and infrastructure system	X	X							X	
Remote control system	X	X								
Personalized emergency bulletins based on individual attributes, location, and situation	10Mbps or more							1,000km/h		
Communications system that enables users to exchange information without worrying about power supplies or being out-of-service even during disasters				X				X	X	
System for providing notifications on optimal evacuation routes during disasters	X			X					X	

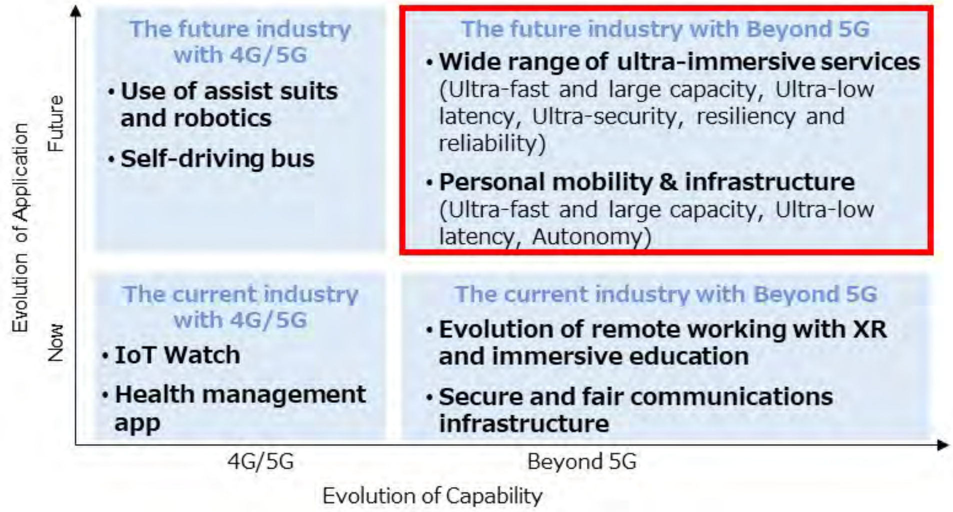

Figure 4.15-7 Measures for aging and declining population in Beyond 5G era

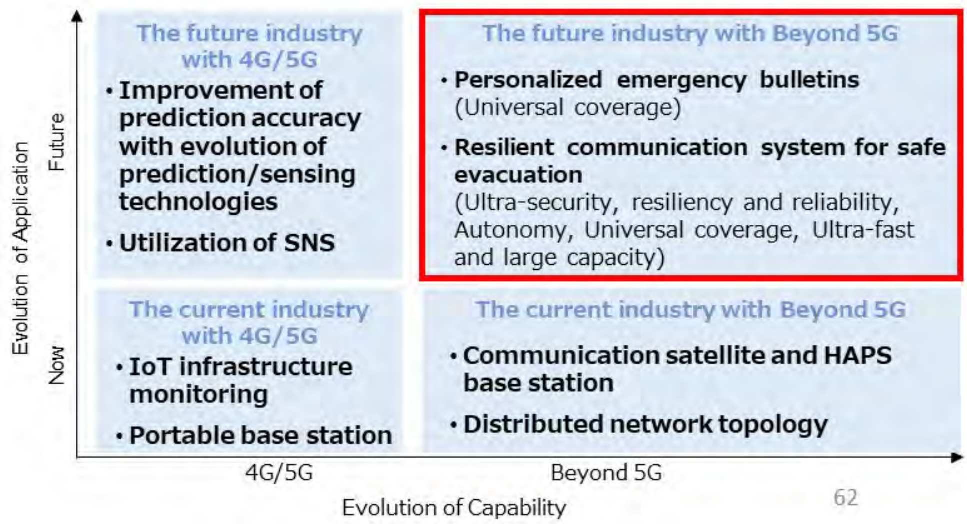

Figure 4.15-8 Measures for natural disasters in Beyond 5G era

4.15.3.5 Summary

This section examined the current situation and future vision of society and described the capabilities for Beyond 5G that are needed to the future vision. The required capabilities would be ultra-fast and large capacity, ultra-low latency, ultra-security, resiliency and reliability, universal coverage and autonomy.

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5. CAPABILITIES AND KPIS REQUIRED IN BEYOND 5G

5. Capabilities and KPIs required in Beyond 5G

5.1 Capabilities required in Beyond 5G

In Chapter 4, we looked at the current challenges and the solutions to those challenges in various industries other than the telecommunications industry, including the dreams that industries are aspiring for, and summarized the expectations for Beyond 5G. This section identifies the unique use cases in various industries based on Chapter 4 and summarizes the capabilities for Beyond 5G required in each use case.

- In the construction and real estate industries, the dream is to achieve automatic construction linking cyberspace and physical space (see section 4.2). One of the capability requirements for Beyond 5G based on use cases such as automatic construction in the Beyond 5G era is positioning accuracy. In particular, in civil engineering and construction use cases, positioning accuracy of 1 to 2 cm will be required.
- In the warehouse and logistics industries, low-latency communication and high-precision synchronization using Beyond 5G local communications will be required for fully automatic operation of logistics facilities (see section 4.3.1). Latency equal to or shorter than that of 5G (in the order of milliseconds within the local network) and time synchronization compatible with Precision Time Protocol (PTP) for the accuracy of internal clocks, including radio segments, (in microseconds) will likely be needed.
- In the aviation industry, supersonic passenger aircraft will become more common, significantly reducing travel time between major cities. Passengers will demand more comfortable space and time inside aircraft through provision of personalized environment and entertainment (see section 4.3.2). From these use cases, capability for high-capacity communications equal to or higher than 5G inside aircraft will be required for Beyond 5G. In particular coverage must be extended to reach supersonic passenger aircraft, which fly higher than the current passenger aircraft altitudes of about 10 km, and to cover outer space, to an altitude of more than 100 km.
- The railway industry faces the problem of shortage of manpower for railway operations (see section 4.3.3). Therefore, driverless operations will become a reality in the Beyond 5G era. Wireless train control systems will require highly reliable, real-time wireless communication to prevent train collisions and over-speeding. During emergency stops for super-high-speed trains, an end-to-end delay of several milliseconds will be required as one of the capabilities needed for Beyond 5G.
- The telecommunications and IT industries are facing challenges in terms of achieving ”digitalization with no one left behind” and establishing stable networks that remain uninterrupted even during disasters (see section 4.4). Thus, in the Beyond 5G era, there is anticipation for use cases enabling universal coverage through HAPS and

other non-terrestrial networks. From these use cases, capability for "100% land coverage" through terrestrial and non-terrestrial networks will be required for Beyond 5G. In addition, the telecommunications and IT industries are aiming to realize Society 5.0, which aims to balance economic growth with the resolution of various social losses and challenges through cyberspace (see section 4.4). Thus, in the Beyond 5G era, there is anticipation for use cases for optimization and future predictions that will enable the provision of the necessary goods and services to the people who need them, when they need them, and as much as they need them. From these use cases, capability for zero-touch operations through autonomous collaboration of devices utilizing AI technology will be required for Beyond 5G. The telecommunications industry must provide communication infrastructures that meet the performance requirements of the other industries.

- In terms of content enrichment, the media industry aims to provide an even more immersive media experience (see section 4.5). Therefore, there is anticipation for use cases enabling holographic communication in the Beyond 5G era. From these use cases, capability for throughput of tens to hundreds of Gbps and for optimization of data compression and split/remote rendering using AI technology will be required for Beyond 5G.
- In the energy resource materials industry, the goal is to improve the harsh working environments at resource development sites in mountains and oceans (see section 4.6). Thus, there is anticipation for use cases enabling immersive remote-control systems using high-definition images (such as 8K)/sensors and HMD/vibration devices at the field in the Beyond 5G era. A video transmission delay of less than 100 milliseconds between the site and the operator is desirable to prevent visually induced motion sickness in such use cases. For example, assuming that the processing delay for video compression/decompression as well as the processing delay for display on HDM is 55 milliseconds, the performance required for Beyond 5G would be 45 milliseconds. In addition, expansion of area (HAPS/ satellite communication/ underwater communication) will also be needed to enable remote control at all sites.
- The possible use cases for the automotive industry include safe driving support, remote operation, and automatic operation (see section 4.7). In the Beyond 5G era, remote driving applications are likely to diversify, such as for local mobility services and for elimination of road parking vehicles in the event of disasters, wherein there is anticipation for use cases enabling remote monitoring and remote control. From these use cases, capability for transmission speed of approximately 50 Gbps over the radio

segment, 1 millisecond end-to-end communication delay[5], and 10^{-6} or higher communication reliability[6] will be required for Beyond 5G.

Beyond 5G base station sensing will be useful in conditions where vehicles travel singly in rural areas or at night in urban areas. Sensing accuracy at the centimeter level will likely be provided by using terahertz waves.

Also, as we move toward the advanced automated driving era, there is a need to consider the possibility that calculations for processing of multiple- (or other-) viewpoint information obtained by single vehicles that are limited to individual vehicles will cause the neural network to excessively expand and will prevent carrying out calculations within a very short span of time solely by relying on the vehicle's GPU and NPU capabilities. To prepare for such requirements, it will likely be necessary to incorporate distributed learning and reasoning functions in vehicles and Beyond 5G base stations.

- For the machinery industry, there are future prospects for realizing customized production in addition to solving the current challenges of achieving flexible retooling of production lines, improved machining accuracy, and increased production volumes in monozukuri and manufacturing sites (see section 4.8.1). Thus, in the Beyond 5G era, there is anticipation for use cases that will enable the creation of extremely flexible and efficient production lines, as well as the realization of "My Factory," where products made in accordance with individual user demands will be manufactured and delivered immediately, through wireless connections between machine tools and production controllers. From these use cases, capability for 100-microsecond-level delay on End-to End (local area communications) will be required for Beyond 5G.
- As Beyond 5G becomes an essential infrastructure, there will be a need for the electronics and precision electronics industry to transform into a social infrastructure and platform industry (see section 4.9.1). Since Beyond 5G will be widely used as a communication function for different devices that are used in daily life and business, functions related to scalability will become critical to enable all kinds of household appliances, electrical equipment, and office equipment around us to work together across multiple industries. For example, it will be necessary to establish interfaces between devices within a communications network, as well as open APIs and interfaces between communication and non-communication systems, and to configure a common platform for data analysis/processing and handling of contents. Also, as awareness on diversity and inclusion permeates and the aging society continues to advance, there will be a need for electrical and precision equipment to become easily

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[5] The values of end-to-end communication delay are proposed by referring to the requirements of 3GPP release 16

[6] Communication reliability is equivalent to Block Error Rate

operable by the users themselves. The autonomy of different devices must be significantly improved, and universal support must be provided during their connection and operation, such as through zero-touch collaboration between devices, manual-free and intuitive operations that do not need complicated settings, and device-free access to services anytime and anywhere.

- In the semiconductor industry, like in other manufacturing industries, there is an increasing demand for manpower saving and full automation of factories (see section 4.9.2). There is a large demand mainly for automation and remote control. Automation of manufacturing and the connection of equipment to IoT have led to enhancement of functions for full automation, operational visibility, and routine inspections during normal production. However, full automation of fine-tuning and maintenance of the device will require remotely controlling the robot carrying out the adjustments while monitoring the device. This requires delay to be kept to approximately 1 millisecond.
- The retail and wholesale distribution industries feature supply chains that entail various operations, primarily, procurement, processing and manufacturing, distribution, stocking, and sales (see section 4.11). The logistics industry, which handles the distribution operations, is at the core of management in retail and wholesale distribution industries, making the challenges of the logistics industry very important. The three challenges of the logistics industry; namely, (1) support for new lifestyles in response to the coronavirus pandemic, (2) measures against labor shortages, and (3) support for a sustainable distribution network, are being tackled in the “Next Comprehensive Logistics Policy” from FY2021-2025. These challenges will be addressed in “Beyond 5G and Logistics DX” through the realization of three use cases; namely (1) sophistication of transport and delivery, (2) smart logistics (capturing all supply chain data and building the data base within DTC/CPS), and (3) compliance with environmental regulations by capturing operational data related to transport and delivery. The capabilities required for the above use cases are as follows:
  - Use Case (1)
    - Massive simultaneous connectivity: Stores
  - Use Case (2)
    - High-capacity communications: 10 - 100 Gbps
    - Reliability: Through services based on supply chain utilization
    - Others: DTC/CPS collaboration for the realization of the use case
  - Use Case (3)
    - Massive simultaneous connectivity: Number of trucks in operation (not only for the same area, but across Japan)
    - High-capacity communications: Through a telematics design
    - Others: Collaboration with RIS, AI/location

*Number of trucks in operation / truck operator: 62,000 truck operators and approximately 1.95 million employees

- In the healthcare industry, the dream is to build a medical and nursing care system to support a super-aging society and extend the healthy life expectancy in response to the current challenge of achieving harmony with a super-aging society (see section 4.12.1). Thus, in the Beyond 5G era, there is anticipation for use cases that will enable remote surgery that can be performed anywhere, real-time health management using nanomachines and micromachines, and performance of minimally invasive treatment and direct treatment of affected parts from within the body. From these use cases, capability for throughput of more than several tens of Gbps for transmission of high-definition video and ultra-security, resiliency and reliability at the level of transmission of operation information between the medical practitioner and the robot will be required for Beyond 5G. Health management and direct treatment from within the body will require energy harvesting and use of external power supplies to enable continued operations within the body for long span. Further, exchanging data and controlling internal devices from outside the body will require injecting several to tens of devices in the body and, when considering the density of people inside a train, massive simultaneous connectivity will be required for communication with several millions to tens of millions of devices. In addition, connecting cameras and devices in the body will require zero-touch, autonomous collaboration between devices.
- The entertainment industry is expected to further change people's lifestyles and drive progress in the future. In association with device and telecommunication technology evolution, a range of new service experiences will be provided one-after-another. (see section 4.14.2). In particular, by providing an ultimate immersive experience and sense of unity that fully stimulates the five senses, it is expected to be possible to create experience value that has never been experienced before and provide applications that surprise and impress people. Initiatives to realize this ultimate immersive experience have recently trained the spotlight on technologies like volumetric video, which can transmit an entire space using ultra-high image quality. In volumetric video, the real world can be converted into three-dimensional digital data by capturing an entire real-world space, which enables a user to interact with the content by moving their viewpoint freely. At the same time, by interacting in the virtual and real spaces in real time, for example, in a remote live event use cases such as live music and watching sports, it is expected that the ultimate sense of presence will be provided for users. In such a use case, as a performance requirement for Beyond 5G communication, large capacity communication at a raw data rate of about 48 -200 Gbps and a low delay time, such as MTP (Motion To Photon) 10 msec and TTP (Time To Present) 70 msec, are required for end-to-end communication. It is also necessary to realize these high-speed, large-capacity and low-delay communications

requirements simultaneously. In terms of communication delivery coverage, in the early stages of the network deployment, coverage will be limited to local areas with relatively static environments such as inside buildings. However, along with the further development of the wireless communication infrastructure, the network deployment is expected to expand in order to support wider area for example mobility uses case such as high-speed trains and airplanes.

- The following use cases are anticipated in the space industry as discussed in section 4.15.1.
    - Protecting life on Earth from space

      Activities aimed at observation of the world in real time at high frequency and high resolution (e.g., observation by orbital satellites such as small observation satellites fabricated by university laboratories and companies, observation by sensors mounted in HAPS in the stratosphere, observation by balloons and aircraft, observation by various IoT sensors located on the ground and at sea, and observation by ground radars, etc.) are gaining ground. Previously, the collected observation data were transmitted to the ground for processing analysis. However, there will be a need to increase the frequency of data collection and transfer, along with the frequency of data processing analysis and prediction processing from once a day to once every few hours by linking the AI and storage systems on-board the NTN platform in space (e.g., fully digital satellites on geostationary orbit) with the terrestrial cloud. Furthermore, it will also be necessary to combine multiple observation data to achieve high accuracy and carry out pinpoint analysis and prediction.

      For example, carry out (1) prediction of abnormal weather phenomena such as linear precipitation zones and torrential rains, (2) observation and prediction of arrival of tsunamis caused by earthquakes, and (3) prediction of land and sea disasters due to volcanic eruptions such as pyroclastic flow, volcanic plume, and ash fall. Data from these predictions and observations will then be used to provide detailed and timely evacuation recommendations and alert information via ground mobile networks to relevant areas, people, and objects.

      In addition to predicting these meteorological and disaster conditions, extensive use of various real-time, high-frequency, and high-resolution observation data will enable routinely providing customized predictions specific to regions, locations, and industries, as well as instruction and control information based on those predictions.

      The capabilities required for the above use cases are as follows.

        - Ultra-fast and large capacity: For stationary satellite feeder links, which require greater capacity and speed, fully digital satellites, namely, HTS (around 2025) will require tens to hundreds of Gbps, and VHTS (around 2030) will require hundreds of Gbps to several Tbps. On the other hand, communication capacity of a few tens of Gbps will be required for the service link per satellite in low and medium orbits.

- Ultra-low power consumption: Operation with solar cells
- Ultra-security, resiliency and reliability: Enable rerouting (redundancy) using nodes or combinations of different NTNs for resilience to impacts of ground disasters and space debris in low orbits (geostationary satellites).
- Autonomy: Autonomous operation of NTN during normal satellite operation
- Scalability: Enable integration functions with other NTN nodes and other stand-alone sensor networks using fully digital satellites.

➢ Use for space activities (Space debris)

Use of Beyond 5G is anticipated for countering the increase of space debris—the most challenging issue in space environment conservation. Results of experiments to detect debris and other obstacles flying at high speeds beyond 8 km/sec using ground radars/in-orbit surveillance indicate that by accurately predicting the trajectory of obstacles in cyberspace and immediately notifying spacecraft in danger of collision, spacecraft can efficiently and effectively orbit while avoiding collisions.

The capabilities required for the above use cases are as follows.

- Ultra-fast and large capacity: High-speed communication of a wide variety of information, including observation results and estimated trajectories
- Ultra-low latency: Information propagation to space aircraft, which instantaneously orbit over a wide area
- Ultra-massive connectivity: Interconnection of large numbers of spacecraft
- Ultra-security, resiliency and reliability: Ensure communication of information to avoid serious damage

➢ Utilization for space activities (Lunar and planetary exploration)

Planetary exploration will require robust communications, for example, with spacecraft near Mars, which is more than 56 million km away (up to 40 minutes round-trip propagation time). In addition, unlike repairable terrestrial communications infrastructure, there will be a need for communications that enable high reliability and autonomous operations. Also, increasing the speed of communications from long distances, which is currently at most a few tens of kbps, will contribute to mission execution and scientific achievements.

In-situ resource utilization (ISRU) is an example of future sustainable activities on the moon, which is 38,000 km away (round-trip propagation time of approximately 3 seconds). For example, local production for local consumption can be implemented for building structures by using the “lunar regolith” found on the moon surface as building materials. Use of Beyond 5G is anticipated not only to achieve high-capacity communications, but also to reduce power consumption and increase communication reliability for storing data and processing computations in space and for leveraging digital twin and robotic technologies, which are needed in performing all the above operations remotely and automatically under the harsh environment of the moon.

The capabilities required for the above use cases are as follows.

- Ultra-low power consumption: Capability needed by lunar and planetary exploration probes with extremely limited on-board resources
- Ultra-security, resiliency and reliability: Capability needed by space probes that are not amenable to repair
- Autonomy: Capability needed for autonomous operations during emergencies for ultra-long-distance communications and during eclipses (probes are not visible)
- Scalability: Capability needed for expansion to the moon and Mars, and for ultra-long-distance communications during navigation

- The HAPS industry aims to create a world where the Internet can be delivered to all people in all places, including rural areas, air, sea, and other places where deployment of conventional ground base stations is not possible. It also aims to build disaster-resilient infrastructures that will support rescue and recovery efforts in the event of natural disasters (see section 4.15.2). In order to achieve this, it will be necessary to provide ultra-wide-coverage communications from high altitudes. Thus, the capability to cover areas with tens to hundreds of kilometers in radius and a few kilometers above the ground through the base station mounted on one HAPS will be required for Beyond 5G.
- With regard to the social issues discussed in section 4.15.3, it will be necessary to predict and detect natural disasters and implement evacuation instructions in order to protect people's lives and property from natural disasters such as earthquakes, volcanic eruptions, storm and flood damage, which are common in Japan. In the Beyond 5G era, there is anticipation for use cases enabling delivery of evacuation instructions simultaneously and in accordance with the situation of each individual. Individual situation here refers to unique individual attributes such as age, gender, disability, and cultural background; to three-dimensional positional information such as whether one is outdoor, indoor, or underground, or what floor the person is in; and to state of activity such as whether one is at work or driving. From these use cases, capability for “connected anywhere”, including remote areas such as mountains and seas, will be required for Beyond 5G. Achieving both capabilities for scalability to receive evacuation instructions even on future means of transportation that travel at a speed of 1,000 km/h, and transmission speed of 10 Mbps or higher so that evacuation

instructions can be delivered via images and voice in various situations will also be required for Beyond 5G.

The following table summarizes the capability requirements of each industry.

Table 5.1-1 Capabilities required by each industry

Category	Requirements	Capabilities required by each industry
Quantitative requirements	Ultra-fast and large capacity	- Throughput of 10 to 100 Gbps (Uncompressed transmission for holographic communications (Media)) - 50 Gbps (Remote monitoring and remote control (Automotive)) - 10 to 100 Gbps (Smart logistics (Retail and wholesale distribution)) - Several tens of Gbps (Remote surgery (Healthcare)) - 48 to 200 Gbps (Volumetric video) - Several tens of Gbps (Low to medium orbit (Space)) - 10 Mbps (Natural disaster prevention measures (Society))
	Ultra-low latency	- Order of milliseconds* within the local network (Fully automatic operation of logistics facilities (Warehousing and logistics)) - Several milliseconds* (Emergency stops for super-high-speed trains (Railway)) - 100 msec* (Immersive remote-control system (Energy resources)) - 1 msec (Remote monitoring and remote control (Automotive)) - 100 micro sec* for local communications (Motion control (Machinery)) - 1 msec* (Robot remote control (Semiconductor)) - Motion-to-photon (MTP) 10 msec*, time-to-present (TTP) 70 msec* (Volumetric video) * Including processing delay at application layers
	Time synchronization accuracy	- Time synchronization compatible with Precision Time Protocol (PTP) for the accuracy of internal clocks, including radio segments, (in microseconds) (Fully automatic operation of logistics facilities (Warehouse and logistics)).
	Ultra-security, resiliency and reliability	- 10^{-6} (Remote monitoring and remote control (Automotive)) - 10^{-7} (Remote surgery (Healthcare)) (unit: block error rate)

Category	Requirements	Capabilities required by each industry
	Positioning and sensing	- Positioning accuracy of 1 to 2 cm (Civil engineering (Construction and real estate)) - Centimeter-level sensing accuracy (Vehicles traveling singly in rural areas or at night (Automobile))
	Ultra-massive connectivity	- Several millions to tens of millions of devices/ km^2 (In-vivo devices (Healthcare))
	Universal coverage	- Supersonic passenger aircraft flying at higher altitudes than current passenger aircraft, which is around 10 km, and coverage area at an altitude of more than 100 km in outer space (Aircraft) - 100% land coverage (Telecommunications and IT) - Coverage area in outer space and the moon (Space) - One HAPS aircraft covers tens to hundreds of kilometers in radius and a few kilometers above the ground (HAPS)
Qualitative requirements	Ultra-security, resiliency and reliability	- Advanced security services, highly secure networks (Finance / Healthcare) - Application of quantum cryptographic communications on the air interface (Automotive) - Resilience, redundancy and complementarity against disasters and terrorism / crime (Warehousing and Logistics)
	Autonomy	- Autonomous optimization and future prediction functions that enable the provision of the necessary goods and services to the people who need them, when and where they need them (Telecommunications and IT industries) - Enhanced autonomy of different devices and universal compatibility for connection and operation (Electronics and precision electronics) - Automatic device connection with zero touch (In-vivo devices, camera collaboration (Healthcare))
	Ultra-low power consumption	- Use of lunar and planetary exploration probes with extremely limited on-board resources (Space)
	Others	- Distributed learning and inference functions (Processing using multiple vehicles and Beyond 5G base stations (Automobile)) - Inter-device interfaces, open APIs and open interfaces between non-communication systems, and common platforms for data analysis/ processing and content handling (Device collaboration (Electronics and precision electronics))

Category	Requirements	Capabilities required by each industry
		- Evacuation instructions can be received even when traveling at a speed of 1,000 km/h (Natural disaster prevention measures (Society)) - NTN nodes can automatically connect to other NTN nodes and local sensor networks (Space) - Mesh networks that do not go through on-ground systems can be built through single NTN nodes or in combination with other NTN nodes (Space)

5.2 Conceptual figure of Beyond 5G and usage scenarios

5.2.1 Contents of proposals from this white paper

5G (or IMT 2020) is represented as the triangle with three usage scenarios i.e. eMBB, URLLC, and mMTC at the three vertexes. Beyond 5G or "IMT for 2030 and beyond" will evolve from 5G while add new usage scenarios. This white paper proposes a conceptual figure of Beyond 5G with six usage scenarios as shown in Figure 5.2-1.

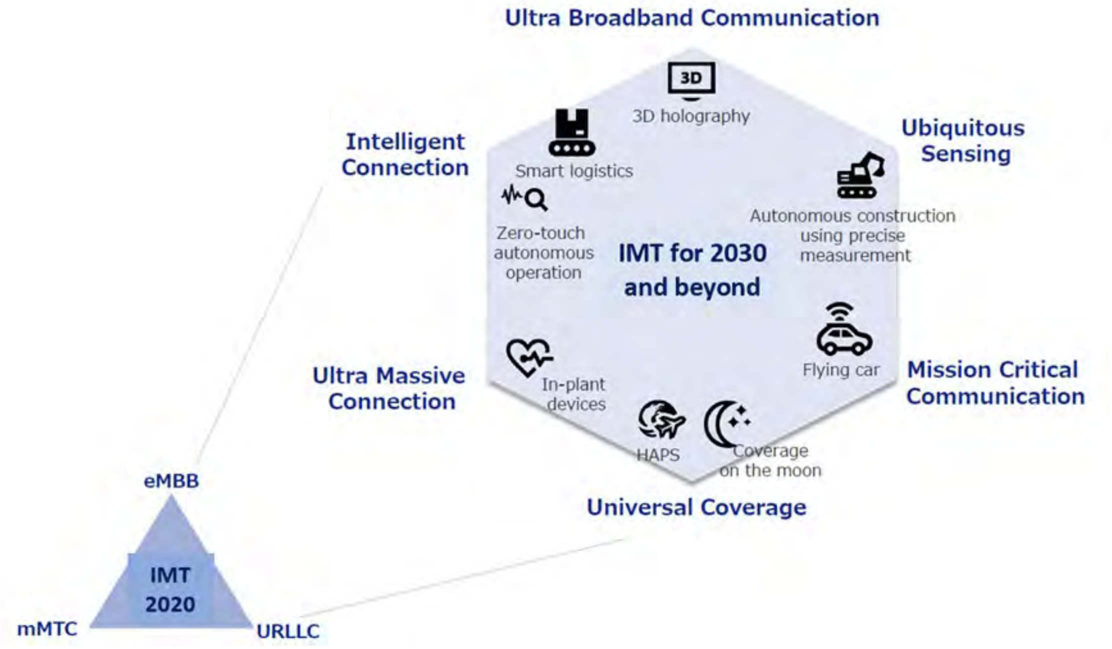

Figure 5.2-1 Conceptual figure of Beyond 5G

Usage scenarios shown in the vertex of the hexagon in Figure 5.2-1 are explained as follows.

Ultra Broadband Communication

This usage scenario extends the eMBB scenario of 5G. Typical applications are such as immersive XR (eXtended Reality) and holographic communications. The scenario will require extremely high data rates, as well as lower latency and larger system capacity. It covers deployments not only for dense urban but also for some rural areas.

Ubiquitous Sensing

This usage scenario refers to the technologies that integrate sensing with communication systems to realize ubiquitous sensing and receiving of those sensed data. Typical usages are, for example, advanced localization, positioning, posture/gesture recognition, tracking, imaging, and mapping, which could be applied to the use-cases such as automatic construction, warehouse management, and automated driving. This usage scenario facilitates interactions between virtual and physical worlds.

Mission Critical Communication

This usage scenario applies to the use cases requiring very stringent transmission reliability and latency characteristics by extending URLLC of 5G. Typical use cases include full automation, remote control, remote operation, robotics collaboration, autonomous driving, and remote medical surgery, etc. These use cases are characterized by the situations where failure or unstableness of the communication service could lead to severe consequences for the applications, including safety-related applications.

Universal Coverage

This scenario intends to provide universal coverage enabling mobile broadband and wide range services everywhere on the ground, including in rural and remote areas as well as in the airspace and over water. Typical use cases are supposed to provide mobile broadband service everywhere people live and to connect promising aerial applications such as UAV and flying cars. This usage scenario requires the interworking between the terrestrial networks and non-terrestrial networks, such as HAPS and satellites. This scenario can also support the rescue and recovery efforts of communication in the event of natural disasters as disaster-resilient infrastructures.

Ultra Massive Connection

This usage scenario extends the scenario of mMTC of 5G. Typical applications include reading dispersed meters, monitoring environmental conditions, and also the applications connecting massive amount of wearable devices, electronic devices or sensors with sporadic traffic in daily life. This usage scenario may also include supporting the massive simultaneous connectivity.

Intelligent Connection

This usage scenario is characterized by incorporating AI-Native functions into Beyond-5G networks and supports AI-powered applications in conjunction with the in-device and in-network AI capabilities. It will leverage local computing offload, distributed learning/inference, and training of AI models, which are performed jointly with a large number of intelligent agents in the network. Typical applications are such as training and inference for collaborative robots, distributed learning and inference for automated driving, and autonomous collaboration between devices with zero-touch capabilities. Another important aspect of this usage scenario is to use AI/ML tools to optimize Beyond 5G systems in all network layers to improve the performance and efficiency on air-interface and network itself.

5.2.2 Comparison with ITU-R Recommendation

This section summarizes a comparison between the proposed content outlined in Section 5.2.1 and the contents of the so-called “Framework Recommendation” for IMT for 2030 and beyond (hereinafter referred to as "IMT-2030") approved in November 2023 at ITU-R [1].

Figure 5.2-1 was proposed to ITU-R Working Party 5D (WP5D) on behalf of Japan. As well as proposals from other countries, ITU-R WP5D adopted contents in Section 5.2.1 and compiled them as "usage scenarios for IMT-2030 and design principles required for all usage scenarios," as shown in the figure below [1].

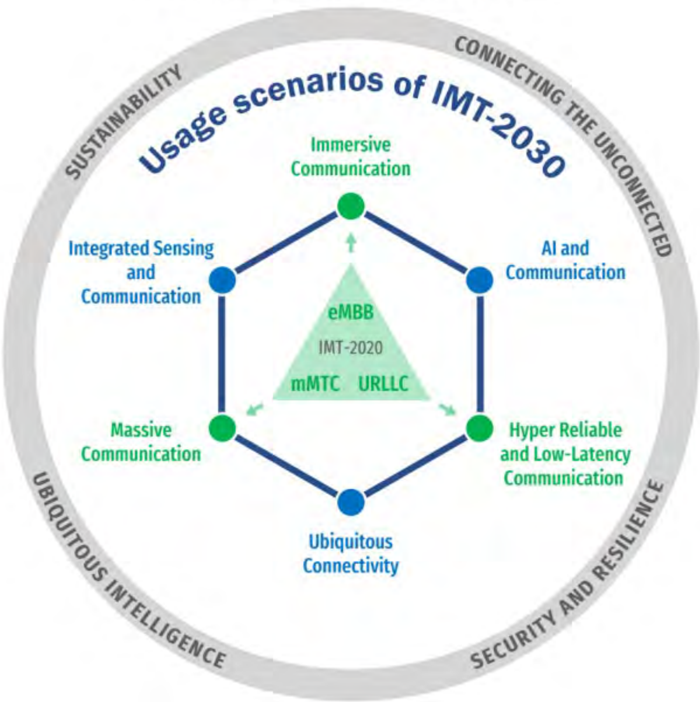

Figure 5.2-2 Conceptual figure of IMT-2030 defined in ITU-R Recommendation [1]

From the comparison between the two figures, it is observed that the following aspects of Figure 5.2-1 are reflected into Figure 5.2-2.

(1) IMT-2030 is an evolution of IMT-2020

(2) Representation in a hexagonal shape

(3) Utilization scenarios at the vertices of the hexagon (with different terminologies)

The correspondence of the terms listed at the vertices of the two hexagons is shown in the figure below.

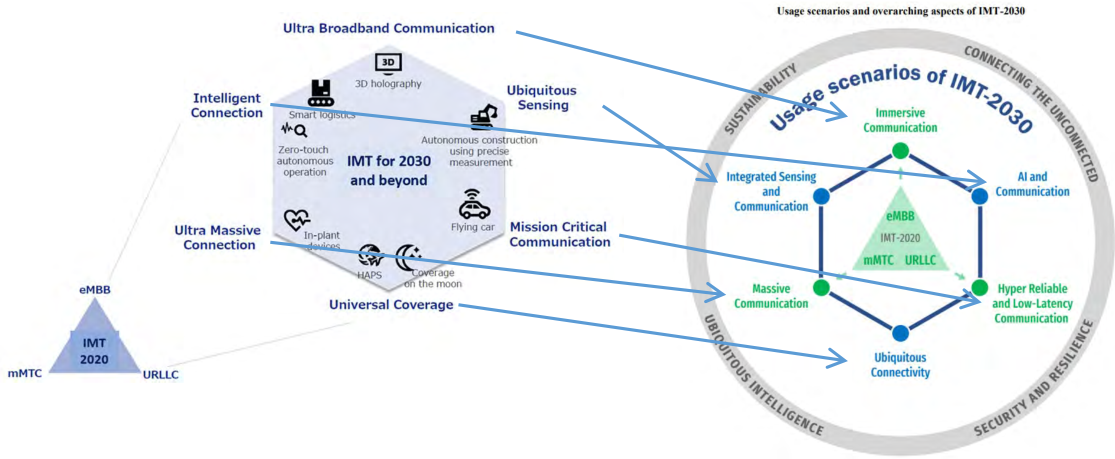

Figure 5.2-3 Correspondence of usage scenarios between Figures 5.2-1 and 5.2-2

It is noted that the contents of the "Qualitative requirements" in Table 5.1-1 are also adopted in the design principles referred to as "Overarching aspects" described on the circle covering the hexagon in Figure 5.2-2.

REFERENCES

[1] International Telecommunication Union, Recommendation ITU-R M.2160-0, “Framework and overall objectives of the future development of IMT for 2030 and beyond,” (Nov. 2023).

5.3 Target Key Performance Indicators

5.3.1 Key features for Beyond 5G in the Beyond 5G Promotion Strategy

The Beyond 5G Promotion Strategy [1] was announced by the Ministry of Internal Affairs and Communications of Japan in June 2020 in response to the recommendations from the "Beyond 5G Promotion Strategy Roundtable" [2]. The recommendation states that "the desired Beyond 5G model will need to incorporate four new functions in addition to further enhancements of the specific features of 5G", and it includes a chart of key features for Beyond 5G as shown in Figure 5.3-1.

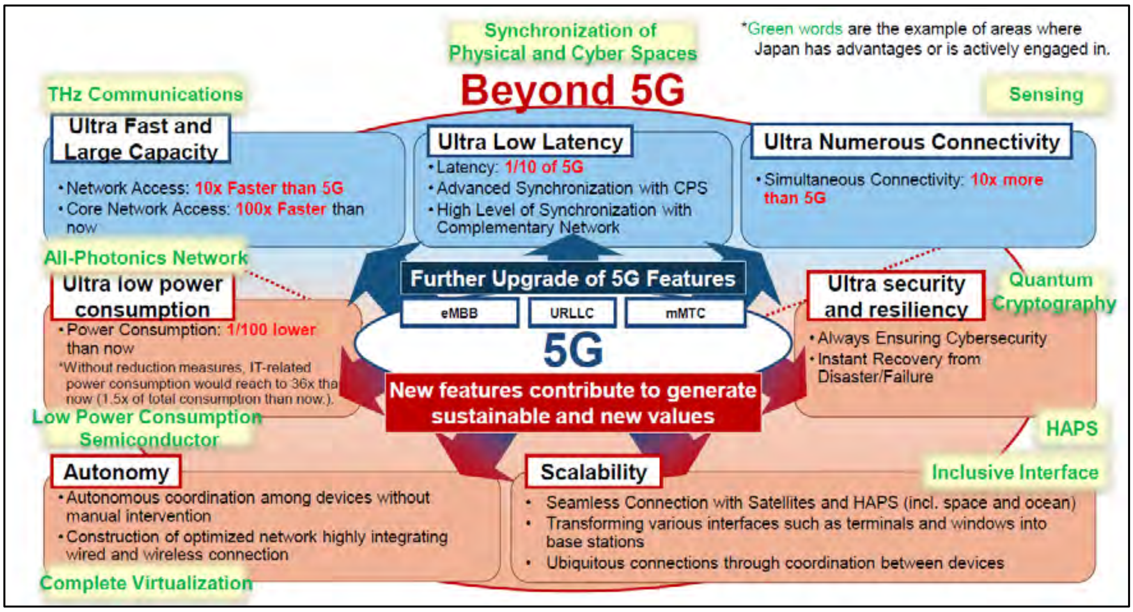

Figure 5.3-1 Key Features for Beyond 5G [2]

The recommendation points to several areas of investigation for the key features as follows.

(1) Further enhancement of specific 5G features

First of all, enhancing 5G's specific features, and thereby providing additional features, such as ultra-fast and large capacity, ultra-low latency, and ultra-numerous connectivity, will make it possible to process massive amounts of data from any location instantly and accurately.

In light of the expected data processing volumes and the number of communication devices that are expected to be deployed in the 2030s, the target for access speed and the number of simultaneous connections should be 10 times higher than that of 5G. The throughput in Beyond 5G's core network should be 100 times higher than at present. In addition, in order to realize the completely synchronized CPS (cyber-physical systems) mentioned above, 1/10th of 5G's latency and a high level of synchronization of the network that supplements it will be required.

(2) New required features

In addition to these continuous evolutions from 5G, Beyond 5G should have the following new features.

*• **Autonomy**: A feature that instantly builds optimal networks that meet the needs of users, regardless of whether the connection is wired or wireless, by utilizing AI technologies, and where all devices autonomously coordinate without the need for human intervention (zero-touch).*

*• **Scalability**: A feature that allows terminals and base stations to connect seamlessly with different communication systems such as satellites and High Altitude Platform Station (HAPS), and also allows terminals, glass (such as windows), and other various interfaces to become base stations (ubiquitous base stations). This feature will allow communications to be used anywhere, including at sea, in the air, and in space, while enabling devices everywhere to work together.*

*• **Ultra-security and resiliency**: A feature that enables guarantee of security and privacy, without users even being aware of them, and services remain connected and instantly restore even when there is a disaster or failure.*

*• **Ultra-low power consumption:** It is calculated that without the development of low power technologies the IT related power consumption in 2030 will have increased to 36 times as much as in 2016 (which would itself be 1.5 times the total of current energy consumption) 1 . In order to cope with this large increase in power consumption it will be necessary to reduce consumption to one per cent of what it is now.*

(Excerpted from "Beyond 5G Promotion Strategy Roundtable Recommendations" [2])

5.3.2 Consideration of Target Key Performance Indicators for Beyond 5G

The above consideration of the key features of Beyond 5G is consistent with the results of communication traffic trends investigation in Chapter 2 and the market expectations described in Chapter 3, 4, and section 5.1. To address these key features, Target Key Performance Indicators (Target KPIs) for Beyond 5G have been derived as shown in Figure 5.3-2 and Figure 5.3-3 respectively[7] [8].

It should be noted that each target KPI is applicable to a specific part of Beyond 5G communication systems. For instance, the minimum transmission delay will be defined as one-way user data transfer time between an application layer of a user equipment and

7 Some of the target KPIs have been reviewed and updated based on further studies took place since the publication of the White Paper 1.0.

8 "Seamless connection between satellites and HAPS," which is one of the items of "scalability" in Figure 5.3-3, is indexed as an extension of the classification of "Area Coverage" in the quantitative index axis in FIG. 5.3-2, i.e. an extension from "Terrestrial" to "Terrestrial + Maritime + Aeronautical + Space".

corresponding peer application layer located at an edge node that gives the shortest transfer path (See Figure 5.3-4). The target KPIs were considered to provide the necessary and sufficient functionality and performance to serve the above market requirements described in Section 5.1, however further study would be needed to define the details. Therefore the technology trends and feasibility related to these KPIs described in Chapter 6 would need to be further comprehensively examined in the future.

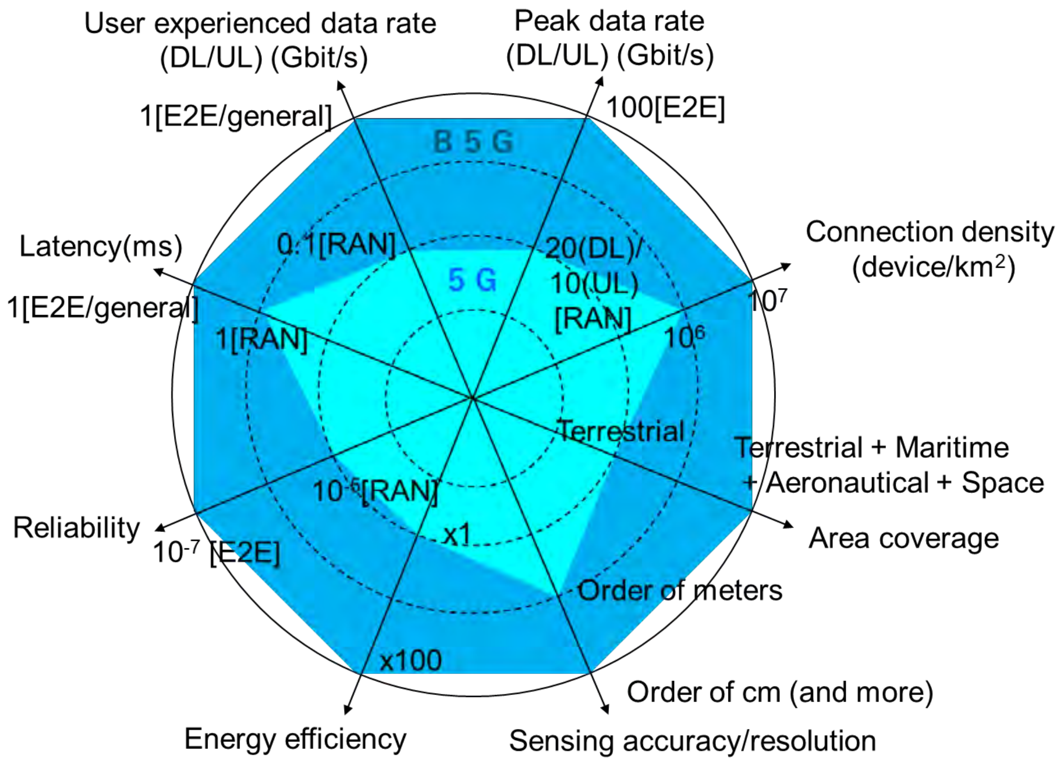

Figure 5.3-2 Target KPIs for Beyond 5G (Quantitative indicators)

Sustainability	Trustworthy / Security / Robustness	Autonomy	Scalability
• Reduce the environmental impact of equipment (use of environmentally friendly materials, improved reusability) • Equipment longevity (software extensibility and modular structure of HW) • Carbon neutrality (use of renewable power sources)	• Cryptographic processing speeds exceeding the peak data rate • Security measures for quantum cryptography/computing • Instantaneous recovery from disasters and failures	• Zero-touch, autonomous coordination of communication devices, computing resources, AI, and sensors to build optimal communication infrastructure. • Achieve full automation that simultaneously satisfies labor-saving, flexibility, and speed in all workflows, from construction to operation	• Seamless connections with satellites and HAPS • Communications within buildings (Via Terminals, windows, etc. as base stations) • Open interfaces (Network API, application API) • Network sensing/Wireless sensing

Figure 5.3-3 Target KPIs for Beyond 5G (Qualitative indicators)

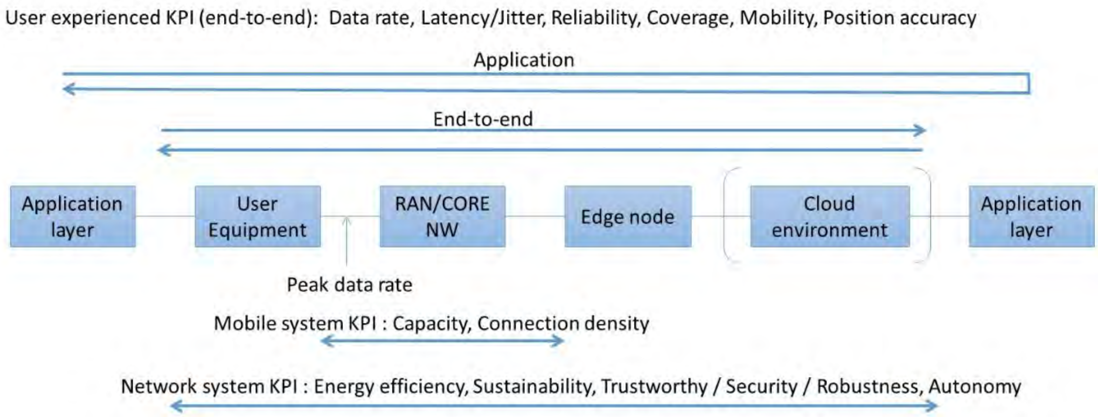

Figure 5.3-4 Scope of the target KPIs

5.3.3 Comparison with ITU-R Recommendation

This section summarizes a comparison between the proposed target KPIs in Section 5.3.2 and the contents of the so-called "Framework Recommendation" for IMT for 2030 and beyond (hereinafter referred to as "IMT-2030") approved in November 2023 at ITU-R [3].

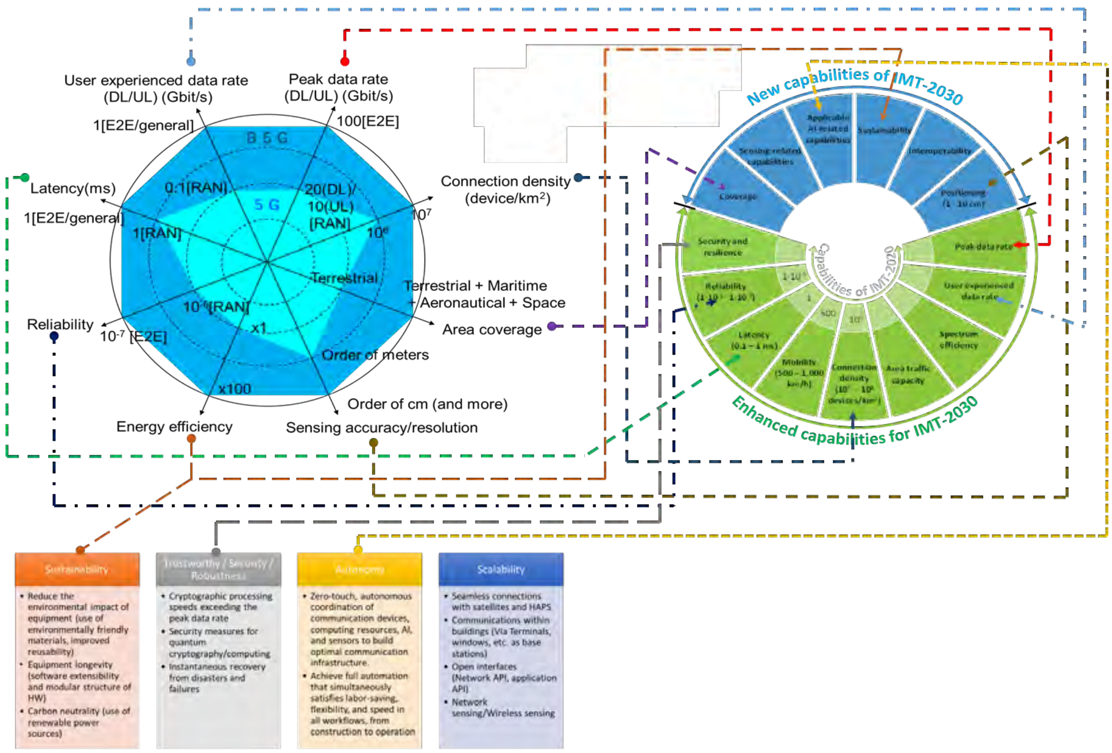

Figure 5.3-5 Correspondence between the target KPIs (left) and IMT-2030 (right)

Figure 5.3-5 shows the correspondence between the target KPIs described in Section 5.3.2 and the capabilities described in the IMT-2030 Framework. All items proposed in Section 5.3.2 except for "scalability" are reflected in the IMT-2030 Framework, and five items are newly described in the IMT-2030 Framework. Table 5.3-1 shows the detailed comparison between the target KPIs and IMT-2030 Framework. The major difference is that this white paper sets quantitative targets for end-to-end, as shown in Figure 5.3-4, but the IMT-2030 Framework targets the air interface.

Table 5.3-1 Detailed comparison between the target KPIs (left) and IMT-2030 (right)

B5GPC White paper		**IMT-2030 Framework**	
Peak data rate (DL/UL, E2E)	100Gbps (E2E)	Peak data rate (under ideal condition per device)	Greater than IMT-2020 (e.g. 50, 100, 200 Gbps)
User experienced data rate (E2E/general)	1Gbps (E2E/general)	User experienced data rate (across the coverage area per device)	Greater than IMT-2020 (e.g. 300Mbps, 500Mbps)
Latency (msec, E2E/general)	1ms (E2E/general)	Latency (over the air interface)	0.1 – 1 ms
Reliability (E2E)	10^{-7} (E2E)	Reliability (over the air interface)	from $1\text{-}10^{-5}$ to $1\text{-}10^{-7}$
Sensing accuracy/resolution	Order of cm (and more)	Positioning (difference between the calculated and the actual horizontal/vertical position of a device)	1 – 10 cm
Connection density (device/km^2)	10^7 devices/km^2	Connection density (Total number of connected and/or accessible devices per unit area)	$10^6 – 10^8$ devices/km^2
Area coverage	Terrestrial + Maritime + Aeronautical + Space	Coverage (the cell edge distance of a single cell through link budget analysis)	-
-	-	Spectrum efficiency (average data throughput per unit of spectrum resource and per cell)	Greater than IMT-2020. (e.g. x1.5 x3 greater that that of IMT-2020)
-	-	Area traffic capacity (Total traffic throughput served per geographic area)	Greater than IMT-2020. (e.g. 30 Mbit/s/m^2 and 50 Mbit/s/m^2)
-	-	Mobility (Maximum speed, at which a defined QoS and seamless transfer between radio nodes which may belong to different layers and/or radio access technologies (multi-layer/multi-RAT)	500 – 1 000 km/h

B5GPC White paper		IMT-2030 Framework	
-	-	Sensing-related capabilities (range/velocity/angle estimation, object detection, localization, imaging, mapping, etc.)	Could be measured in terms of accuracy, resolution, detection rate, false alarm rate, etc.
Energy efficiency	x100	Sustainability - Energy efficiency (quantifiable metric of sustainability. It refers to the quantity of information bits transmitted or received, per unit of energy consumption (in bit/Joule) - Environmental sustainability (the ability of both the network and devices to minimize greenhouse gas emissions and other environmental impacts throughout their life cycle)	Important factors include improving energy efficiency, minimizing energy consumption and the use of resources (e.g. optimizing for equipment longevity, repair, reuse and recycling)
Sustainability	- Reduce the environmental impact of equipment (use of environmentally friendly materials, improved reusability) - Equipment longevity (software extensibility and modular structure of HW) - Carbon neutrality (use of renewable power sources)		
Trustworthy /Security/ Robustness	- Cryptographic processing speeds exceeding the peak data rate - Security measures for quantum cryptography /computing - Instantaneous recovery from disasters and failures	Security and resilience	- Security refers to preservation of confidentiality, integrity, and availability of information, such as user data and signalling, and protection of networks, devices and systems against cyberattacks such as hacking, distributed denial of service, man in the middle attacks, etc. - Resilience refers to capabilities of the networks and systems to continue operating correctly during and after a natural or man-made disturbance, such as the loss of primary source of power, etc.

B5GPC White paper		IMT-2030 Framework	
Autonomy	- Zero-touch, autonomous coordination of communication devices, computing resources, AI, and sensors to build optimal communication infrastructure - Achieve full automation that simultaneously satisfies labor-saving, flexibility, and sopped in all workflows, from construction to operation	Applicable AI-related capabilities (the ability to provide certain functionalities throughout IMT-2030 to support AI enabled applications.)	include distributed data processing, distributed learning, AI computing, AI model execution and AI model inference, etc.
Scalability	- Seamless connections with satellites and HAPS - Communications within buildings (via Terminals, windows, etc. as base stations) - Open interfaces (Network API, application API) - Network sensing /wireless sensing	-	-
-	-	Interoperability (radio interface)	-

REFERENCES

[1] “Release of “Beyond 5G Promotion Strategy—Roadmap towards 6G—”, Ministry of Internal Affairs and Communications, Japan, (June 30, 2020).

[2] “Beyond 5G Promotion Strategy Roundtable Recommendations”, Beyond 5G Promotion Strategy Roundtable (June 2020).

[3] International Telecommunication Union, Recommendation ITU-R M.2160-0, “Framework and overall objectives of the future development of IMT for 2030 and beyond,” (Nov. 2023).

Appendix Example of decomposition analysis of "Reliability" into RAN and CN

When "Reliability", which is one of the target KPIs shown in Figure 5.3-2 is set as "End-to-End packet transmission error probability (PBLER) < 10^{-7}", the results of a simple examination of the transmission quality required for the wireless and wired transmission sections constituting the transmission system are attached below as reference information.

In the configuration shown in Figure 5.3-4, the transmission system under consideration assumes a configuration in which the application layer in the right side is directly connected to the edge node without using the cloud.

Figure 5.3-6 shows the examination model for transmitting packets in the uplink direction (from the application layer on the User Equipment to the other application layer implemented on the Edge node). The analysis is carried out on the premise of simple one-way transmission without assuming retransmission control in the radio access part.

Data transmitted from the application layer on the User Equipment side is divided into packets of N_{RAN} bytes and transmitted to the RAN node by the wireless transmission link. The success probability of each packet transmission is $1\text{-}P_{BLER\_RAN}$. Packets correctly received by the RAN node are concatenated for each $N_{OPT/RAN}$ and conform packets of N_{OPT} bytes, transmitted to the CORE network node via the wired transmission line with a transmission success probability of $1\text{-}P_{BLER\_OPT}$, and transferred to the application layer on the opposite side via the Edge node.

Hereinafter, assuming that the transmission packet length of the wireless transmission part (between the user Equipment and RAN) is 32 bytes or 400 bytes (N_{RAN}) and the transmission packet length of the wired transmission part (between RAN and CORE network) is 1500 bytes (N_{OPT}), and that wired transmission is performed via optical fiber lines having an average bit error rate (P_{BER_OPT}) of 1×10^{-9} to 1×10^{13} in the wired transmission part, the results of deriving required transmission quality of packet transmission (P_{BLER_RAN}) for transmission in the wireless part are shown.

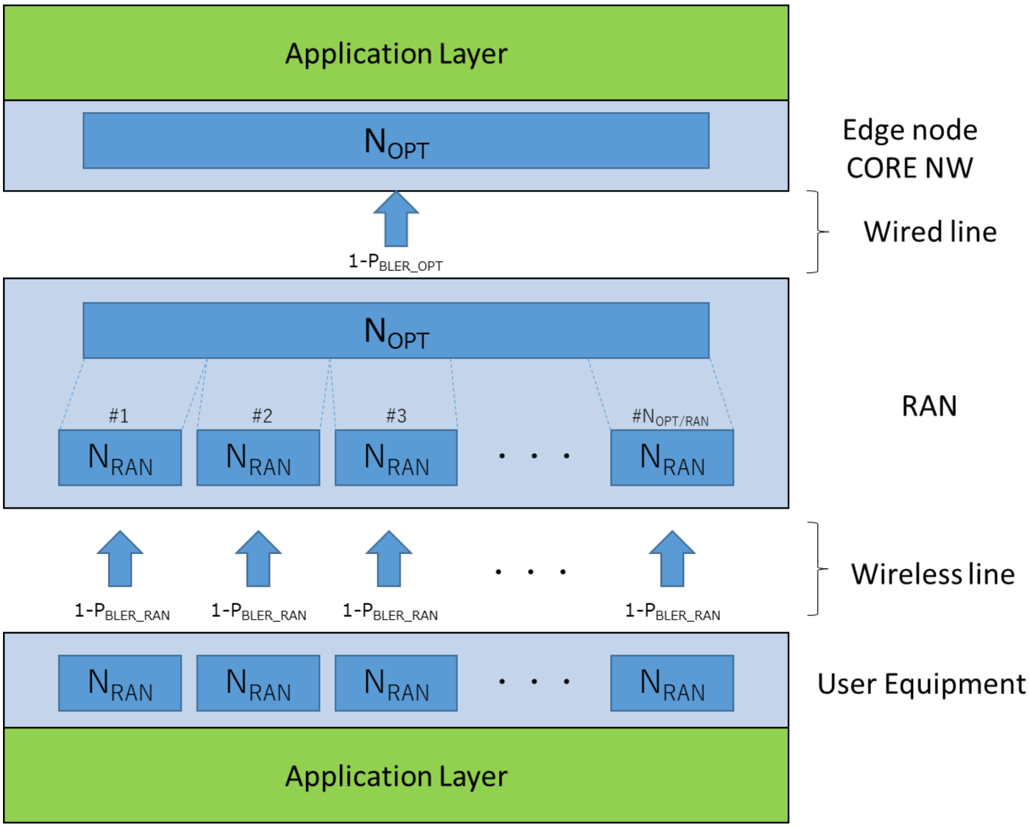

Figure 5.3-6 An examination model for End-to-End transmission

The packet transmission success probability $1-P_{BLER\_OPT}$ of the wired transmission part is given by the following formula from the transmission bit error rate P_{BER_OPT} in the transmission path.

$$1 - P_{BLER\_OPT} = (1 - P_{BER\_OPT})^{N_{OPT}}$$

In order to obtain the target End-to-End packet transmission success probability P_{BLER} when P_{BER_OPT} is given, the transmission success probability $1-P_{BER\_RAN}$ of the radio section must satisfy the following relationship.

$$(1 - P_{BLER\_RAN})^{N_{OPT/RAN}} \geq \frac{1-P_{BLER}}{1-P_{BLER\_OPT}} \ ,$$

where

$$N_{OPT/RAN} = \left\lceil \frac{N_{OPT}}{N_{RAN}} \right\rceil .$$

Table 5.3-2 shows the result of obtaining the required P_{BLER_RAN} by these equations with N_{OPT} = 1500 and $P_{BLER} = 1 \times 10^{-7}$. In order to achieve an End-to-End packet transmission success probability of $1 - 10^{-7}$ or higher, the bit transmission error rate of the wired transmission part must be 1×10^{-12} or less, and under such conditions, the packet transmission failure probability of the wireless line P_{BLER_RAN} must be lower than 1.9 × 10^{-9} to 3.3 × 10^{-9}, depending on the wireless packet length (N_{RAN}).

Table 5.3-2 Example of End-to-End Packet Transmission Quality and Wired and Wireless Transmission Quality analysis

N_{RAN}	P_{BLER_RAN}	1-P_{BLER_RAN}	$N_{OPT/RAN}$	P_{BER_OPT}	P_{BLER_OPT}	1-P_{BLER}
32	N/A	N/A	46	1×10^{-9}	99.9988%	99.99999%
32	N/A	N/A	46	1×10^{-10}	99.99988%	99.99999%
32	N/A	N/A	46	1×10^{-11}	99.999988%	99.99999%
32	1.9×10^{-9}	99.99999981%	46	1×10^{-12}	99.9999988%	99.99999%
32	2.1×10^{-9}	99.99999979%	46	1×10^{-13}	99.99999988%	99.99999%
400	N/A	N/A	3	1×10^{-9}	99.9988%	99.99999%
400	N/A	N/A	3	1×10^{-10}	99.99988%	99.99999%
400	N/A	N/A	3	1×10^{-11}	99.999988%	99.99999%
400	2.9×10^{-8}	99.9999971%	3	1×10^{-12}	99.9999988%	99.99999%
400	3.3×10^{-8}	99.9999967%	3	1×10^{-13}	99.99999988%	99.99999%

6. TECHNOLOGY TRENDS

6. Technology trends

This chapter starts with an overview of the market demands and notable technology trends as the big picture of technology trends in Section 6.1, followed by a description of the End-to-End architecture for Beyond 5G in Section 6.2. In the End-to-End architecture, characteristic elements such as digital twins, Beyond 5G infrastructure, and orchestrator are explained, along with their value proposition and enabling technologies. From Section 6.3 onwards, individual technology trends are described, such as frequency-related technologies, system platform and applications, trust assurance technologies, network energy efficiency improvement, network coverage expansion by non-terrestrial networks (NTN), and wireless and optical communication technologies. In this paper, the overall technology trends for Beyond 5G are described as comprehensively as possible. In addition, for the particularly important technology topics, supplementary volumes are issued for each technology topic. As of now, the following eight papers have been published as the outcomes of the Beyond 5G Promotion Consortium (https://b5g.jp/output/). These supplementary volumes are issued only in English, from the perspective of disseminating our strong technologies of the B5G Promotion Consortium members to the world.

- Cell-Free / Distributed MIMO
- Radio Technologies for higher frequency
- E2E Architecture
- Sustainability and Energy Efficiency
- NTN Technologies
- Relay and Reflector Technologies
- AI/ML Technologies
- Sensing Technologies

6.1 Technology trends towards Beyond 5G

As mentioned in the previous chapters, various efforts are being made to develop technologies for Beyond 5G in order to meet the market demands and expectations for the 2030s and to contribute to the achievement of the target KPIs described in section 5.3. Before going into the role of these technologies and their implications in section 6.4-6.8, we describe an overview of market demand and deployment below, and also touch upon the perspective of Global Commons.

Overview of AI/ML technologies, sensing technologies, and trustworthiness technologies are also outlined.

6.1.1 Market demands

As the roles and expectations of information and communications systems as a social infrastructure have expanded, the required values have subsequently transformed into something more universal. The concept of an inclusive, sustainable, and dependable society that Beyond 5G consortium is advocating toward the 2030s [1] was, therefore, examined in consideration of these market demands and trends.

Realizing the society that embodies these ideas entails functions and features that satisfy the target key performance indicators to support the foreseen use cases, as well as the technologies and features to be implemented in those use cases. Since technical breakthroughs will also be required to meet some of the KPIs, constructive and continuous consideration and contribution by stakeholders will be crucial.

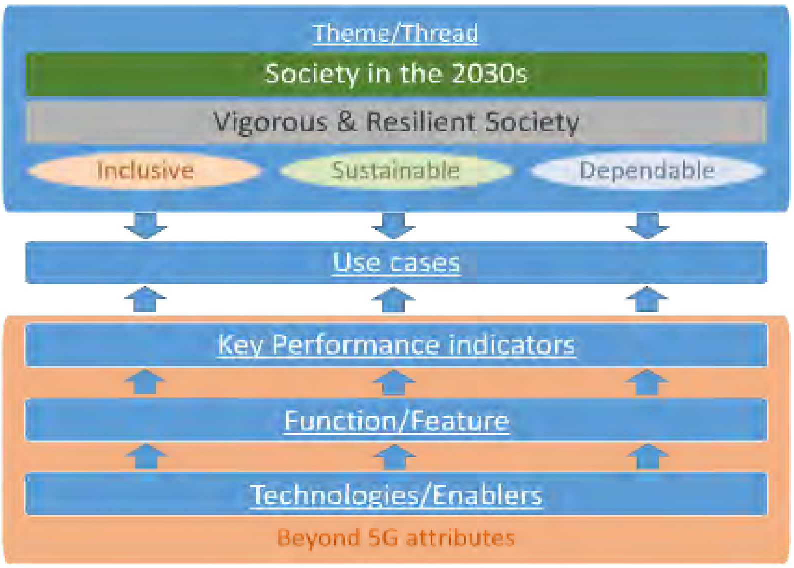

Figure 6.1-1 Technologies and enablers supporting societies in the 2030s

In a sense, this remarkable development of mobile phone systems is the result of the use of universal standards, as discussed in section 2.5. The key to the development of global standards in the future is to develop standards that reflect the expectations and demands of new stakeholders while making the most of the valuable "golden eggs" of existing assets.

In other words, it will be important to provide a wide range of services to various markets as an inclusive, sustainable, and dependable social infrastructure suitable for the Beyond 5G era by applying breakthrough technologies while efficiently utilizing and developing 4G and 5G information and communication infrastructures that have already been widely deployed as social infrastructures.

Section 6.4-6.8 outlines the various technologies and features supporting the Target Key Performance Indicators that contribute to the society and embody the above three principles.

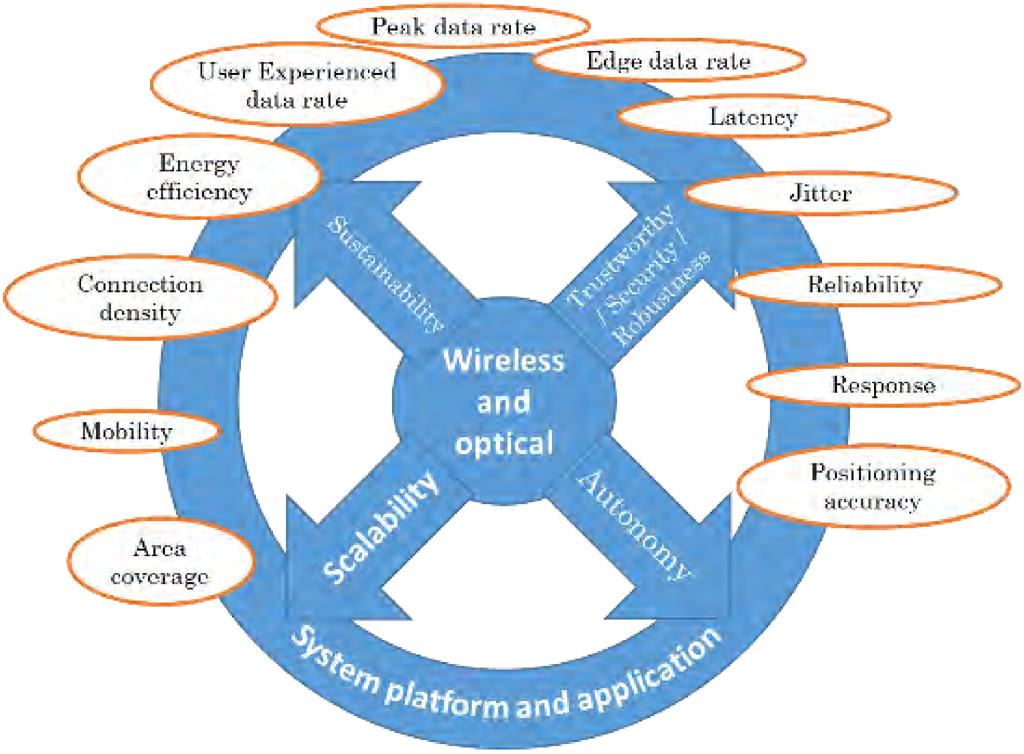

Figure 6.1-2 Technologies supporting the Target Key Performance Indicators

6.1.2 Overview of Key Technology Trends

(1) Beyond 5G Architecture

To realize the vision of the future society in the 2030s and to respond to the diverse needs of users, the architecture of Beyond 5G that enables various services and applications is shown in Section 6.2. This architecture consists of several functional components as shown below, and explains the realization technologies for each of them. In addition, as examples of applications using this architecture, architectures for providing user-centric services, network autonomous operation, and network and service fault tolerance are also shown. Furthermore, for more details on these realization technologies, please refer to the supplementary volume “E2E Architecture”.

- Digital twin management
- Network Computing Convergence
- E2E Network Technology
- Orchestrator
- Network AI function
- Migration function

(2) Frequency Resource Utilization

To deliver the high performance required by Beyond 5G, effective utilization of existing frequency resources and the development of new frequency bands are essential. In Section 6.3, we introduce the latest research findings on the utilization trends of existing and new frequency resources, as well as radio propagation characteristics, both domestically and internationally.

(3) Beyond 5G and AI/ML Technologies

AI and machine learning (ML) are inseparable from Beyond 5G and evolve together. In other words, the evolution of AI/ML technologies will be greatly utilized in the evolution of various technologies for Beyond 5G (AI/ML for Beyond 5G), and ultra-high-speed and low-latency communication technologies by Beyond 5G are essential for CPS/digital-twin utilizing AI/ML technologies (Beyond 5G for AI/ML). This white paper deals extensively with these perspectives as follows. Details are provided in the chapters listed in parentheses.

(a) AI/ML for Beyond 5G

The applications of AI/ML technologies in Beyond 5G include the understanding of physical layer characteristics and their control, communication control at the upper layers, network optimization, and automation of operation and management. In utilizing these AI/ML technologies, it is desirable not only to completely replace conventional technologies with learning-based technologies, but also to develop AI/ML technologies with modeling of physical characteristics and various other knowledge that has been developped over the years.

- Path loss modeling in wireless communications (6.3.2)
- Improving PHY/MAC layer efficiency and performance in wireless communications (6.8.8)
- Advanced/large-scale MIMO performance improvements and simplified system design (6.8.3)
- Improving energy efficiency through traffic forecasting and wireless network control (6.6)
- Autonomous operation of non-terrestrial networks (6.7)
- Autonomous security technologies (6.5.2)
- Providing entire system from applications to IT and network (6.2.4)

(b) Beyond 5G for AI/ML

Large-scale CPS/Digital Twin is envisioned as killer service of Beyond 5G, and is viewed as a distributed system of AI/ML processing from the terminal to the edge and cloud. Beyond 5G should not only provide ultra-high speed and low-latency communication for such distributed processing, but also provide new architectures to realize such services. It also should provide optimizations in terms of application performance, power consumption, and other aspects.

- XaaS for digital twin, robot control, real world reproduction and augmentation (6.4)
- Network AI architecture to support AI-enabled services and applications (6.2.2)
- Application-aware network optimization (6.2.3)
- Improving energy efficiency for AI training and inference in distributed networks (6.6)

(4) Beyond 5G and Sensing Technology

Similar to the relationship between AI/ML technology and Beyond 5G, sensing technology can be considered in both aspects of Beyond 5G advancement through sensing as well as sensing with Beyond 5G. This white paper deals extensively with these perspectives as follows. Details are provided in the chapters listed in parentheses.

(a) Sensing for Beyond 5G

In Beyond 5G wireless communications, sensing of wireless environment is performed while transmitting data, and making this sensing more accurate is essential for improving wireless communication performance. The sensing data obtained here can be used not only for wireless communications, but also for various applications, as described in the next paragraph.

- Integrating sensing into wireless communications to improve performance and enable new use cases (6.8.3, 6.8.8)

(b) Beyond 5G for Sensing

The use of high-frequency radios including millimeter wave bands is also expected to realize high-precision spatial sensing and positioning by taking advantage of their properties. Such sensing is provided by wireless communications (fixed and UAV base stations) and optical communications. In addition to such sensing, network architecture to collect and process large amounts of data from cameras/LiDAR and other sensors, as well as sensing of real space as a digital twin are also expected.

- Inferring wireless communication environment and highly accurate positioning (6.8.6)
- Enhancing sensing capabilities with UAV base stations (6.7.3)
- Sensing via optical wireless communications (6.8.11)
- Integration of communications, computing, and sensing capabilities (6.2.2)
- Real space sensing as a Digital Twin (6.4)

(5) Trustworthiness and network fault-tolerance

Technologies ensure the trustworthiness of Beyond 5G, such as security, privacy assurance, reliability, and resilience for safe and secure use of Beyond 5G are examined in

"6.5 Trust-enabling technologies". These reliability technologies are analyzed from the viewpoint of communication network trustworthiness and related technologies.

For technologies that ensure the network trustworthiness, research on ensuring confidentiality and integrity, authentication and authorization technologies and trust models, ensuring traceability — collecting and managing log, event, and traffic flow information, ensuring resistance to attacks and failures (ensuring availability), and ensuring security coordination in the context of network design of Beyond 5G are covered in the section. As operation technologies for Beyond 5G networks, the following are considered: log event traffic analysis, centralized management of information resulting from incidents, operation automation technologies for integrated response and recovery, privacy protection functions, and reliability diagnosis of users/user equipment. In addition, as technologies related to security management of Beyond 5G networks, we are studying threat analysis, advanced risk analysis, dynamic policy enforcement technology, and automatic health audit technology. In addition, as technologies related to security management of Beyond 5G networks, studies regarding threat analysis, advanced risk analysis, dynamic policy enforcement technology, and automatic health audit technology are also captured.

The related technologies for trustworthiness are discussed in the following aspects of Beyond 5G: ultra-high-speed, high capacity, ultra-low latency, ultra-simultaneous connections, ultra-low power consumption, autonomy, and scalability.

Fault tolerance of communication networks is discussed from the viewpoint of network architecture to ensure fault tolerance of services for the entire system and end-to-end in “6.2 Network Architecture”, and from the viewpoint of network fault tolerance and system fault tolerance in “6.2.5 Resilience”, respectively, showing examples of Beyond 5G architecture to ensure fault tolerance.

For Beyond 5G, it is important to establish, deploy, operate, maintain, and manage systems that apply these technologies ensuring trustworthiness and technologies related to fault tolerance of communication networks. Given that Beyond 5G will provide a wide range of advanced services in a variety of usage scenarios as an essential social infrastructure, it is foreseen that the scale and nature of incidents and failures that threaten the safety and security of society will also vary widely. Therefore, in addition to the continuous development and application of trustworthiness technologies and technologies related to fault tolerance, it is important to develop and study the overall safe and secure social infrastructure, including social systems and business schemes, as well as its usage forms.

REFERENCE

[1] “Beyond 5G Promotion Strategy Roundtable Recommendations,” Beyond 5G Promotion Strategy Roundtable (June 2020).

6.2 Beyond 5G Architecture

In this section, we describe the overall architecture of Beyond 5G to realize the vision for 2030 described in the previous sections and to provide Beyond 5G infrastructure to meet various user requirements. In Japan, Beyond 5G is intended to advance Society 5.0, and the Beyond 5G architecture aims to enable efficient provision of functions such as communications and services using Beyond 5G infrastructure to advance Society 5.0.

6.2.1 Overall Architecture

(1) Functional architecture configuration

Communications in Beyond 5G will evolve higher speed, multiple connections, and lower latency from 5G through various technologies, as described in Section 6.7 and 6.8. In addition, locations which are not covered by conventional TN (Terrestrial Network), NTN (Non-Terrestrial Network) in Section 6.7 will be developed by using satellites and HAPS (High Altitude Platform Station). These networks will enable ubiquitous connectivity, i.e., anytime, anywhere communications. To realize such networks, the communication infrastructure will be highly virtualized and software-controlled. In addition, the overall architecture of Beyond 5G will be controlled based on the user's specific intention, i.e., user intent. The architecture will provide the optimal communications that meet the performance required by applications and the quality needed by users anytime, anywhere. To obtain the communications, the users do not need to consider the Beyond 5G infrastructure, wireless or wired communication technologies, communication areas, communication band congestion, security, etc. In Beyond 5G, "users" are not only people who use smartphones, but also terminals that realize things and services, such as robots, drones, sensors, and other IoT terminals. That is, user-centric communications will be realized in which users, including a variety of people, things, and services, play a central role and secure the necessary communication functions from the Beyond 5G infrastructure.

Society 5.0 is expected to solve economic development and social issues through a Cyber-Physical System (CPS) that highly integrates virtual space and real space. CPS described in Section 6.4 uses sensors and other devices ubiquitous in society to collect information from various people, things, and services. Beyond 5G infrastructure can connect and control virtual space and real space by digital twin to realize CPS. The digital twin will enable the realization of various Society 5.0 services.

There are two types of digital twins in Beyond 5G: "Real-world Digital Twin" target is a digital twin for actual society and services that realize Society 5.0, and "Network Digital Twin" target is the Beyond 5G infrastructure. In order to construct and control the Real-world Digital Twin, we need to collect a vast amount of data from various people, things, and services using sensors and other devices in various places of society. The vast amount of data is used for projecting real space into virtual space. Then, it requires to effect from virtual space to real space to analyze and determine the vast amount of data. The requirement of Network

Digital Twin is not only understands the state of the Beyond 5G infrastructure by projecting and effecting in real and virtual space, but also verifies multiple candidate actions, such as control, in advance. Real-world Digital Twin and Network Digital Twin are not considered to be independent, but to be interconnected. For an example, we consider the situation in real space projected by the Real-world Digital Twin in virtual space. The situation can be used to verify candidate controls by the Network Digital Twin in virtual space. This is to ensure that communication can be provided to each user in the Beyond 5G infrastructure in real space.

In Beyond 5G, various services and applications to realize Society 5.0 will operate, and it requires to provide network functions and computing resources that are optimal for each service/application requirement. To realize them, Beyond 5G requires not only to provide network functions up to 5G, but also to provide distributed computing resources in the entire infrastructure on demand. In addition, an orchestrator that enables autonomous control/optimization of the entire infrastructure is also required. Although network resiliency has been addressed for public/social infrastructure up to 5G, Beyond 5G is expected to operate public/social systems that are more closely related to social life. Orchestrator and Network Digital Twin will play a major role to secure end-to-end service/application/network resiliency for the entire infrastructure.

AI (Artificial Intelligence) is expected to increase its range of application dramatically in Beyond 5G compared to 5G. First, in the Real-world Digital Twin, AI will be utilized in various functions such as analysis of vast amounts of data in virtual space. Second, focusing on Beyond 5G infrastructure, AI will also be used to control the infrastructure, such as Network Digital Twin and Orchestrator. However, AI will use not only for individual controls such as network resource allocation, but also for perspective controls of the entire infrastructure. For example, AI in the Network Digital Twin and Orchestrator will work together to combine increasingly complex Beyond 5G infrastructure functions to provide communications suitable for each user based on the user intent. In addition, AI will be applied to network resources. For example, AI for Air-interface will be able to control radio propagation estimation, error correction in radio signal processing, radio resource allocation such as scheduling, and optimal selection of beams for radio links. In AI for Air-interface, it will be applied to millisecond-order control, which is a shorter cycle than the Orchestrator's hundreds of milliseconds to second-order control cycles. AI also will be used at the application level, such as image processing in terminals. In Beyond 5G, AI will be used in various places and the convergence of AI and telecommunications will be promoted.

From the above, the Beyond 5G architecture (Figure 6.2-1) was developed to enable efficient provision of functions such as communications and services using Beyond 5G infrastructure.

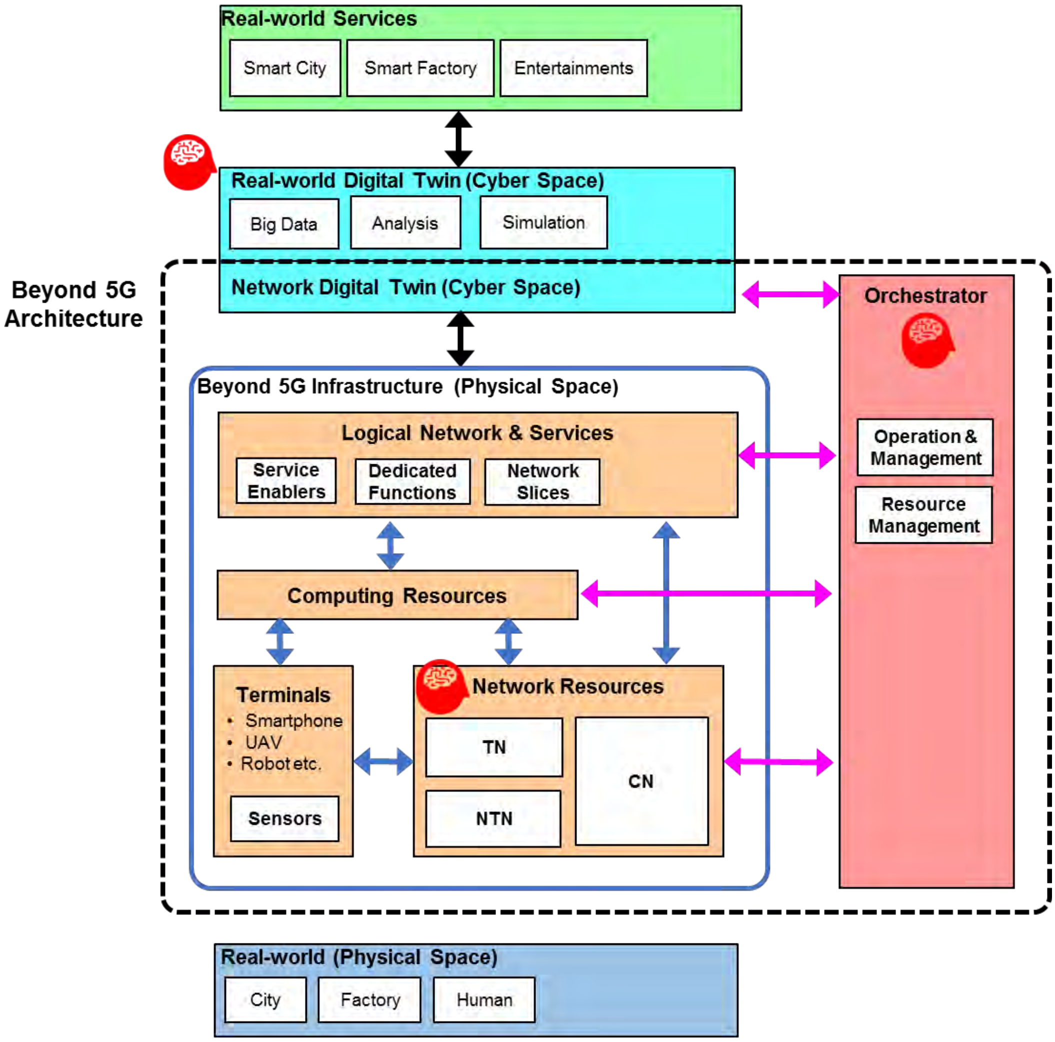

Figure 6.2-1 Beyond 5G network architecture

A description of the element included in Figure 6.2-1 follows. The term "Beyond 5G architecture" hereafter refers to the Network Digital Twin, Beyond 5G infrastructure, and the Orchestrator. AI icons are presented in the areas where it will be used in a characteristic way.

(a) Digital Twin

There are two types of Digital Twin: Real-world Digital Twin for real society and Network Digital Twin for Beyond 5G infrastructure.

- **Real-world Digital Twin**

  Real-world Digital Twin is a projection of the real world (cities, factories, people, etc.) as a virtual space (Real-world Digital Twin) with collecting information using the communications and services provided by the Beyond 5G architecture. In the virtual space, the collected information is converted into big data, analyzed, simulated, and acted upon. The target of actions from the Real-world Digital twin is not only Real-world Services such as smart cities, smart factories, and entertainment, but also network digital twins. In the Real-world Digital Twin, AI will be utilized in various areas such as analysis and simulation of Big Data, which is a set of collected information.

- **Network Digital Twin**

  The Network Digital Twin is a representation of a virtual space that is a projection of the Beyond 5G infrastructure as a real space. It is linked to the Real-world Digital Twin, and it is possible to verify how control by the Orchestrator affects the Beyond 5G infrastructure and real space in the Real-world Digital Twin. The verified results will be used to control the Beyond 5G infrastructure via the Orchestrator.

(b) Beyond 5G Infrastructure

In Beyond 5G, this infrastructure provides communication and computing functions in real. It consists of the following elements. The relationships within the infrastructure are indicated by blue arrows in Figure 6.2-1.

- Logical Network & Services

  Logical Networks & Services are management units that provide logical networks and services created on a per-user or per-service basis. These include the following items:

  - ✧ Service Enablers: they enable the provision of actual services such as XaaS (e.g., MaaS, RaaS, XR).
  - ✧ Dedicated Functions: they provide the functionality required by users and network.
  - ✧ Network Slices: they are logical networks that provide not only the entire infrastructure, but also communication functions to Service Enablers and Dedicated Functions.

  The management unit is composed of resources such as Computing Resources and Network Resources (described below), which are allocated and managed by the Orchestrator. The specific image of 5G is the logical network in NFV/SDN (Network Function Virtualization / Software Defined Network) and virtualized RAN (Radio Access Network).

- Computing Resources

  This means computing resources in the Beyond 5G architecture. Beyond 5G allows flexible usage of computing resources in various locations, including not only the Cloud (Center/Edge) in 5G, but also computing resources such as those in Terminals.

- Network Resources

  This means resources that provide communication functions in the Beyond 5G architecture. It consists of TN, which includes the core and RAN of mobile networks, NTN such as a network by satellite, HAPS, and CN (Core Network) which is a wired network. In Beyond 5G, AI will be used for millisecond-order control to provide network resources. Application example includes radio resource allocation such as inference of radio propagation, error correction in radio signal processing, scheduling, and optimal selection of beams for radio links, as AI for Air-interface.

- Terminals

It is the terminal portion that communicates with Network Resources and has computing resources. In Beyond 5G, "Terminals" include not only terminals such as smartphones operated by humans, but also robots, drones, sensors, and other terminals that enable the IoT in the broadest sense. Terminals also have sensor functions by built-in cameras and other sensors, and them in conjunction with Network Resources. A specific example of the latter is Integrated Sensing and Communications (ISAC) in mobile networks.

- Orchestrator

This is the part that controls the entire Beyond 5G architecture in conjunction with the Beyond 5G infrastructure and Network Digital Twin. Figure 6.2-1 shows the relationship by the pink arrows. The Orchestrator has two functions: Operation & Management, which manages operations, and Resource Management, which manages resources within the infrastructure. In 5G, AI was applied to control individual functions such as Operation & Management and Resource Management. In Beyond 5G, AI will be used to control the entire infrastructure, which will become more complex, as described in the previous section.

The Beyond 5G architecture will enable the following.

1. Digital Twin: A digital twin that integrates real and virtual spaces in the real-world will be realized. Beyond 5G architecture providing the communication and computation capabilities to combine real and virtual spaces.
2. Network and Computing Convergence: Enables the provision of network resources as well as computing resources used by services and applications.
3. User-centric network: This is an infrastructure to realize end-to-end communications according to the performance and quality of experience (QoE) required by each user based on the user intentions, including not only people but also things and services.
4. Orchestrator: Enables rapid provision of optimal infrastructure functions for each service, as well as optimization of the entire Beyond 5G system. In addition, it will ensure system-wide, end-to-end fault tolerance so that social systems do not become a halt in a failure.
5. Convergence of AI and telecommunications: AI will be used in many places, including within Beyond 5G infrastructure.

(2) Comparison with functions to be realized in 5G

In Beyond 5G, it is necessary to know how things will change from 5G for an evolution clarification. Figure 6.2-2 shows what is being realized in 5G based on Figure 6.2-1.

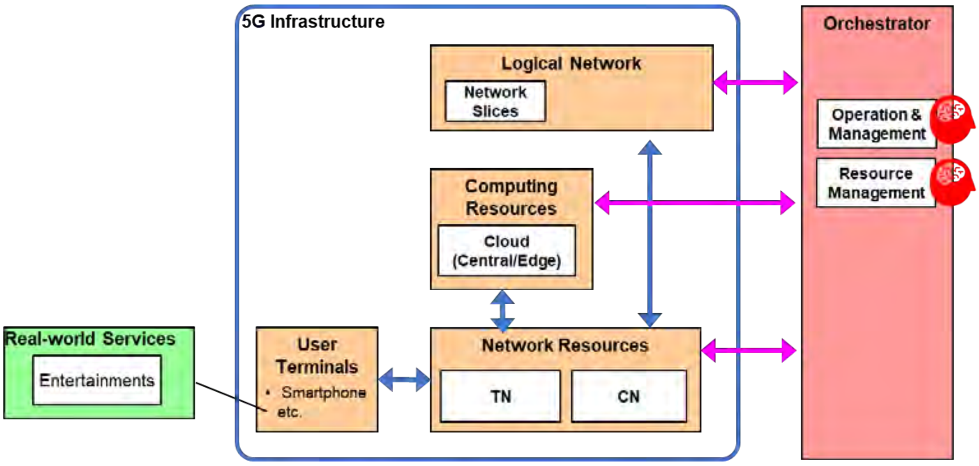

Figure 6.2-2 What is realized in 5G based on Beyond5G architecture.

The differences between what is realized in Beyond 5G from it in 5G are as follows.

- The digital twin is not realized with a strong relationship between the Real-world and Network, such as Real-world digital twin and Network digital twin shown in Figure 6.2-1. In the detail, it will not provide communication functions and computing in an optimal way for Digital Twin in a 5G network. It will be used only as a communication pipe.
- The Logical Network portion will not provide any functionality related to services present in the Beyond 5G infrastructure. Only Network Slice through network and RAN virtualization will be provided.
- Computing Resources will be provided by the Cloud (Central/Edge) and will not be able to utilize Computing Resources in various locations as realized in Beyond 5G infrastructure. In addition, the usage of Computing Resources is limited to the realization of virtualized networks and RANs in Network Resources and cannot realize various functions in Beyond 5G infrastructure.
- Network Resource is mainly provided by TN and CN. NTNs are also beginning to be applied mainly to Low Earth Orbit (LEO) satellites, but they are mainly treated as backhaul for mobile networks or as additional networks. There is a big difference in the level of realization, such as the communication function where TN, NTN, and CN are integrated, and users are not aware of the difference between them in Beyond 5G.
- Smartphones are mainly used as terminals, and the real-world services provided by the smartphones include web browsers, videos, and other entertainment services for people. Communications by IoT devices such as sensors will be used in 5G, but their communications are one type of user terminals. The 5G infrastructure will not provide communication functions and services based on different terminals, as envisioned in the Beyond 5G infrastructure.

- The Orchestrator manages the 5G infrastructure in terms of Operation & Management and Resource Management. However, it is not as complex as Beyond 5G Infrastructure, and is managed from the perspective of individual operations and resource management. In addition, AI will not be applied to the management of the entire infrastructure for optimization but will be applied to individual managements such as Operation & Management and Resource Management.

(3) Usage scenarios and important features

This section describes how actual usage scenarios and visions, which is described in Chapter 5 and earlier, will be realized in the Beyond 5G architecture. The globally recognized usage scenarios are defined in the ITU-R IMT-2030 Usage Scenario (Figure 6.2-3) [1], which shows 6 Usage Scenarios and 4 Overarching Aspects. Figure 6.2-4 shows a mapping of these contents will be realized by the functions of the Beyond 5G architecture. All of the Usage Scenarios and Overarching Aspects are realized (A to J in Figure 6.2-4). Unique content in the Beyond 5G architecture includes the following items (K to M in Figure 6.2-4).

- Realization of User/Network functions in Dedicated Functions through the conversation of networking and computing: This enables on-demand provision of high real-time/wide bandwidth applications and AI inference to various terminals with different performances.
- Realization of a user-centric network based on user intent which is the specific intention of the user: This enables communication functions that are optimal not only for people, but also for things and services.
- Automation with autonomy in Orchestrator: In the conventional manner. the many person-hours required to operate and manage increasingly complex Beyond 5G infrastructure. This is an important technology to realize advanced infrastructure with fewer man-hours for an aging society with a declining birthrate. Also, with regard to AI, a mechanism will be built on the premise of automation.

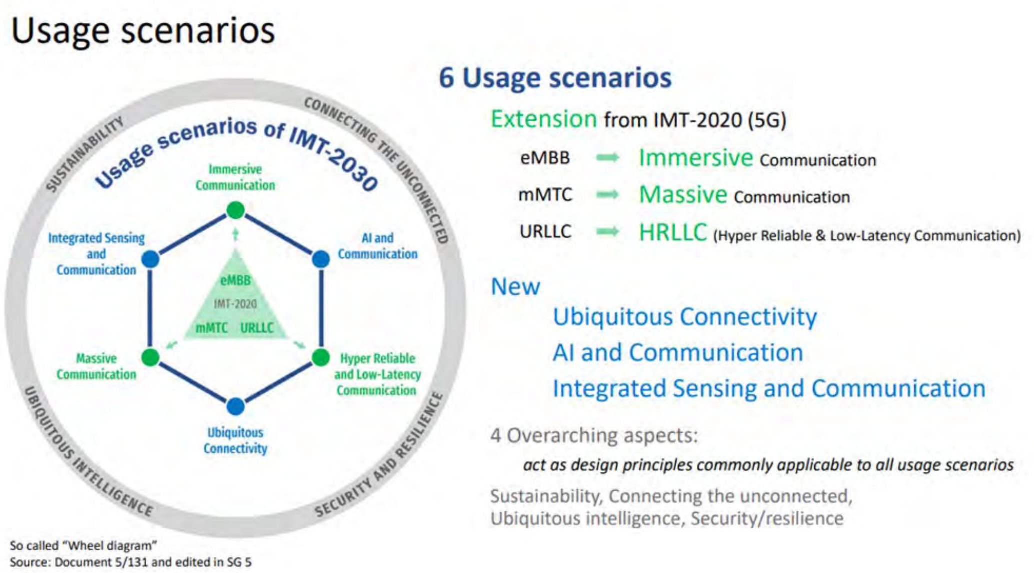

Figure 6.2-3 Usage Scenario in IMT-2030

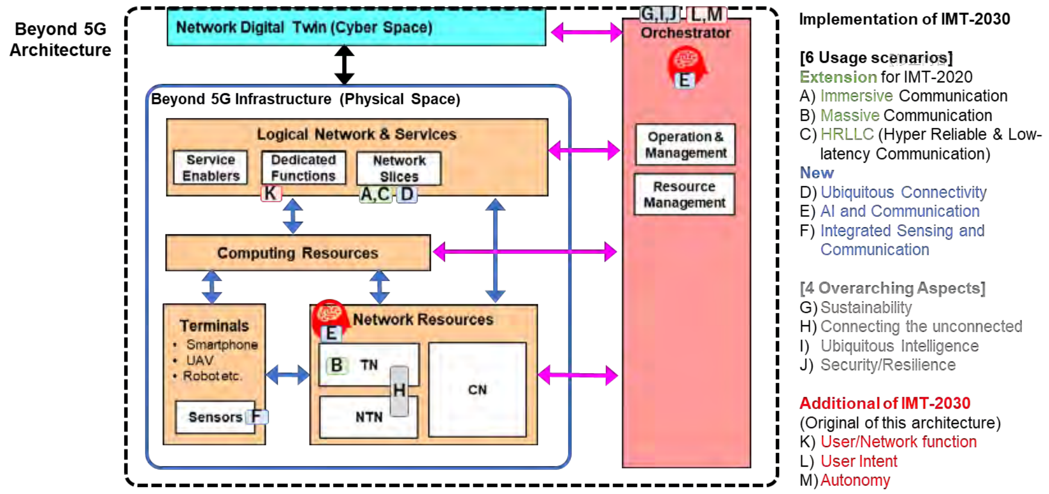

Figure 6.2-4 What is realized in the Beyond 5G architecture.

6.2.2 Architectural Enabling Technologies

This section provides an overview of the technologies required for the entire network providing the communication functions to realize the Beyond 5G architecture. For details on each of the technologies, please refer to the supplementary volume on "E2E Architecture". The related technologies to realize the individual elements are introduced in the supplementary volume such as "Cell-Free/ Distributed MIMO" and "Radio Technologies for higher frequency" etc.

(1) Management of Digital Twins

Beyond 5G provides a platform for digitizing the real world and the Beyond 5G infrastructure, and managing and controlling them as digital twins in the virtual space. One of the major features of Beyond 5G is to unify the two types of digital twins, the real-world digital twin and the network digital twin, as shown in Figure 6.2-1. In the real world, various things are deployed in the three-dimensional space where people live and work, such as cities, factories, and humans, and by digitizing them as digital twins, a platform for providing various services in the real world, such as smart cities, smart factories, and entertainment, is created (real-world digital twin). Similarly, in the Beyond 5G infrastructure, the communication resources, computing resources, terminals, and the logical networks and services that are virtually constructed from them are digitized as digital twins, and by providing them to the orchestrator, a platform for realizing and optimizing various services of Beyond 5G is created (network digital twin).

With these two types of digital twins, optimization of the Beyond 5G infrastructure can be performed using the network digital twin, and services in the real world can be realized and optimized using the real-world digital twin. Furthermore, in Beyond 5G, as shown in Figure 6.2-5, the benefits of integrating and accessing both digital twins without distinction and optimizing both based on both information are very large. For example, on the one hand, it is conceivable to dynamically optimize services in the real world, such as robot control, traffic control, and media quality, based on information on the Beyond 5G infrastructure, such as wireless communication environment and availability of computing/communication resources. On the other hand, it is also conceivable to dynamically optimize the Beyond 5G infrastructure based on the state of services in the real world, such as the tasks assigned to robots, their current positions, and the interests and situations of users who are still watching media. By these bidirectional effects, the Beyond 5G infrastructure can be optimized and its capabilities and utility maximized, while at the same time improving the efficiency, safety, and perceived quality of various services in the real world.

In addition, Beyond 5G has the role of providing a platform for managing both digital twins as described above. By using the ultra-high-speed and low-latency communication provided by Beyond 5G, and the distributed high-performance computing infrastructure, a large number of digital twins can be constructed in real time for various objects spread in the real world, and they can be provided to various services.

In the special issue of E2E Architecture, “Digital-Twin for and by Beyond 5G”, the above-mentioned digital twins are explained. Then, functional designs such as probabilistic digital twins and cross-domain orchestration are discussed, and finally, use cases such as wireless communication design optimization, human-robot collaboration, and sustainable smart mobility are introduced.

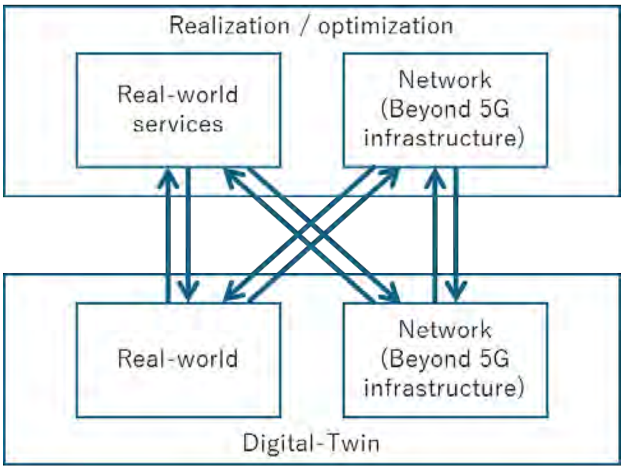

Figure 6.2-5　Digital Twin of Real Space and Beyond 5G Infrastructure

(2) Integration of Network Functions and Computing Resources

(a)　Virtualized RAN using general-purpose equipment

The virtualized core network has been continuously developed and launched since the 4G era as NFV (Network Function Virtualization). The component of B5G base station would be transferred from vendor-specific equipment to general-purpose one using virtualized technologies. For instance, hardware accelerators of B5G base station would be used not only ASIC (Application Specific Integrated Circuit) as existing system but also the general-purpose device which is memory, CPU (Central Processing Unit), FPGA (Field Programmable Gate Array) and GPU (Graphics Processing Unit) which are used for general servers.

The virtualized RAN and virtualized core network have been popularized at the 5G era. The RAN architecture would be changed because of higher traffic volume and wider allocated frequency bandwidths at the Beyond 5G era. AI applications would be running over RAN with distributed computing resources, the RAN equipment could execute computing processing that are difficult to execute due to the limitation of terminal's capacities instead of terminals. Therefore, it could easily provide network environments with higher-performance AI applications and extremely low latency.

The processing capacity of non-virtualized conventional base station is generally determined in advance (e.g., processing performance of each baseband device = number of base stations). So, it is to install equipment with the same processing performance between urban areas and rural areas which have different traffic volume. Meanwhile, the virtualized base station could allocate of computing resources with low traffic volume in rural areas, while allocating surplus computing resources with large traffic volume in urban areas. As a result, it would become optimized the allocation of calculation processing performance resources for base stations in all areas, and the network operator could suppress excessive capital investment costs for network construction.

(b) Optimum collaboration of network functions and computing resources

In the Beyond 5G era, network operators will have higher flexible/ end to end deployment methods of network functions using the virtualized RAN/core network and various kinds of access method (e.g., optical networks and NTN (Non-Terrestrial Networks)). For public/ private network operators, the deployment of network functions will be more flexible from logical and physical viewpoints, and be more widely located from the local area to the distributed one [2, 3]. The optimum usage method for distributed computing resource collaborated with network functions will be important in the Beyond 5G era. The reason is that high real-time/broadband communications (e.g., VR/AR (Virtual Reality/ Augmented Reality) terminals) and AI inference will become popular applications, and require higher performance of arithmetic processing power using several types of computing resource (e.g., memory, CPU, FPGA, GPU).

To achieve these targets, the network architecture has been studying provided the virtual computing resource as a network endpoint. In this network architecture, the technology of network transport is employed APN (All Photonic Network), the computing resource deployed in different network domain (RAN, MEC, core network, cloud) can be used as virtualized one computing resource via APN, so network operators can use optimum computing resource on demand from requirements of communications and applications [4].

This network architecture can provide higher performance processing method on behalf of VR/AR terminals, and provide high-quality services for terminals of inferior performance. Service operators will be able to release from the performance limitation issue for terminals of inferior performance, and provide high-quality services for various types of terminals independent of terminal's performance. This network architecture can also provide the autonomic/dynamic deployment and resource allocation method for the optimum computing resource based on the prediction of traffic demand via AI inference. This approach seems to be effective for temporary events and unpredictive situations (e.g., disasters), because it is sufficient to take small/medium-scale measures if the traffic demand exceeds the expectation in the local area.

(3) User-centric and application aware network technologies

In the current mobile network, communications are under the control of the network, and applications on smartphones, which are mainly used by people, use predefined communication services. However, communications with terminals in Beyond 5G are not only conventional smartphones directly used by persons, but also various "users" of IoT such as robots, drones and other flying objects, AR/VR, and other things and services. These will be combined to provide services. Those communications are expected to accelerate toward the era in which Beyond 5G will be used, as labor shortages and a decrease in the number of skilled workers accompanying the declining birthrate and aging population, especially in developed countries. In order to realize the necessary communication environment, an overall network technology that can flexibly construct networks according to the requirements of each "user" and the "applications" is required. As these technologies, we introduce the user-centric network and the application-aware network optimization. For details, please refer to Section 6.2.3 The supplementary volume "User-centric Network" also describes the technical implementation and current demonstrations of these technologies.

(4) Orchestrator

Various services and applications realizing Society 5.0 will operate on Beyond 5G. Beyond 5G is required to quickly provide the optimal network and computing functions for each service and application. Therefore, the Orchestrator will optimally allocate network and computing resources distributed within the Beyond 5G infrastructure and provide them to users.

The network and computing resources handled by Beyond 5G span various domains. For example, network resources are managed by different domains such as TN, NTN, and CN, and computing resources are distributed across MEC (Multi-access Edge Computing) to cloud servers. The Orchestrator manages these distributed resources and resources managed in different domain and allocates network and computing resources to meet the functionality and performance requirements of users and services.

Beyond 5G is expected to become a critical infrastructure for society, and important social services will be provided on Beyond 5G. The Orchestrator not only satisfies the requirements of a user or service as described above, but also achieves overall optimization so as not to interfere with entire services in Beyond 5G. In addition, it is also important to respond to communication failures due to large-scale disasters and large-scale failures, which have become a social issue in recent years. In Beyond 5G, ensuring fault tolerance by the Orchestrator is also an important function to ensure that services continue without stopping social systems in the event of a failure. The Orchestrator ensures fault tolerance of the entire system and end-to-end by performing overall optimization, such as prioritizing service continuity by reducing the quality of provision for each user and service.

In this way, Orchestrator balances the optimal allocation of geographically and management domain-distributed resources to a service and a user, and the overall optimization for the entire Beyond 5G system and fault tolerance. Since management and control of large-scale systems is difficult to be performed manually, Beyond 5G will be operated autonomously by an AI-based Orchestrator.

See Section 6.2.4 for details on network autonomous operation aiming at autonomous operation of Beyond 5G, and Section 6.2.5 for ensuring fault tolerance of Beyond 5G as a critical infrastructure.

(5) Network AI Architecture

AI functions in Beyond 5G communication systems are expected to be applied to both application services and native network functions with the background of innovative improvements in capabilities. As shown in Figure 6.2-1, Beyond 5G supports AI-based services and applications, and incorporates this capability as an AI-based function that consistently drives end-to-end systems. Specifically, Beyond 5G's air interface and network design leverages end-to-end AI and machine learning (ML) to enable customized optimization and automated operations and maintenance (O&M). This is commonly referred to as AI for Network (AI for NW, AI4NET). In addition, each Beyond 5G network element will organically integrate communications, computing, and sensing functions, driving the evolution from centralized intelligence in the cloud to ubiquitous intelligence in Beyond 5G networks. This is a deepened architectural concept called Network for AI (NW for AI, NET4AI) or AI as a Service (AIaaS). In AIaaS, Beyond 5G capabilities integrate communications technology, information technology, data technology, and industrial intelligence into the wireless network to serve as an intelligent, AI-native integrated architecture, including large-scale distributed training, real-time inference at the edge, and native data desensitization. It is possible to adapt to the application of AI.

(a) Key Requirements for Network AI Architecture

- From Cloud AI to Network AI

  In centralized learning such as cloud AI, data is collected from the entire network and transmitted to centralized entities, so it is costly and constrained. On the other hand, network AI, which enables AI to learn and reason within the network, can also help improve energy efficiency. In addition, intensive learning has restrictions on learning using personal information. In addition, in cloud AI, learning is often done offline by accessing training data and using abstract models of the real environment. However, the drawbacks of such processes are that many details are oversimplified and important metrics are ignored, resulting in performance improvements. Beyond 5G (MEC)'s high-performance distributed infrastructure has the potential to open new possibilities for real-time network AI, especially in latency-required use cases (such as closed-loop control in industrial scenarios).

- Closely coordinated ICDT infrastructure

  For AI to be used more effectively in Beyond 5G networks, it is necessary to build a new network foundation that closely integrates Information, Communication and Data Technology (ICDT). Currently, network connectivity and computing services are relatively independent systems, and the mutual collaboration mechanism is realized only through the functional publishing interface of the management layer. The new, interconnected architecture not only ensures the real-time performance of these interfaces, but also establishes a universal and unified standard system that greatly facilitates Beyond 5G AI applications.

- Organized and managed secure data services

Beyond 5G systems essentially generate huge amounts of data at any given time, ranging from operation to management, from the control plane to the user plane, from environmental sensing to terminal information. Because these different types of data come from a wide range of technologies or business domains, Beyond 5G requires data to be organized and managed efficiently while keeping data security and privacy in mind.

- Flexible deployment of AI in the network

  Ease of deployment is essential to attract services from external partners, especially when a certain level of network and IT expertise is required. This requirement is primarily related to the design of AI management and orchestration functions.

  As discussed at the beginning of this section, Beyond 5G architecture features optimize end-to-end services and enable native and service-based AI support. In response to these requirements and in order to realize their features, the following two concepts (task-oriented communication and operation management of AI services) were introduced.

(b) Task-Oriented Communication

Task-oriented communication is one of the key paradigm shifts for Beyond 5G to support new services such as AI and sensing. Conventional communication services are connection-oriented, and communication resources are allocated based on requests from end users and services regardless of whether the end user wants to communicate with other users or to connect to a server on the cloud. As a result, the connection is established based on the intention of the user.

Task-oriented communication, on the other hand, employs a completely different design concept that establishes connections based on tasks that the network provides to the user. For example, an AI task may collect and process data for a region according to user movement, real-time population distribution, or frequency of terminal use. The public transport cloud will be able to leverage this task's information to understand the mobility of cities during rush hours. In this way, companies can easily achieve their goals by using Beyond 5G's AI service, which collects data from specific users to get the information they need. The construction of task-oriented communication may include task management, orchestration and scheduling of heterogeneous resources, data management, and connection management. Beyond 5G's AI tasks provide the ability to handle coordination between computing, data, connections, and algorithms. In the technical annex of E2E Architecture, a particular article titled “Task-Oriented 6G Native-AI Network Architecture” provides this in detail.

(c) Operation and management of AI services

When considering native AI support, an AI service operations management framework is an essential element. The framework will be used to facilitate the seamless integration and deployment of AI services, including the operation of AI services and the management of AI services. An important aspect of the operation of AI services is that the operation is provided with multiplayer involvement, and it must function transparently and efficiently. For this reason, it may be necessary to ensure trust through blockchain. Management of AI services includes AI workflow orchestration, data management, and heterogeneous resource orchestration. The operation and management of AI services also includes network operations using AI for Beyond 5G's own network. Beyond 5G network operations using AI are also described in 6.2.2(4).

(6) System architecture and migration towards Beyond 5G

One of the open issues for enabling Beyond 5G is architectural evolution and migration path toward Beyond 5G infrastructure illustrated in Figure 6.2-1. In particular, the system architecture introduced in the first release of the standards for a new generation of mobile communications is the long-lived baseline while the system is in operation. Any technology evolutions after the first release need to be backward compatible. Thus, the first release of the standards is of paramount importance to introduce revolutionary technologies in a non-backward compatible manner. Cutting-edge technologies, such as AI/ML, cloud-naiveness, NTN/HAPS for universal access, can be natively integrated into the basic system architecture. Technologies aimed for sustainability and energy efficiency in the ICT sector are also demanding trends to strive for global climate change. Meanwhile, the commercial 5G services have been successfully evolved over the world, moving ahead towards 5G standalone operation. A decent balance needs to be struck for revolutionary innovation of Beyond 5G as well as leveraging the investment for 5G networks. For 4G to 5G migration, an operation of Non-standalone (NSA) mode was supported to leverage the existing EPC/LTE infrastructure, as well as the support of the standalone (SA) mode of operation. For NSA and SA, several architecture options were standardized, e.g., with respect to whether RAN is connected to EPC or 5GC. In order to support smooth spectrum refarming, the technology of Dynamic Spectrum Sharing (DSS) was supported. As the 5G commercial deployment grows, there are several lessons learnt from the 5G standardization, development and deployment, which should be taken into account when Beyond 5G standardization takes place. In 5GC, Service Based Architecture (SBA) was introduced for cloud-native infrastructure. For Beyond 5G, one open issue is whether SBA is extended to the other NW domain than CN, built upon the existing 5G system architecture. RAN disaggregation for cloud-native architecture is another topic to be discussed for enabling flexible RAN deployments. Detailed architecture aspects are elaborated in the supplementary volume for E2E architecture.

6.2.3 User-centric and application aware network technologies

In Beyond 5G, communications with terminals in Beyond 5G are not only conventional smartphones directly used by persons, but also various "users" of IoT such as robots, drones and other flying objects, AR/VR, and other things and services. These will be combined to provide services. In order to realize the necessary communication environment, an overall network technology that can flexibly construct networks according to the requirements of each "user" and the "applications" is required. This section shows user-centric network and application-aware network optimization as enabler technologies.

User-centered network

In Beyond 5G, it is necessary to construct and provide a flexible network in order to provide communications not only to people as described above, but also to "users," including IoT in the broad sense of the term (used in the same sense hereafter in this section). This concept of flexibly constructing and providing a network centered on users is called a "User-centric network”. User-centric networks adopt an architecture in which network functions related to individual users can be defined, configured, and controlled based on their specific intentions (User intent) [13]. The current network architecture is network function-centric. However, User-centric network uses virtualization technologies both wired networks and radio access networks, and each user has a logical network that is provided with all functions necessary for communications and services. The resources for the logical networks are provided from networks and computers in Beyond 5G network. Users would also have control for the generated or their data and the processing privileges (authentication, permissions, access control and etc.) corresponding to such data.

- Key Requirements for User-Centric Networks

1) From network-function-centric to user-centric

Each user has its own "dedicated network" that is virtually constructed from communication and computing resources within the network. Communications are provided a combination of TN (Terrestrial Network) and CN (Core network), including terrestrial mobile networks, as well as NTN (Non-terrestrial Network), including satellites and HAPS (High Altitude Platform Stations). In the mobile network, which provides mainly wireless communications to terminals, a new technology is required to build an area that is not restricted by base stations in a cellular network. The new technology can build an area that is not restricted by base stations, where communication is available anytime and anywhere to meet various communication requirements. It also enables mobility management, policy management, session management, and user personal information management. User-centric network functions are decoupled from network-oriented network functions, and they become them simple, flexible, and easy for user’s control.

2) From centralized to decentralized functions

Network availability and robustness considerations require a distributed architecture. This significantly reduces the risk of DDoS (Distributed Denial of Service) attacks and SPOF (Single Point Of Failure) for communications. In addition, the design principle of integrated network functions per users can reduce communication processing complexity and communication delays, because it eliminates the need for message exchange between network functions. The decentralization functions improve trust in user data. Personal information is accessed from a single trust anchor in a centralized architecture, but, in a decentralized architecture, the user's digital realm is created with clearly defined boundaries of processing authority with rich data resources based on a user-centric network approach. This will enable the use of auditable and tamper-resistant distributed ledgers (e.g., blockchain), and it can be authenticated by the data owners themselves. This digital realm is also useful for the development of digital twins and for digital asset management.

- Technologies that enable user-centric networking

To improve network scalability and reliability and effectively reduce the cost of network implementation, the type of network functionality must be minimized. In User-centric network, the type of network functionality can be reduced by implementing a few basic functions to achieve an overall service.

1) User service functions

User service functions are network functions that are specific to each user and implement all functions necessary for mobile users to access services. All user service functions consist of a single runtime entity, are constructed as a peer-to-peer network, and operate in a distributed fashion. As a result, communication interactions within user service functions are reduced and complexity is reduced, resulting in a flexible and manageable implementation and low latency.

2) Network service functions

The Network Services function will implement network-oriented functions (e.g., network access, global policy, network function publishing, etc.) that are key to the operation and maintenance of the entire network. As the first point of connection for users to the network, the Network Services function will work with the Orchestrator to provide lifecycle management and global coordination of user services functions.

The user data management architecture with multi-party trust for user-centric networks consists of a blockchain that acts as a trust anchor and distributed storage. Authentication, permissions, and access control are implemented by smart contracts deployed on the blockchain. All access permissions to personal information are granted by the data owner.

As securing communication paths, which are the key to network services, TNs, NTNs, and CNs are used in conjunction with the Orchestrator to meet the specific communication for user requirements. In the mobile network, which mainly provides communication to users, a technology will be used to provide communication anytime and anywhere in response to user requests. Cell-Free is a candidate technology, and it dynamically coordinates many base stations based on the user requests, rather than constructing a communication area based on cells centered on base stations.

Application-aware network optimization

It has become increasingly important for industries to promote DX by utilizing Beyond 5G, IoT, and AI to realize a highly productive and prosperous society. Thus, in addition to the policy to improve the average quality of experience (QoE) of users at each area, there is a need to strengthen policies that precisely protect DX/IoT application performance (work speed, productivity, etc.) per communication session. For this purpose, it is necessary to intelligently and automatically control the RAN according to the conditions of application, network, and site, so that DX/IoT applications can be used stably at high performance. This section describes the application-aware network optimization architecture that realizes such a sophisticated world.

- Social Background

Because of the labor shortage and the decrease in skilled workers due to the declining birthrate and aging population, there is an increasing need to replace humans with machines in several tasks to solve social issues. Accordingly, the need for automation, remote monitoring/control, and labor saving using DX/IoT will likely increase in the future. In the DX/IoT area, there are many use cases that require the mobility and ease of equipment installation, and where wireless communication is essential. High DX/IoT application performance (working speed, productivity, etc.) must be ensured, often resulting in stricter requirements for communication quality [13].

- Key requirements

(1) Response to diversification and fluctuations in application requirements

The expansion of applications including industrial DX/IoT has led to the need to meet diverse communication requirements. In the DX/IoT domain, dynamic fluctuations of requirements must also be dealt with in consideration of the application performance (working speed, productivity, etc.) and real-world conditions (mobile device collision risk, etc.).

(2) Guaranteeing strict communication quality requirements in the vertical domain

In the DX/IoT domain, maintaining high application performance is crucial (e.g., image analysis accuracy of surveillance cameras, transportation speed of logistic robots, duration of automatic construction, or safety of autonomous cars). Application performance is important as it affects the performance of the core business at each industry. High communication quality capabilities are often required to achieve high application performance [13]. For example, in factory automation, latency must be approximately 1 msec to 10 msec or less, and availability must be 99.9999% or more for applications related to device control and automation.

(3) Support traffic for mixed diverse applications

In the DX/IoT domain, applications and their requirements are diverse, and even the same application may generate multiple types of traffic with different requirements. A method of constructing slices for each traffic type by network slicing technology can be considered, but slice separation may not be suitable due to ineffective use of radio resources or when the same application generates multiple types of traffic. In this case, it is necessary to be able to meet a wide range of requirements at the same time, such as realizing large-capacity communications while maintaining low latency and high reliability.

- Application-aware network optimization architecture

Mobile network specifications will become more sophisticated toward the Beyond 5G era, however, intelligent and automatic network optimization during operation will be crucial in responding to the changing conditions of applications, networks, and sites.

(1) Response to diversification and fluctuations of application requirements

In order to respond to the diversification and fluctuations of application requirements, DX/IoT applications, networks, and real-world situations are analyzed in real-time, and the network and communications are intelligently and automatically optimized. As a result, the functions and performance of advanced mobile networks can be fully utilized, and DX/IoT applications can be used stably at high performance. The development of various AI systems is indispensable for realizing this requirement.

(2) Guaranteeing strict communication quality requirements in the vertical domain

Since radio quality fluctuates, use of space diversity is necessary to guarantee strict communication quality requirements in both uplink and downlink. An effective method is to create a large number of communication paths and increase the room for intelligent and automatic path selection, channel selection, and beam management in accordance with the application, network, and real-world conditions.

(3) Support traffic for mixed diverse applications

Supporting traffic for mixed diverse applications requires radio resource allocation mechanism that flexibly accommodates diverse applications with different communication quality requirements. The key is to intelligently and automatically optimize the radio resource allocation scheduler and the mixed numerology for multiplexing signals with different numerologies in the frequency domain.

- Challenges

  Considering the extensive spread of the network architecture and the social implementation, standardization problems must be addressed. The O-RAN Alliance is investigating standard specifications for intelligent and automatic network optimization using machine learning, with a view to supporting a wide variety of applications [14]. These standardization activities must be pursued more actively.

  As subject of future studies, the following issues must be solved to promote social implementation of the application-aware network optimization architecture.

  1) How can we define and standardize the performance metric and requirement for each of the diverse applications?
  2) Will the data required by AI (e.g., RAN-related data) be properly disclosed?
  3) Will the functions and interfaces for optimizing RAN be properly published?
  4) How can we utilize network devices of multiple vendors, networks of multiple operators, and heterogeneous networks to ensure spatial diversity?

- Future vision: Beyond 5G accelerates development of DX/IoT applications and AI systems

  Conventionally, IoT devices are equipped with intelligent functions that are specific to its vendor or model, and the controller software is also tied to a specific vendor and model. When Beyond 5G realizes a stable wireless communication environment with low latency, intelligent and high-load data processing will be possible on the cloud or edge server. This makes it easier for the controller installed in the cloud or edge server to coordinately control IoT devices of multiple vendors, and for multiple models to optimize the entire system. Furthermore, achieving simplification, lightweight implementation, and generalization of IoT devices will likely drive the spread of DX/IoT solutions, and as a result, accelerate the developments in DX/IoT applications and AI systems.

6.2.4 Autonomous network operation

To promote DX by utilizing 5G, AI and IoT, and to realize a highly productive and prosperous society, everyone should have quick access to the network for various use cases. It is, therefore, necessary to be able to intelligently and automatically provide the entire system, including applications, IT, and network, in one step in accordance with the business requirements and the situation at the site. This section describes the architecture of an autonomous network that realizes such a world.

As 5G/AI/IoT increasingly permeate society, DX is attracting attention as an initiative to radically reform operations on the premise of utilizing 5G/AI/IoT. Since use of networks is indispensable in improving the efficiency of business and creating new values through DX, anyone should be able to flexibly and promptly use the network in accordance with the requirements for each use case. However, securing sufficient engineers is sometimes difficult due to the labor shortage and the decrease in the number of skilled workers brought about by the declining birthrate and aging population, especially in developed countries. First, in order to provide the network required in business, the entire system must be constructed, including related applications and IT infrastructures, which require advanced technical knowledge. In particular, a society where the increasing demand for network is being supplied by a declining number of engineers is reaching its limits. Therefore, expectations for the solution by autonomy brought about by DX are increasing.

- Key requirements for autonomous network

To satisfy labor-saving, flexibility and agility for Beyond 5G network operation, network operation must be fully autonomous among the workflow from network construction to operation. TM Forum defines the following six steps for progress in autonomous network [15];

Level 0: Manual Operation & Maintenance
Level 1: Assisted Operation & Maintenance
Level 2: Partial Autonomous Network
Level 3: Conditional Autonomous Network
Level 4: High Autonomous Network
Level 5: Full Autonomous Network

TM Forum divides operation process into five processes, "Execution," "Awareness," "Analysis," "Decision," "Intent/Experience." The upper automation level the autonomous network achieves, the later process is automated. The level 5 autonomous network can automatically deal with all situations.

While the autonomous network level in 5G network operation is from level 2 to level 3, Beyond 5G will improve autonomous level to level 4 to level 5.

To achieve level 5 autonomous network, the following problems should be solved.

1) Providing networks based on business requirements

Since the users who need the network in the next decades are workers in various industries, the request should be expressed not in the language of ICT but in the language of each industry. In providing the network, it is necessary to interpret the requirements expressed in the language of each industry, translate them into ICT requirements, and think of ways to realize them. Since there are a wide variety of industries, a wide variety of demands must be met. In addition, networks should be provided appropriately in consideration of the various constraints due to business situation.

2) One-stop provisioning of end-to-end network across applications, IT and networks

Providing networks that can be used in the field of business requires building the entire system, including communication infrastructures such as RAN and core-network, IT infrastructures such as on-premise and cloud, and related applications, which should be provided as a one-stop service. In order to arrange these components separately, each component must be understood before combining them. Technical knowledge and working man-hours are, therefore, required, which in turn prolong the lead time for providing the network.

3) Autonomous decision making that does not require detailed instructions by humans

In constructing and providing the entire network in response to various demands, appropriate means of implementation must be considered in accordance with various situations. Presently, for example, all the details must be decided, such as the type of network and the type of cloud platform to be used, and the model of the network device and its configuration value. In addition, appropriate means must be selected from various response methods, from local response such as parts replacement, to drastic configuration change such as architecture change, for events such as failures and security risks during operation. If human instructions are required to make each of these decisions, it will be difficult for a small number of engineers to supply the increasing demand for network. Therefore, the network itself must be able to exert autonomy and acquire decision-making ability.

- Required network functions

The entire network operation consists of multiple layers and function groups. All of these factors need to be reformed toward the realization of autonomous networks, but it is difficult to replace all of hem at once. The functional groups required for network operation are divided into the three layers shown below, and the ideal form for each layer is discussed.

<u>1st stage: Softwarization of components</u>

A network is a system consisting of multiple components, and the concrete essence of all networks are the specific operations, such as “start,” “stop,” “change settings,” and “refer to status” for each component of the network. The network cannot be provided promptly if these operations are performed by human workers. Each operation, therefore, should be performed mechanically through an electronic instruction issued from a program. Replacing a component with a mechanically operable one is called softwarization. Softwarization is typically achieved through virtualization and the development of application programming interfaces (APIs).

2nd stage: Automation of monitoring and control across network

Controlling the electronically operable components to operate the entire network requires performing a series of operations in the correct order and gaining a central grasp of the state of multiple components. Therefore, automated monitoring and control functions are necessary.

3rd stage: Autonomy of situation judgment and response policy planning by advanced intelligence

Automation of monitoring and control can automate many of the tasks traditionally required for network operation, but this alone still leaves the task of "planning" to humans.

Therefore, tasks such as "designing the specific configuration of network based on the requirements," "planning a series of operation procedures required to build the designed network," "detecting anomalies that affect the satisfaction of requirements from changes in the state of the network components," and "planning the work necessary to continue to maintain the satisfaction of the requirements against the detected anomalies" must be executed autonomously.

- Network automation technologies

Among the above-mentioned functions, realizing autonomy listed in the third stage in particular entails solving the following problems so that the network can be used safely and securely as a social infrastructure.

1) Realization of high intelligence

Extremely diverse and unknown situations occur during the construction and operation of networks. It is impossible for humans to give instructions on how to deal with all of them in advance. Therefore, autonomous ability, such as "acquiring a response method from past cases," "creating and trying various cases automatically," and "judging unknown situations based on similar cases in the past," is required. Utilization of AI/ML is considered to be the key to achieving this.

2) Explainability and cooperation with people

If the contents of the autonomous network are black-boxed, they may become unhandled when an unintended operation is performed, making it difficult for the network provider to operate such a mechanism. If the network is given the autonomy and discretion to make judgments, it must also be held accountable. Further, it also needs the ability to adjust its decision according to human instructions as needed.

3) Scalability

The network is related to various components and technical elements that are provided by various companies and organizations. As new components and elements are being developed every day, they will continue to evolve on a daily basis. Therefore, the components and technical elements handled by autonomous networks also need to be freely extensible by a third party and need to be constantly updated.

To overcome the above issues, we need to promote appropriate standardization and cooperate with various organizations to stimulate technological development efforts. As such examples, we introduce the activities of ONAP (Open Network Automation Platform) and ITU-T (International Telecommunication Union-Telecommunication Standardization Sector) respectively below.

Activity example 1: ONAP

ONAP promotes standardization of a wide variety of functions, including design time and operation time, and aims to achieve optimization of the entire network by utilizing open interfaces [16]. As application scenarios, they target various communication services, such as 5G, VPN, and vCPE.

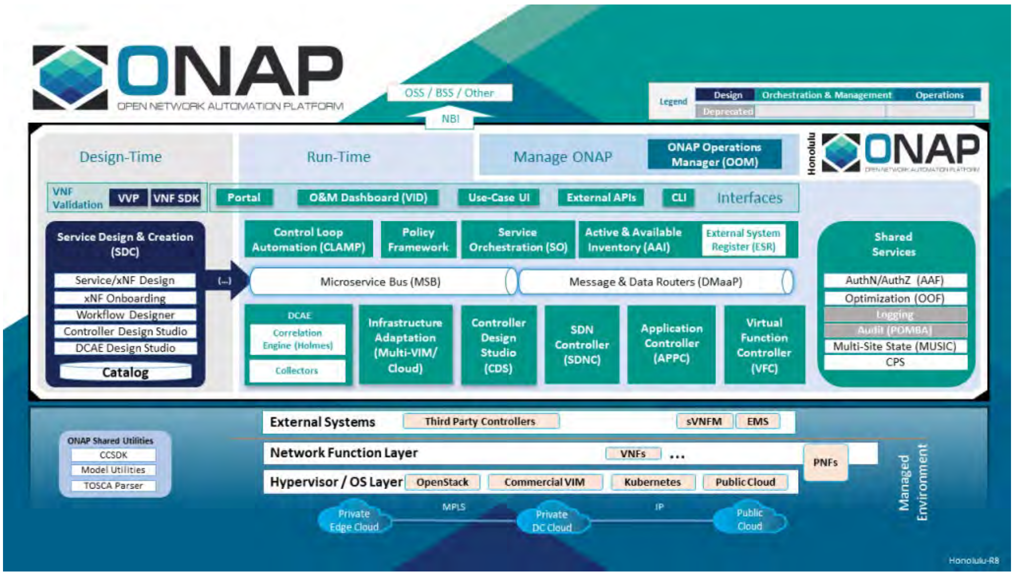

Figure 6.2-6 Overall architecture of ONAP

Figure 6.2-6 shows the overall architecture of ONAP. The Design-Time framework manages network-related design information (e.g., Helm chart, YAML). Based on the design information, the Run-Time framework controls communication equipment (e.g., router, mobile core) that constitutes the communication service. In addition, it receives requests from communication carriers and customers through the Northbound Interface (NBI). To realize autonomous network operation, it is necessary to control communication services based on “intent” that represents the intentions and expectations of communication carriers and customers. In the Kohn release, the latest release of ONAP as of November 2022, the development of functions related to communication service control by “intent” is promoted [17]. It is expected that autonomous network operation can be achieved by receiving intent information from communication carriers and customers via NBI and autonomously configuring and controlling communication services to satisfy the intent.

Activity Example 2: ITU-T

Focus Group on Autonomous Networks (FG-AN) in the ITU-T is working to define high-level requirements such as architecture framework and use cases for achieving autonomous network operation [18]. Figure 6.2-7 shows an example of the architecture discussed in FG-AN [19]. The architecture in Figure 6.2-7 relates to the framework for achieving UCN that operates autonomously. To satisfy the user's end-to-end communication quality requirements, the network controller can be created autonomously or updated based on the data accumulated in the Knowledge Base subsystem shown in the figure. Furthermore, an appropriate network controller is selected and applied according to various conditions such as network congestion.

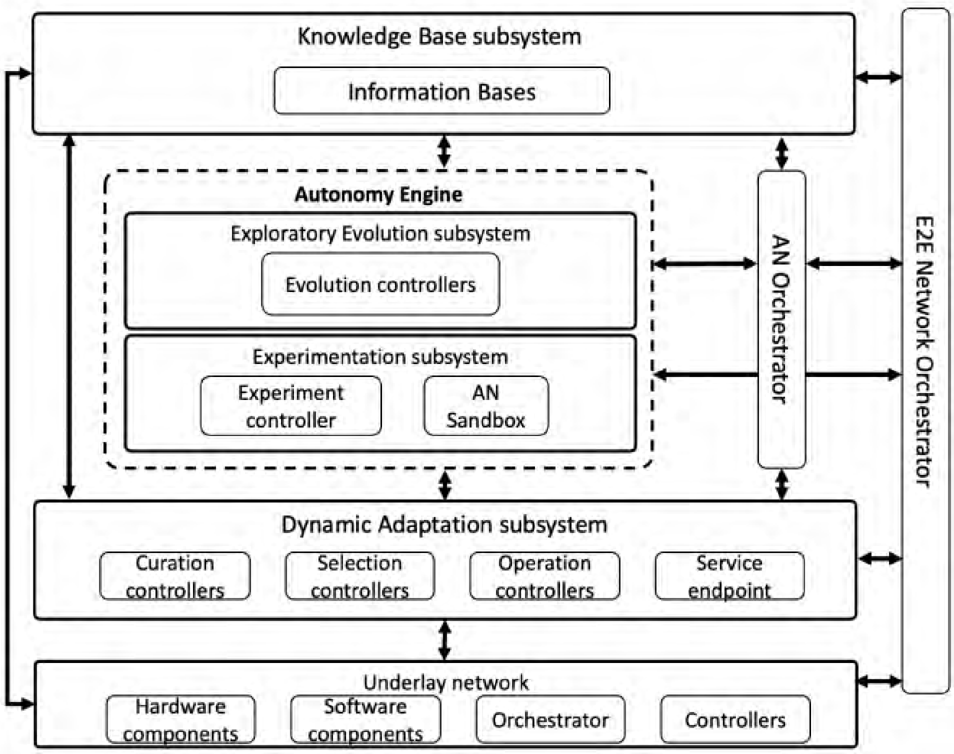

Figure 6.2-7 Examples of control architectures for autonomous networks

While strengthening cooperation with various organizations as described above, we need to solve the following problems and promote the standardization of autonomous networks.

1) Sharing knowhow in a multi-vendor environment
2) Verifying operations smoothly by adopting a common framework among many operators
3) Reflecting desired specifications or functions by providing source code

- Future vision: The evolution of Beyond 5G eliminates human bottlenecks and accelerates the further sophistication of network infrastructures.

Until now, human engineers have been responsible for daily network operations, but autonomous networks should relieve humans from such routine tasks. When that happens, it will be possible to concentrate efforts on further strengthening the autonomous network, such as developing response methods for new failure events and more advanced network functions. As a result, the advancement of network infrastructure will progress at an accelerating pace, paving the way for establishing the foundation that underpins the realization of DX.

6.2.5 Resilience

In the age of Beyond 5G since the 2030s, it is assumed that various services utilizing various features of Beyond 5G will be provided, and it is expected that it will become an increasingly important social infrastructure. For this reason, ensuring resilience is an important requirement in the consideration of architectures since the 2030s [16]. For example, in addition to autonomous driving of automobiles, there is also the possibility of the practical application of autonomous driving of ships and, in the future, autonomous driving of flying cars in line with the expansion of coverage. In addition, telesurgery utilizing the features of ultra-low delay and ultra-high speed and large capacity is being put into practical use, and it is thought that ensuring high QoS for these mission-critical services will become more and more important. Thus, Beyond 5G services are provided by vertical combination of network and various systems. In this section, we focus on two aspects of Beyond 5G resilience such as networks and systems, and also consider the resilience required for Beyond 5G. In addition, this section presents a resilient Beyond 5G architecture and explains how it works.

(1) Network resilience

In the age of Beyond 5G, communication networks are positioned as a particularly important infrastructure, and it is becoming increasingly important to ensure the resilience of networks themselves. The main causes of communication network failures are failures and damage to communication equipment and facilities, and they can also be caused by aging degradation or human errors such as construction. Depending on the scale of the failure, the failure may be a small-scale failure in a specific link or a specific device, or a large-scale failure in a plurality of base stations or a plurality of communication links or devices. In some cases, a large-scale failure occurs only in a specific operator and does not affect other operators at all. On the other hand, a large-scale disaster may occur due to a natural disaster such as an earthquake or tsunami.

Table 6.2-1 Main causes and scale of network failures

	Example of failure location	Cause
Large-scale failure	➢ Multiple communication nodes or links, ➢ Specific operator failures, etc.	➢ Natural disasters such as earthquakes and tsunamis, ➢ Simultaneous failure of multiple facilities and equipment
Small-scale failure	➢ Specific communication nodes or links, ➢ Specific equipment, etc.	➢ Deterioration of equipment, ➢ Construction errors, etc.

Depending on the scale of these failures, measures to ensure resilience may differ. In the case of a small-scale failure such as a failure of a specific communication link or equipment, there is a method of setting a detour route to avoid a failure location. In this case, there is a method in which a fault location is specified from the configuration management information of the network, the shortest detour route is specified by the Dijkstra method or the like, and switching is performed at once by the zero-touch operation. At this time, the detour route is identified using artificial intelligence (AI), machine learning (ML), etc. at the central management control center called the operation system, and it is transmitted to the related detour node to be switched all at once. Since management control is performed by a specific centralized management control node, the node itself may be damaged in the event of a large-scale disaster, which is considered to be unsuitable as disaster resilience. On the other hand, there is a system [21] in which a communication node or a base station adjacent to a fault quickly specifies a fault location and searches for a detour route in an autonomous distributed manner. In this case, since the node adjacent to the failure starts the route search voluntarily, the recovery time is shorter as compared with the centralized management control method. In addition, since it is a distributed management, it is considered that there is a possibility of coping with medium-scale failures.

Table 6.2-2 Classification and characteristics by management control method

	Scale of failure	Recovery time
Centralized management control	Small-scale failure	Relatively long
Distributed management control	Small-scale to medium-scale disability	Shorter

If both the centralized management control and the distributed management control fail due to a large-scale failure caused by a natural disaster such as an earthquake or tsunami, not only the terrestrial network (TN) but also the non-terrestrial network (NTN) may be temporarily used as a bypass route. Further, when a large-scale failure occurs only in a specific operator, the base station operated by another operator may be temporarily shared to offload the traffic.

In particular, with regard to information and communication systems for disaster prevention and mitigation, it is necessary to have communication means that can be reliably connected between disaster prevention bases even in the event of a disaster, and to be able to link systems and share information. For this reason, efforts are being made to share data by installing servers at each disaster prevention base, connecting the servers by a plurality of various communication means, and synchronizing and cooperating [22].

In this way, even though it is a Beyond 5G, as has been developed in the past, the network itself, including NTN and HAPS (High Altitude Platform Station), should be made redundant in the form of mesh or loop (ring) as an automatic failure recovery function in the event of a failure. In addition, it is important to have a function that identifies the point of failure instantly and reconfigures the detour route automatically using SDN (software-defined networking) technology. As for the detour route search, it will be important to provide an automatic recovery service according to the QoS requirements of service users with zero-touch operation using the AI/ML function. As for the autonomous operation of the network, see section 6.2.4 also.

(2) System resilience

In the future, various services and functions that take advantage of the characteristics of Beyond 5G will play increasingly important roles, and it is expected that they will be provided through networks that ensure the aforementioned resilience. It is considered that systems that provide these services and functions also need to be as resilient as the network itself. As more and more diverse services are provided in the future, the functions that make up them will become increasingly complex. The integration of complex systems may reduce the flexibility of reconfiguration in the event of an emergency. For this reason, in order to build a system that is highly resilient to failures, subsystems that are components of the system are brought together, and the subsystems are replaced with other subsystems as necessary after determining the status of each subsystem. In this way, it is considered necessary to make the operation of the system sustainable as a whole by responding flexibly. For example, as shown in the figure below, it is assumed that the flight management system is provided by a combination of subsystems of a certain non-terrestrial network (NTN) and a terrestrial network (TN). At this time, when a failure occurs in the NTN or TN subsystem, it is possible to ensure the sustainability of the service by switching to another subsystem that has been brought over and does not have a failure. Switching subsystems and choosing the best combination is the responsibility of the orchestrator. Therefore, it is desirable to provide an open common interface between the orchestrator and the subsystems. As a service, a system configuration combined with an avatar robot control system or a smart city management system instead of a flight management system will be treated in the same way. In this way, by ensuring the resilience of services, it is possible to ensure the sustainability of services.

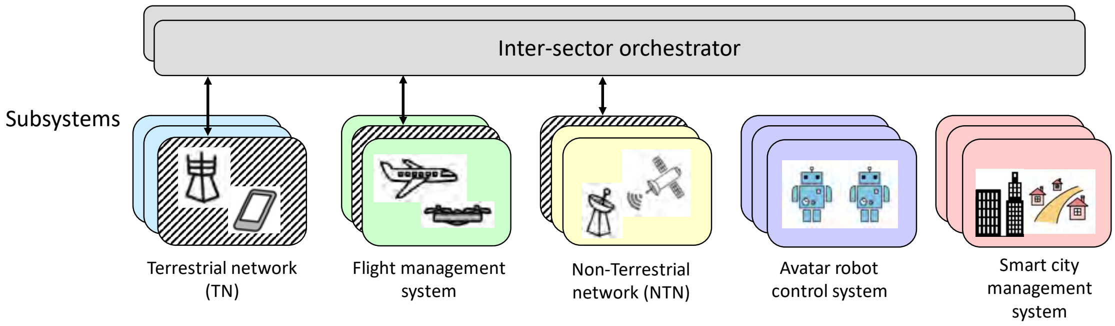

Figure 6.2-8 Orchestration of subsystems [9]

The above reconstruction decisions and subsystem combinations have involved humans to some extent. As the system becomes more complex, there may be limits to the time and capacity to respond. Therefore, it is important to have an orchestrator that automates the integration and decoupling of subsystems, and to have a mechanism that positions various subsystems under the rules that can be agreed upon. In addition, it is necessary to provide an environment in which service providers focus on the startup of necessary services at the time of a failure by hiding the complexity by black-boxing the existence of subsystems.

(3) Resilient Beyond 5G Architecture

In order to ensure resilience, the Beyond 5G architecture [23] includes a mechanism for providing a service enabler function that facilitates the handling of subsystems by service providers in addition to an orchestration function that optimally combines subsystems across networks and systems. The architecture is shown in the figure below. As with SEAL (Service Enabler Architecture Layer for Verticals) [24] under consideration in 3GPP SA6, service enablers are assumed to provide a part of common service functions that across related industries. However, the architecture shown here is not limited to network services. In addition, an orchestrator is not only a function of connecting communication network services across heterogeneous networks such as NTN and TN by zero-touch operation, as in the case of ZSM (zero-touch network and service management) [25] being studied by so-called ETSI,

[9] A part of figures is provided by NICT

but also a function of selecting and combining the optimum subsystems across subsystems operated by a plurality of business operators (hereinafter referred to as sectors) in the architecture shown here. In this way, by enabling zero-touch operation for optimization between sectors, it is possible to provide sustainable services. This architecture will provide a mechanism that ensures not only the aforementioned network resilience but also the resilience of the systems that provide the services. See also Figure 6.2-1 for an overview of the Beyond 5G architecture.

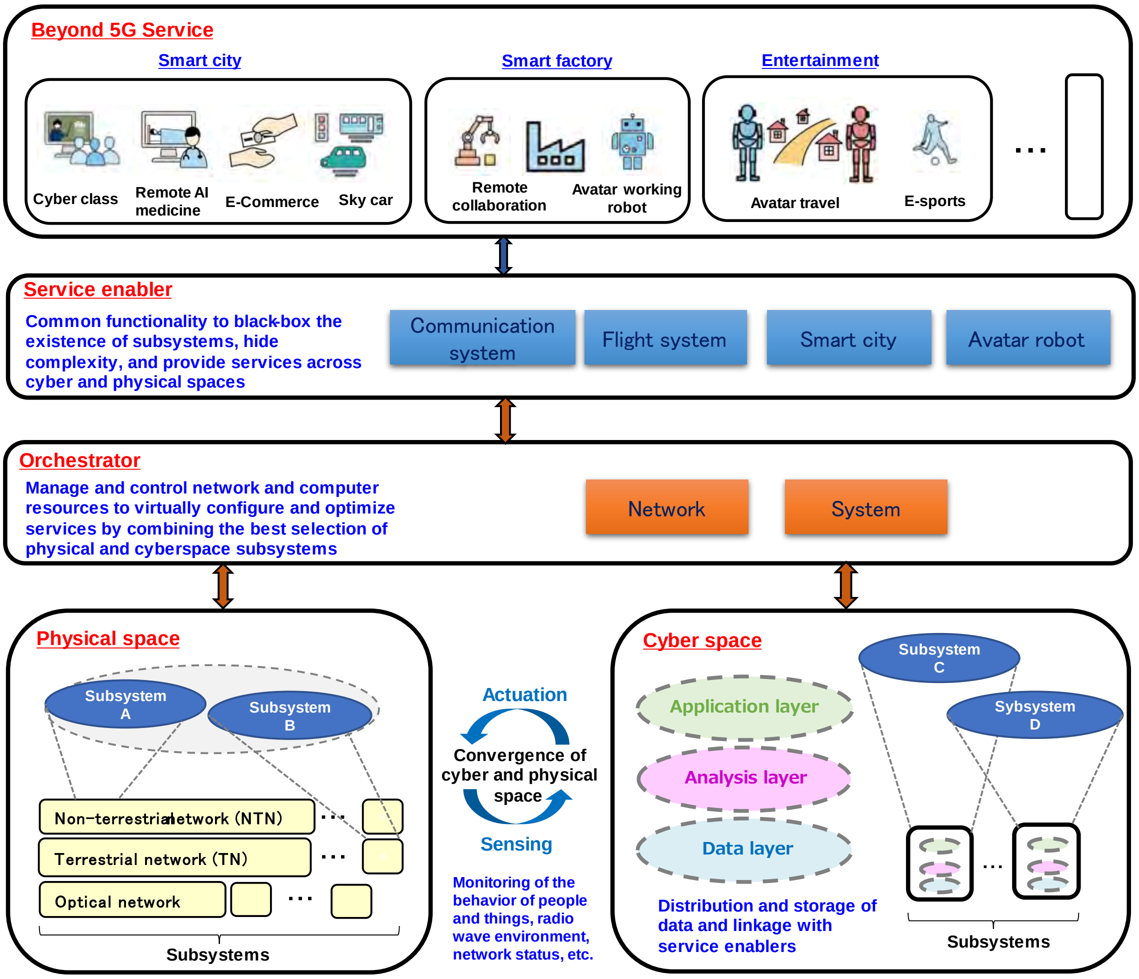

Figure 6.2-9 Beyond 5G architecture application to resilience[10]

An example of the service enabler function in this architecture is shown in Table 6.2-3. Beyond 5G is expected to expand the coverage of telecommunications services not only on land but also at sea and in space. As a service enabler function corresponding to this, it is assumed that functions such as highly reliable aerial communication and wide-area maritime communication are required corresponding to the communication system. In addition, service

[10] A part of figures is provided by NICT

enabler functions, such as high-precision position identification and optimum flight routes, will be important in response to the spread of drones and the practical application of flying vehicles in the future. In addition, since avatars are expected to play an active role in various situations with the spread of Metaverse, service enabler functions such as industry-common avatar VR collaboration and ultra-realistic sensation sharing functions are also required. Furthermore, since it is assumed that the activity between avatars becomes active, it is also assumed that the service enabler function of the identity authentication of the avatar becomes important. In response to smart cities, the service enabler function for Digital Twin management and the service enabler function for monitoring the flow of people and traffic will also become important for virtualizing the entire target city.

Table 6.2-3 Examples of service enabler functions

Target systems	Individual function
Communication systems	➢ High-resilience air communication ➢ Wide area marine communication
Flight systems	➢ High-precision positioning ➢ Optimal flight paths
Avatar robots	➢ Collaborative VR work ➢ Ultra-realistic sharing ➢ Personal identification
Smart cities	➢ Digital twin management ➢ Ascertaining human traffic

On the other hand, Table 6.2-4 shows an example of the orchestrator function in this architecture. In response to the aforementioned network resilience, it is important to manage the communication quality in order to ensure the automatic fault recovery function of the network itself and QoS for service users. In addition to drones and flying vehicles, the expansion of coverage will also make it more important for HAPS, the Low Earth Orbit (LEO) satellite, and the Geostationary Orbit (GEO) to be able to manage frequency resources associated with their orbits. On the other hand, in order to ensure the resilience of the system, the functions of the orchestrator, such as the automatic failure recovery function of the subsystem and the edge computer resource management function corresponding to the time fluctuation of the human flow and population density, are also considered to be important.

Table 6.2-4 Examples of orchestrator function

Targets for ensuring resilience	Individual function
Networks	➢ Automatic failure recovery ➢ Communication quality management ➢ Frequency resource management
Systems	➢ Automatic failure recovery ➢ Edge computing resource management ➢ Artificial intelligence and machine learning ➢ Distributed processing ➢ Low power consumption control

(4) Summary

As targets to ensure resilience, this section shows the resilience of networks and the resilience of systems. Examples of the Beyond 5G architecture to ensure such resilience are shown, and various functions and mechanisms of the orchestrator and the service enabler are shown as components. In particular, service enablers may have different functions for different use cases, as they depend on the corresponding system. We also showed that the orchestrator required different functions depending on the target network and system.

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6.3 Technical aspect of radio spectrum

6.3.1 Trends in radio frequency resource utilization and investigation on usage of the frequency bands 7 – 15 GHz

To provide the high performance required for Beyond 5G, it is essential to effectively utilize existing frequency resources and develop new frequency bands. This section first provides overview of the trends in the existing and new radio frequency resource utilization. And the results of WC-23 (World Radiocommunication Conference 2023) are shown focusing on frequency bands that have the potential to accommodate wider channel bandwidths than around 100 MHz when studying new frequency bands for Beyond 5G. Furthermore, highlighting 7125 − 8400 MHz and 15.35 GHz from those frequency bands as ranges to be studied in WRC-27 Agenda Item 1.7, an investigation of Japanese domestic usage of them is discussed. Finally, status in Japan and 3GPP of the frequency range 6425 − 7125 MHz is explained that WRC-23 identified for IMT in Agenda Item 1.2.

6.3.1.1 Trends in radio frequency resource utilization

In the 5G NR of 3GPP, as shown in Figure 6.3-1, the radio frequency used in the fourth-generation system (LTE-Advanced) has been expanded, and the use of the sub-6 GHz band (FR1 region) and the frequency band of 24.25 GHz or higher (FR2 -1, FR2 -2 regions) is also being promoted.

In Figure 6.3-1, the horizontal axis represents the frequency, and the vertical axis represents the bandwidth of the frequency band on the logarithmic axes defined by the standard, and the diagonal lines in the figure represent points where the ratio of the bandwidth (BW) of each frequency band to its center frequency (fc) is 0.3% to 30%, respectively.

In the lower frequency portion of the FR1 region, frequency division duplexing (FDD), which performs simultaneous transmission and reception by separating uplink and downlink streams in the frequency domain, is mainly used, and it can be seen that the BW/fc is suppressed to several% or less so as to obtain sufficient interference suppression between uplink and downlink of the radio streams. In the upper frequency region in the FR1, i.e. frequency bands exceeding 3 GHz, and in the FR2-1 and FR2-2 regions, time division duplex (TDD) is applied to separate the uplink and downlink in the time domain. Therefore, frequency bands with BW/fc of exceeding 10% are also specified, and broadband high-speed communication and large-capacity communication can be realized.

In addition to further effective utilization of these frequency resources, utilization of the EHF band including terahertz range (shown as pale blue shaded part in Figure 6.3-1, which enables broadband and high-speed communication, is useful towards Beyond 5G development.

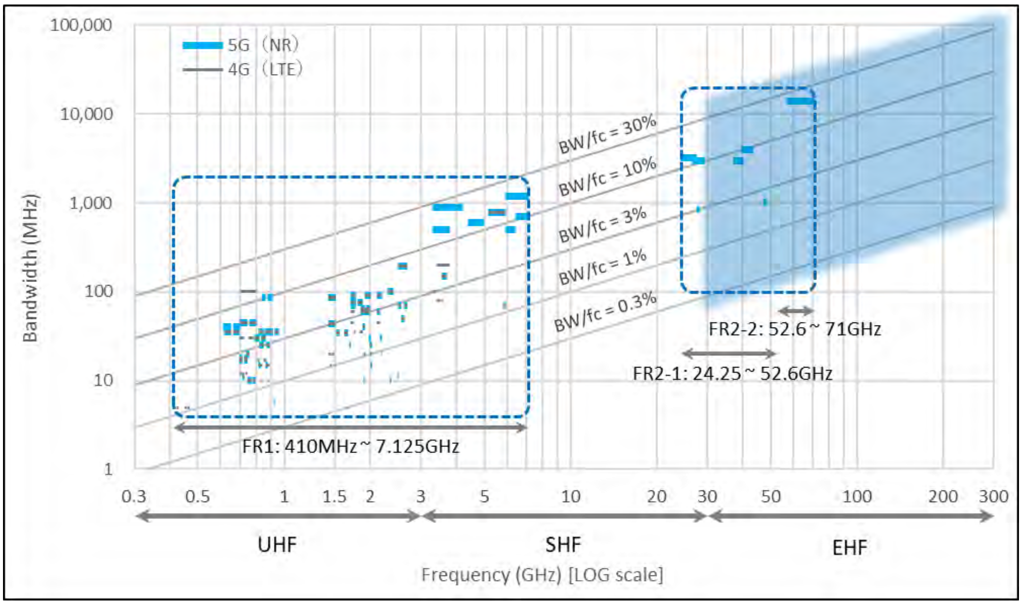

Figure 6.3-1 Frequency bands defined for 4G and 5G
(3GPP specifications [1] [2] [3] [4]) and expansion to EHF band

As in other regions and countries, radio spectrum resources are being used by various radio systems in an extremely dense manner in Japan (see Figure 6.3-2). Given the increasing demand due to the sharp surge of communication traffic, it is crucial to develop a rational way to make more effective use of the existing frequency bands already used in 4G and 5G systems, and to exploit the new spectrum for the benefit of the public..

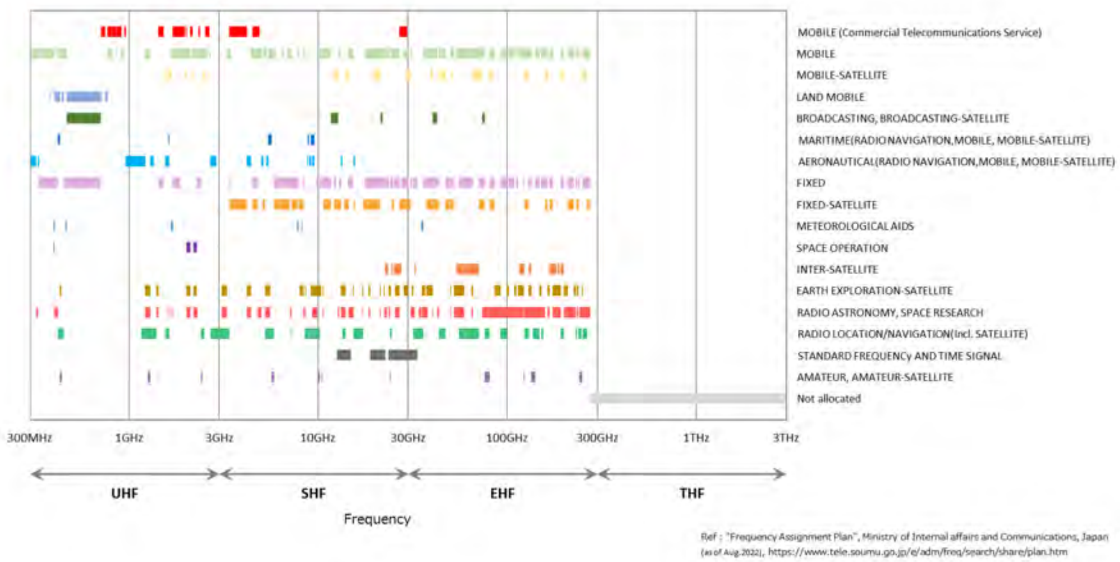

Figure 6.3-2 Frequency assignments in Japan [5]

For potential future use of the radio frequency, there has been the following discussions and views in different organizations and groups. For Beyond 5G, the use of new frequency resources beyond 6 GHz band, mmWave, and Terahertz, which enable further broadband, are being studied, on the other hand several organizations also mentioned that it is important to use the existing frequency bands below 6GHz and the new bands together.

ITU-R Working Party 5D is drafting a Report ITU-R M.[IMT.Above 100 GHz] to provide information on technical feasibility of IMT in bands above 100 GHz, including information on propagation environment and channel models, as well as newly developed technology enablers such as active and passive components, antenna techniques, deployment architectures, and the results of simulations and performance tests. The new report is to be completed in May 2024. Furthermore, studies related to radio propagation are also found in the section 6.3.2 of this White Paper.

The APT Conference Preparatory Group for WRC-23 (APG-23) was established with the objective of harmonizing views and developing common proposals from the Asia-Pacific region for the World Radiocommunication Conference-23 (WRC-23), and APG23-5 meeting in February 2023 had agreed to have further discussion on WRC-23 Agenda Items 10 (New proposal for WRC-27 agenda item) including

- Allocation of 275-300 GHz to MS, FS, RAS and EESS (passive) on a primary basis, and
- IMT for 2030 and beyond.

The APT Wireless Group (AWG) is covering various aspects of emerging wireless systems including IMT/IMT-Advanced to meet the upcoming digital convergence era in the Asia-Pacific region. AWG published a survey report in May 2023 for "Current status and future plan of usage in the frequency ranges of 7.125-24 GHz and 92-300 GHz in Asia Pacific region" in order to support a further study on considering the possibility of additional frequency bands for International Mobile Telecommunications (IMT), in the view of the harmonization of spectrum usage, the efficient and effective deployment of IMT systems[11].

Hexa-X in April 2021 delivered a report describing the vision to guide the future research towards 6G [6]. It presented spectrum evolution aspects in 6G which includes the extension of spectrum boundaries, spectrum allocations above 52.6 GHz and spectrum utilization improvements. Hexa-X's report "Targets and requirements for 6G - initial end-to-end architecture" [7] in February 2022 also discussed the spectrum evolution aspects relevant to extending spectrum utilization both in frequency ranges already in use (i.e., low, mid, and mmW) and in new frequency ranges (i.e., 100-300 MHz and above) to address 6G service requirements as well as flexible spectrum usage and management.

The Next G Alliance is an initiative to advance North American mobile technology leadership over the next decade through private sector-led efforts. Its work will encompass the full lifecycle of research and development, manufacturing, standardization and market readiness. The Next G Alliance in June 2022 released a report for 6G technologies. [8] The report stated that more spectrum is required to accommodate 6G innovation, and further studies are necessary into the novel usage of spectrum between 7 to 24 GHz, along with an extension to upper Millimeter Wave (mmWave) frequency bands. The 7 to 24 GHz range can leverage massive Multiple-Input and Multiple-Output (MIMO) technology to ensure good coverage and improve capacity. And mmWave and THz spectrum can be considered for providing high data rates and enabling accurate localization and sensing.

The IMT-2030 (6G) Promotion Group is the flagship platform in China to promote 6G R&D and international cooperation, and it is driving the cutting-edge research on 6G technology and industry in China. It released its white paper in June 2021, which discussed the efficient use of high, medium, and low frequency bands to fulfill 6G spectrum needs, as well as terahertz/visible light communications.[9]

The 5G Forum in Korea is an organization with the aim of further evolution of 5G including 6G around year 2030. 5G Forum its white paper in February 2021, stated the followings.[10]

- it is essential to utilize a new and wider spectrum, such as in the terahertz bands and optical bands.
- Although the new spectrum above 100GHz is attracting an increased amount of interest for 6G communication systems, spectrum resources under 6GHz are still very important due to their capacity to broadcast over a much wider coverage area than such a high-frequency spectrum. Under-6GHz, mmWave, and THz spectrum resources need to be utilized together.

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6.3.1.2 Identification of spectrum in WRC for IMT terrestrial component

The WRC (World Radiocommunication Conference) is a meeting held normally every three or four years to revise Radio Regulations, that is the treaty governing international radio order such as the use of the radio frequency spectrum and the satellite orbits, the regulations and technical standards regarding the operation of radio stations. WRC is a very important meeting when studying new frequency bands for Beyond 5G, since each country will decide how to use each domestic frequency bands based on WRC decisions.

WRC-23 was held during November 20 and December 15, 2023 and made the following decisions regarding future spectrum for terrestrial IMT. WRC-23 Agenda Item 1.2 had the following conclusions on 6425 – 7125MHz as frequency bands for IMT terrestrial component.

- 6425 – 7025 MHz is identified for IMT in the entire Region 1[11] and in three countries (Cambodia, Lao and Maldives) in Region 3[12],
- 7025 – 7125 MHz is identified for IMT in both Region 1 and Region 3, and
- 6425 – 7125 MHz is identified for IMT in two countries in Region 2[13] (Mexico and Brazil).

Furthermore, new agenda items for WRC-27 were agreed including one for future terrestrial IMT spectrum. The new agenda item for the terrestrial IMT spectrum is to carry out sharing and compatibility studies and develop technical conditions for the use of IMT in the following frequency bands (Agenda Item 1.7).

- 4400 - 4 800 MHz,
- 7125 – 8400 MHz and
- 14.8 - 15.35 GHz.

[11] Region 1: Europe, Russia, Arab and Africa
[12] Region 3: Asia and Pacific
[13] Region 2: North and South Americas

WRC-23 also agreed to have a preliminary agenda item for WRC-31, to study frequency-related matters for IMT identification in the frequency bands 102 - 109.5 GHz, 151.5 – 164 GHz, 167 - 174.8 GHz, 209 - 226 GHz and 252 - 275 GHz. It should be noted that WRC-27 will review whether it should be an agenda item for WRC-31 not and its frequency bands thus it is subject to change.

REFERENCES

[1] World Radiocommunication Conference 2023 (WRC-23) "Provisional Final Acts", December 2023

6.3.1.3 Survey on radio frequency on the range of 7125 MHz to 15.35 GHz

The survey on usage of radio frequency ranges of 7125 MHz to 15.35 GHz in Japan was conducted to evaluate existing radio systems, their usage status, possibilities of contiguous and wide spectrum. The followings are views on the ranges of 7125 – 8400 MHz and 14.8 – 15.3 5 GHz, which are in the scope of Agenda Item 1.7 for WRC-27.

1) 7125 – 8400 MHz

For the usage status in Japan in this range, 7425 – 7725 MHz is used by fixed systems for commercial telecommunications, public, general and broadcast auxiliary services. The number of radio station on 7425 - 7725 MHz is approximately 3,750 as of year 2021. 7250 – 7750 MHz (space-to-Earth) and 7900 – 8400 MHz (Earth-to-space) are used by fixed and mobile satellite systems for commercial telecommunications and public services. 8025 – 8400 MHz is used by earth exploration satellites (space-to-Earth).

It should be noted that the whole range is allocated to Mobile Service on a primary basis in ITU Radio Regulation. It is expected to have wide and contiguous spectrum on this range for IMT considering that WRC-23 identified 7025 – 7125 MHz for IMT in Region 3 including Japan. In WRC-23, this range was proposed by ASMG[14] and CITEL[15] for future IMT spectrum, and Vietnam and Lao in APT region proposed this range. India made a similar proposal for 7125-7750 MHz.

2) 14.8 – 15. 35 GHz

[14] Arab Spectrum Management Group (ASMG)

[15] The Inter-American Telecommunication Commission (CITEL)

For the usage status in Japan in this range, 14.4 – 15.35 GHz is used by fixed or mobile systems for commercial telecommunication services. The number of radio stations on 14.8 – 15.35 GHz is 1,085 as of year 2021. 14.7 – 14.9 GHz and 15.25 – 15.35 GHz are used by mobile systems for public services (helicopter video transmission system). The number of radio stations for the helicopter video transmission system is 63 as of year 2021.

It should be noted that the whole range is allocated to Mobile Service on a primary basis in ITU Radio Regulation. In WRC-23, this range was proposed by ASMG and RCC[16] for future IMT spectrum, and Vietnam, Lao and India in APT region proposed this range. Japan proposed a study of 14.9 – 15.2 GHz.

Some parts of the ranges for future IMT spectrum are extensively used by the incumbent radio systems. Therefore, it is vital to study the compatibility between those radio systems and IMT, and find sharing conditions ensuring the deployment of Beyond 5G possible while protecting the incumbent systems.

REFERENCES

[1] MIC Radio Use Web Site, Spectrum Charts (as of 1st March 2023)

[2] MIC Radio Use Web Site, Frequency Assignment Plan (as of December 2023)

6.3.1.4 Status of the range 6425 MHz - 7125 MHz

As described above, WRC-23 identified 6425 – 7125 MHz for IMT in some regions and countries, in Agenda Item 1.2 to study the spectrum for terrestrial component of IMT. 6425 – 7125 MHz is a continuous frequency range of 7125 MHz - 15.35 GHz of which the usage status was investigated in the section 6.3.1.3, and it is an important frequency band from the perspective of securing the continuous and wide band expected for Beyond 5G in the future.

For this band in Japan, the “Land Wireless Communications Committee” in MIC (Ministry of Internal Affairs and Communications) from the fiscal year 2021 to 2022 has conducted sharing studies between Wireless LAN on 6GHz band and the incumbent systems, such as telecommunications business fixed stations, public/general business fixed stations, satellite communication systems (uplink), radio astronomy, and broadcast program relay systems.

Globally, a Study Item is underway at 3GPP to investigate the regulatory framework of each country/region for 5.925 - 7.125 GHz, and the study results are to be compiled in TR 37.890 in March 2024. In addition, a band plan for the 6GHz band has already been defined,

[16] The Regional Commonwealth in the field of Communications (RCC)

and the possibility of using IMT with the premise of protecting incumbent systems is a future study item.

Table 6.3-1: 6GHz band plan in 3GPP (licensed band)

Band number	Lower limit (MHz)	Upper limit (MHz)
n104	6425	7125

Table 6.3-2: 6Ghz band plan in 3GPP (unlicensed band)

Band number	Lower limit (MHz)	Upper limit (MHz)
n96	5925	7125
n102	5925	6425

China has already allocated this band for IMT use, and it has been officially effective from July 1, 2023. [1]

REFERENCES

[1] Ministry of Industry and Information Technology, "中华人民共和国无线电频率划分规定", July 2023

6.3.2 Studies related to Radio Propagation

This section summarizes several recent results of studies on the nature of radio propagation and related studies.

(1) Path loss of frequency band at 2 GHz, 26 GHz, and 300 GHz bands in urban microcell scenario

Path loss measurement results at 2 GHz, 26 GHz, and 300 GHz conducted in an urban microcell environment around the Tokyo station were reported in [1][2].

The path loss measurement was made in a typical urban microcell environment as shown in Figure 6.3-3.

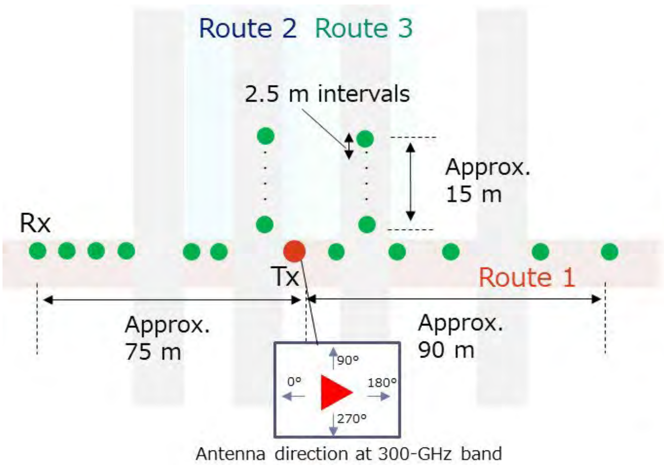
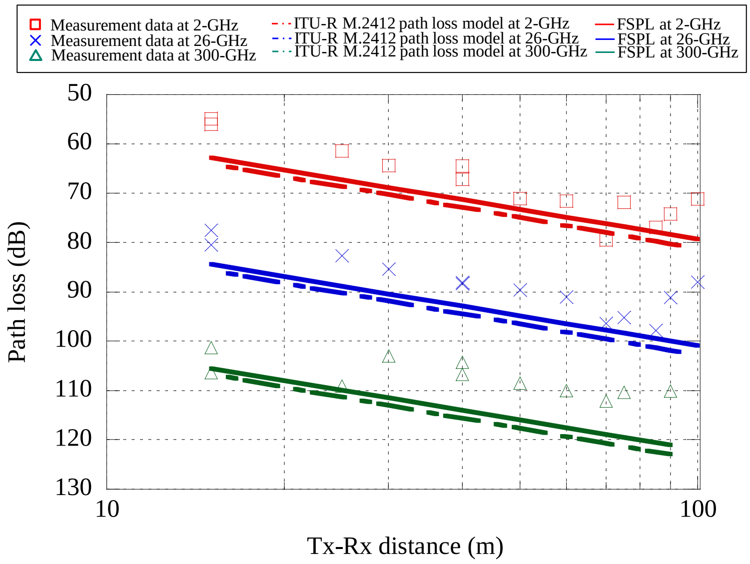
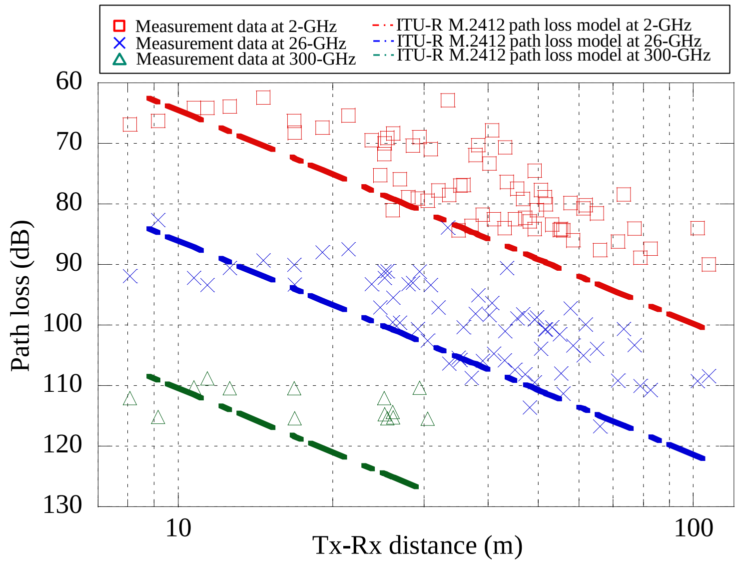


Figure 6.3-3 Path loss measurement in an urban microcell environment

Figure 6.3-4 shows the measurement results with the free space path loss (FSPL) model in ITU-R M.2412 [3]. Results show that the measurement path loss in route 1 is lower than the ITU-R M.2412 path loss model due to the reflection and scattering from surrounding objects, and the measurement path loss in routes 2 and 3 show a similar tendency as the ITU-R M.2412 path loss model at 2 GHz and 26 GHz. At 300 GHz, measurement results show a similar tendency at the range from 8 m to 20 m of Tx-Rx distance, while the measurement data at 30 m is lower than the ITU-R M.2412 path loss model.



(a) Route 1



(b) Route 2 and 3

Figure 6.3-4 Measurement of path loss characteristics

REFERENCES

[1] M. Inomata et.al, “Radio Propagation Characteristics for Pioneering Terahertz Wave Bands in 6th Generation Mobile Communication Systems,” IEICE Technical Report RCS2020-98 (2020-10).

[2] M. Inomata et.al, “Path Loss Characteristics from 2 to 100 GHz Bands in Urban Microcell Environment for 6G,” IEICE Technical Report, A･P2021-51 (2021-08).

[3] ITU-R M.2412, “Guidelines for evaluation of radio interface technologies for IMT-2020,” Sep. 2017.

(2) Indoor line-of-sight and outdoor urban street canyon environments

Propagation simulations based on ray-tracing method for indoor line-of-sight (LOS) environments and outdoor urban street canyon at 3 GHz and 97 GHz, experimental measurements of propagation loss (at 3 GHz, 20 GHz, 97 GHz, 160 GHz, and 300 GHz) and angle of arrival (at 28 GHz, 40 GHz, 97 GHz, 160 GHz, and 300 GHz), and measurement of human body blockage loss (from 0.8 GHz to 150 GHz) were studied in [1] -[5].

Results of studies on the ray-tracing method and propagation loss measurement for indoor LOS environments are briefly introduced below.

- Ray-tracing and free space propagation model comparison for indoor line-of-sight

  A comparison of ray-tracing and free space propagation model for indoor line-of-sight environment at 3 GHz and 97 GHz is shown in Figure 6.3-5. At both frequencies, the distributions of the ray-tracing results are similar with the free space losses, while the absolute loss at 97 GHz is larger than that at 3 GHz.

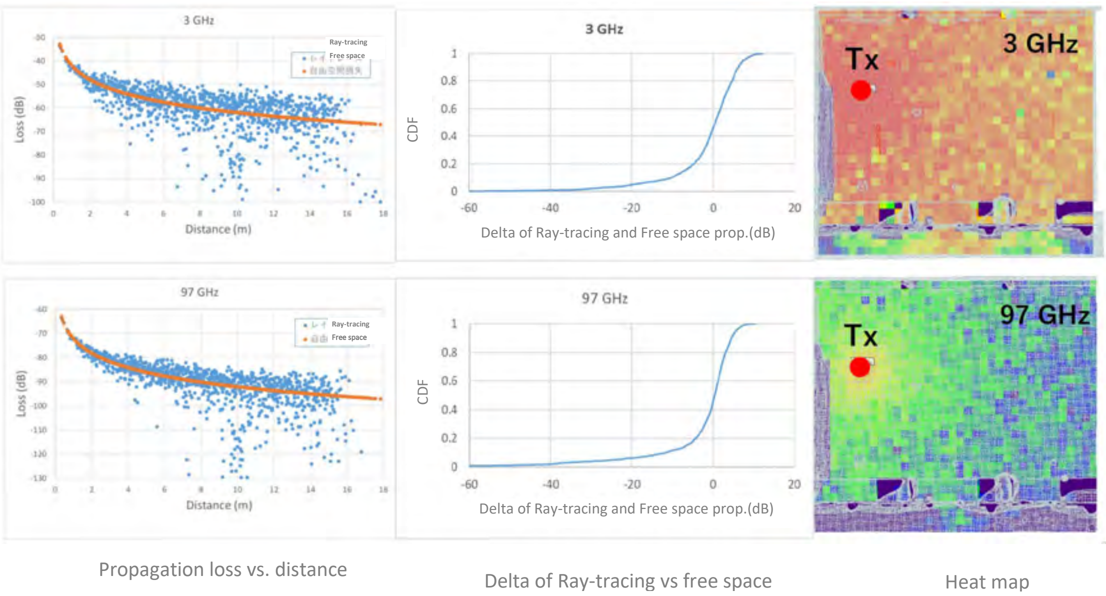


Figure 6.3-5 Ray-tracing and free-space propagation model comparison (indoor propagation) [1]

- Ray-tracing and free space propagation model comparison for outdoor street canyon

  Figure 6.3-6 presents a comparison of ray-tracing and free space propagation model for outdoor street canyon environment at 3 GHz and 97 GHz. At both frequencies, the distributions of the ray-tracing results are similar with the free space losses, while the absolute loss at 97 GHz is larger than that at 3 GHz.

Figure 6.3-6 Ray-tracing and free-space propagation model comparison (Outdoor street canyon) propagation [1]

- Measurement results for indoor line-of-sight environment

  A comparison of ray-tracing and free space propagation model for outdoor street canyon environment at 3 GHz and 97 GHz is shown in Figure 6.3-7. At both frequencies, the distributions of the ray-tracing results are similar with the free space losses, while the absolute loss at 97 GHz is larger than that at 3 GHz.

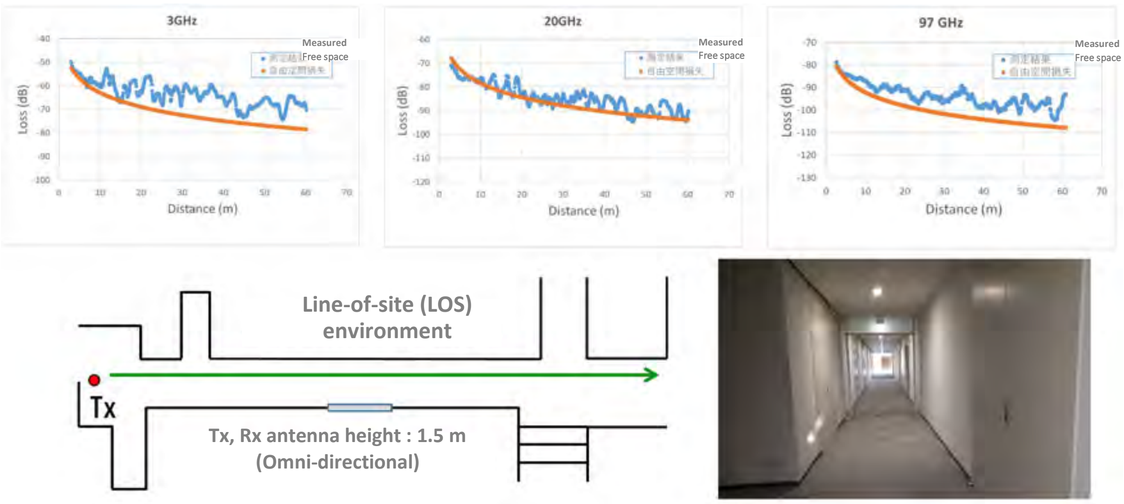


Figure 6.3-7 Measurement results for indoor line-of-sight environment [1]

- Delay spread and angular spread up to 100 GHz band

  Further relevant studies for delay spread and angular spread up to 100 GHz band can be found in [2].

- Angle of arrival of radio waves at 160 GHz and 300 GHz

  The influence of reflected waves at 300 GHz has been studied by simulation [3]. In addition, some measurements of the propagation loss of direct and reflected waves at 160 GHz and 300 GHz have been performed in the corridor and conference room environments. 160 GHz measurement results in the corridor have been reported in [4][6].

  Figure 6.3-8 shows the measurement results of the angles of arrival of radio waves at 160 GHz and 300 GHz in the conference room [5][6].

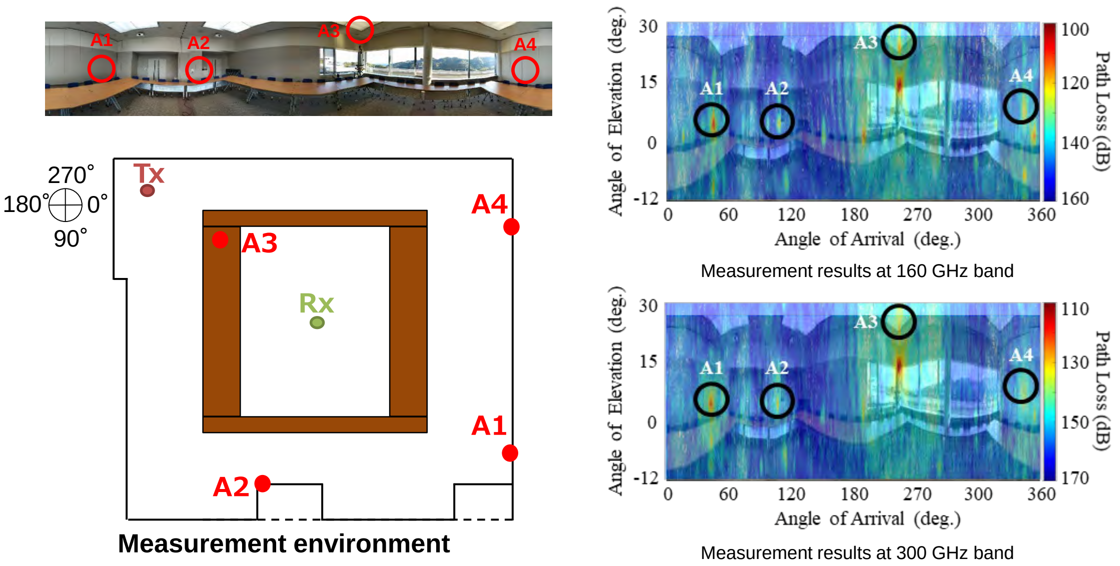


Figure 6.3-8 Measurement results for indoor line-of-sight environment [5]

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[1] Y. Oda, “Technical study on radio wave propagation characteristics of Terahertz wave”, Planning and Strategy Committee of Beyond 5G Consortium, (in Japanese, Feb. 2021).

[2] M. Nakamura et.al, “Delay Spread and Angular Spread up to 100 GHz band in an Indoor Environment”, IEICE Technical Report AP2020-105, (in Japanese, Jan. 2021).

[3] M. Nakamura et.al, “The Effect of Reflection Wave at 300 GHz-Band in Indoor Environment Simulations”, Proc. IEICE Gen. Conf. B-1-23, (in Japanese, Mar. 2022).

[4] M. Nakamura et.al, “Measurement of 160 GHz-Band Reflected Waves in an Indoor Environment with Human Blockage”, Proc. Commun. Conf. IEICE B-1-12, (in Japanese, Sep. 2022).

[5] M. Nakamura et.al, “Measurement of Multipath Waves at 160 GHz and 300 GHz Bands in an Indoor Environment”, IEICE Technical Report AP2022-40, (in Japanese, Jun. 2022).
[6] “PATH LOSS STUDY in indoor scenario TOWARDS A PDN Report ITU-R M.[IMT.Above 100 GHz]”, ITU-R WP5D, Doc. 5D/1312-E.

(3) Path loss modeling using machine learning

In the statistical modeling of radio wave propagation characteristics, propagation loss is expressed by a formula incorporating environmental parameters such as building height and road width. The formula is then adjusted to simulate actual measured data using a multiple regression analysis method.

In order to obtain model equations for specific locations and environments, parameters such as building height and road width must be extracted from input data of map data and other spatial information. The method for obtaining these parameters from the map data using deep learning technology was examined in [1][2][3]. Using this method enabled constructing a highly accurate radio wave propagation characteristic model specific to an arbitrary place.

Figure 6.3-9 shows the root mean square error (RMSE) from the measurement results when using the aerial photograph or the image of the building occupancy rate shown in Figure 6.3-10 as the input image, either for the receiving location or for both the receiving and transmitting locations.

More accurate results could be obtained by using the building occupancy information at the transmitting and receiving points.

Figure 6.3-9 Aerial photograph (left) and building occupancy chart (right)

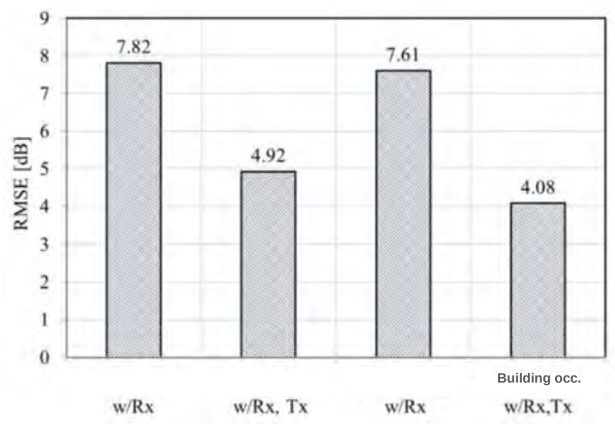

Figure 6.3-10 Root mean square error (RMSE) from the measurement results

REFERENCES

[1] T. Hayashi, T. Nagao and S. Ito, “A study on the variety and size of input data for radio propagation prediction using a deep neural network,” 2020 14th European Conference on Antennas and Propagation (EuCAP), 2020.

[2] T. Nagao and T. Hayashi, “Study on radio propagation prediction by machine learning using urban structure maps,” 2020 14th European Conference on Antennas and Propagation (EuCAP), 2020.

[3] T. Nagao and T. Hayashi, “Geographical Clustering of Path Loss Modeling for Wireless Emulation in Various Environments,” [Manuscript submitted for publication] 2022 15th European Conference on Antennas and Propagation (EuCAP), 2022.

(4) Design of ground to NTN communication using the 100 GHz band

Link budgets from the ground up to an altitude of about 20 km are studied for application to feeder links to the High Altitude Platform Station (HAPS) and aircraft [1][2]. Regarding HAPS frequency assignment, discussions on the assignment of the Q-band are currently taking place in ITU-R Working Party 5C [3].

According to the atmospheric gas attenuation model [4] at altitudes up to 20 km from the 0 km above sea level (Figure 6.3-11), the propagation loss at around 100 GHz is the smallest in the terahertz band. Even considered about losses of clouds and rainfall, the 100 GHz band has better properties for feeder link systems [2].

The feasibility of the feeder link system that uses the HAPS at an altitude of 20 km and 100 GHz band to ensure the data rate of 20 Gbps in clear weather and 10 Gbps in light rain, as shown in Figure 6.3-12, is studied. Table 6.3-1 shows examples of link budgets for different weather conditions. The received carrier noise density ratio (C/N_0) in Table 6.3-1 for clear weather is 153.2 dB-Hz, and the difference from the desired C/N_0 110.9 dB-Hz for 256-QAM-OFDM in Table 6.3-2 is 42.3 dB as a margin.

As an example, the following is a calculation example of the effective data rate under the following conditions. Assuming a frequency bandwidth of 2 GHz for one channel, the data rate of 11.4 Gbps can be obtained under 256-QAM-OFDM conditions. Similarly, 8.3 Gbps can be estimated using 64-QAM-OFDM.

Bandwidth	2.0 GHz/channel
Modulation bits	8bit/symbol (256-QAM), 6bit/symbol (64-QAM)
OFDM symbol length	4.5 μ s (GI=0.404 μ s)
FFT length	8192
Number of subcarriers for user	6900
LDPC coding rate	1344/1440

Moreover, two-channel aggregation technique will enable the effective data rate of 20 Gbps in sunny weather and 10 Gbps in the light rain condition.

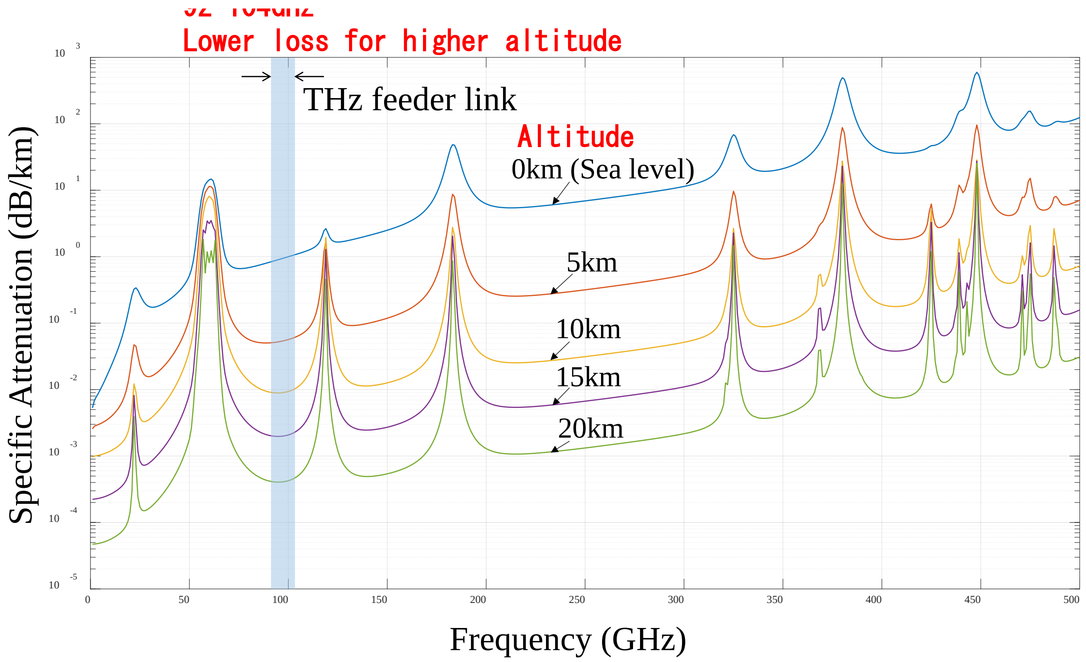

Figure 6.3-11 Propagation losses due to atmospheric gases and related effects [4]

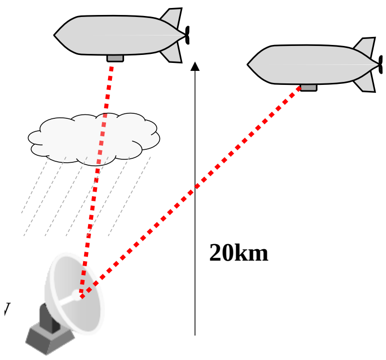

Figure 6.3-12 Concept of ground to NTN communication using 100GHz band

Table 6.3-1 Link budget for ground to NTN communications using the 100GHz band

		Sunny	Clouds	Light Rain	Severe Rain
Transmitter (HAPS)	Transmitter Output Power [dBm]	30	30	30	30
	Backoff and Loss [dB]	-20	-20	-20	-20
	Transmitter Antenna Gain [dBi]	40	40	40	40
	EIRP [dBm]	50	50	50	50
Propagation distance: 0-20km	Free Space Propagation Loss [dB]	-158.5	-158.5	-158.5	-158.5
	Atmospheric Absorption Loss [dB]	-2.3	-2.3	-2.3	-2.3
	Propagation Loss by Cloud [dB]	0	-2.1	-15.6	-26.9
	Propagation Loss by Rainfall [dB]	0	0	-6.6	-21.6
Receiver (Gateway)	Receiver Antenna Gain [dBi]	75	75	75	75
	Receiver Level [dBm]	-35.8	-37.9	-58.0	-84.4
	Antenna Noise Temperature [K]	217.2	217.2	217.2	217.2
Receiver C/No [dBHz]		**153.2**	**151.1**	**131.0**	**104.6**

Table 6.3-2 Link budget for ground to NTN communications using the 100GHz band

Modulation	16-APSK	QPSK-OFDM	64-QAM-OFDM	256-QAM-OFDM
PAPR [dB]	0.9dB	8.5dB	9.2dB	9.3dB
Symbol length [µs]	2.3 (GI=0.4)	4.5 (GI=0.4)		
Occupied Bandwidth [GHz]	0.7	2.0	2.0	2.0
[dBHz]	93.0	93.0	93.0	93.0
Desired Eb/No [dB]	16.7	10.5	18.7	23.8
SNR [dB]	22.7	13.5	26.5	32.8
Coding Gain [dB] @BER=1E-6	5.6	5.0	5.3	5.9
Desired C/No [dBHz]	**104.1 dBHz**	**98.5 dBHz**	**106.4 dBHz**	**110.9 dBHz**

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[2] K. Tamesue, et.al, “Scheme Design for High-Throughput Terahertz feeder link in Non-Terrestrial-Networks”, The 41st JSST Annual International Conference on Simulation Technology(JSST2022), Sept, 2022.

[3] Working Party 5C (WP 5C) - Fixed wireless systems; HF systems in the fixed and land mobile services.
<https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5c/Pages/default.aspx>

[4] Recommendation ITU-R P.676-12(2019), Attenuation by atmospheric gases and related effects.

(5) Indoor propagation characteristics in the 300 GHz band

Indoor radio propagation characteristics in the 300 GHz band are measured for the realization of future high-capacity wireless LANs. Path loss and cross-polarization characteristics were measured using a linearly polarized horn antenna with a gain of 24 dBi (vertical polarization [V]), a waveguide antenna with a gain of 8.7 dBi (vertical polarization [V], horizontal polarization [H]), and a patch array antenna with a gain of 3.4 dBi [1] (right-handed circular polarization [RHCP]) in a corridor, a lobby and a garden [2] (Figure 6.3-13). In the corridor, The measurement conditions are 300 GHz ± 8.64 GHz (Bandwidth 17.28 GHz), transmit power -7 dBm, and 2501 measurement points using VNA [2].

Figure 6.3-14 shows the propagation loss for a combination of three types of antennas. The dotted line is a theoretical curve derived from the Friis formula in ITU-R M.2412 adjusting each antenna gain for the free space path loss (FSPL). Results show that measured data correspond with the theoretical curves and the communication distance of about 25m is obtained.

Figure 6.3-15 shows the effects of reflection for indoor structures on vertical and horizontal cross-polarization using waveguide antennas. Compared to the in-line-of-sight (LoS) propagation, the cross-polarization characteristics were degraded due to the effects of reflections by floors, walls, and ceilings.

Figure 6.3-16 shows the results of propagation loss for three different locations and different obstacle conditions (LoS and persons) for the combination of waveguide antennas (blue bars), and waveguide and patch array antennas (red bars). It is considered that the propagation loss is existed by locations and combination of antennas, however, is most affected by obstructions. Propagation loss due to people is smaller in the corridor than in other locations, possibly due to the effect of reflections from walls in the small space.

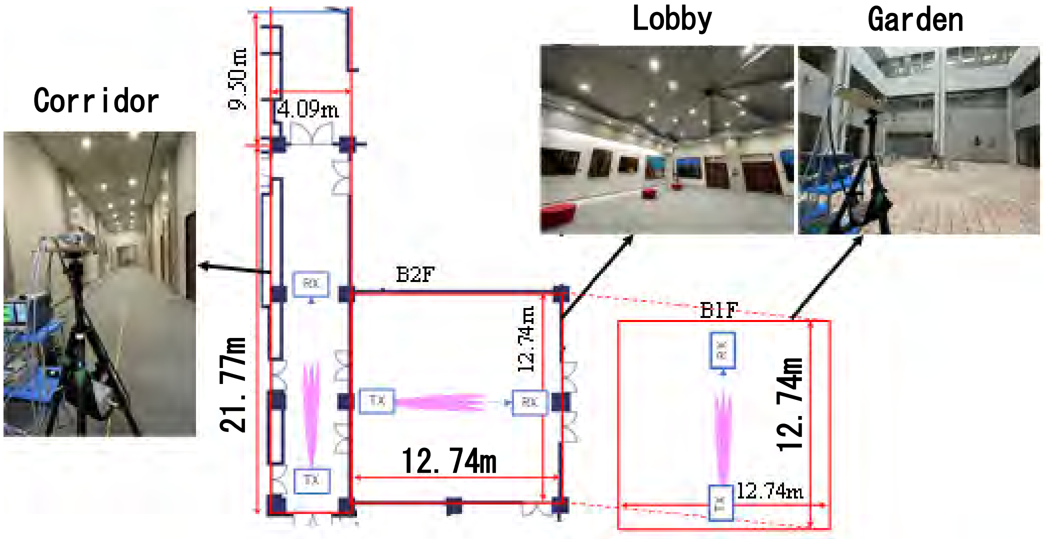

Figure 6.3-13 Propagation experiment locations

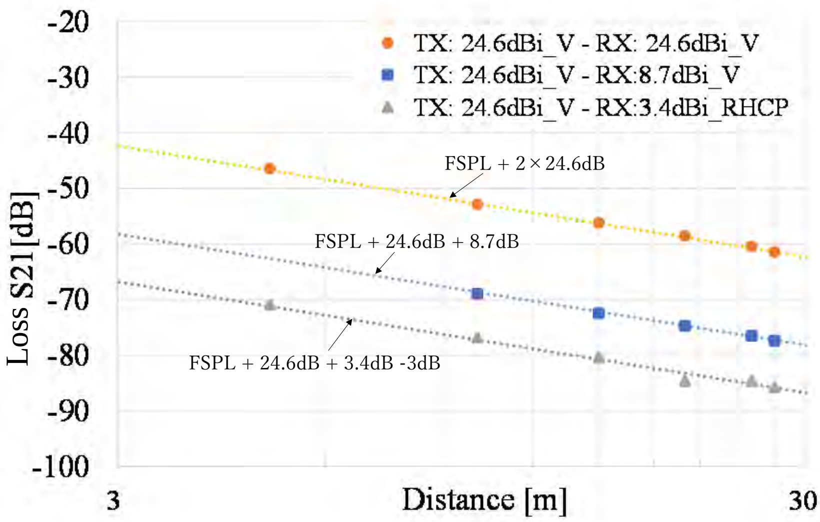

Figure 6.3-14 Propagation loss in a corridor

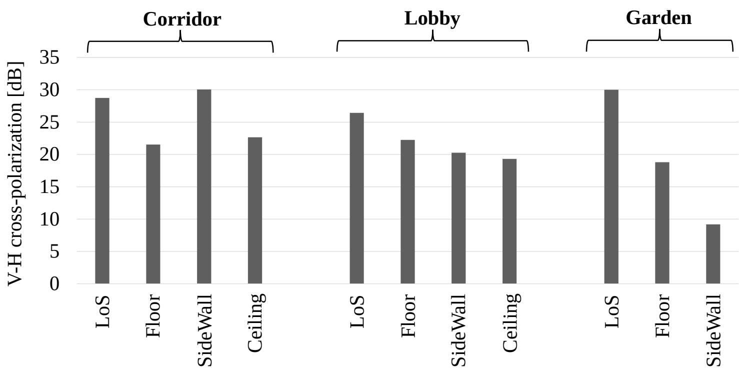

Figure 6.3-15 Effect of indoor structures on cross-polarization

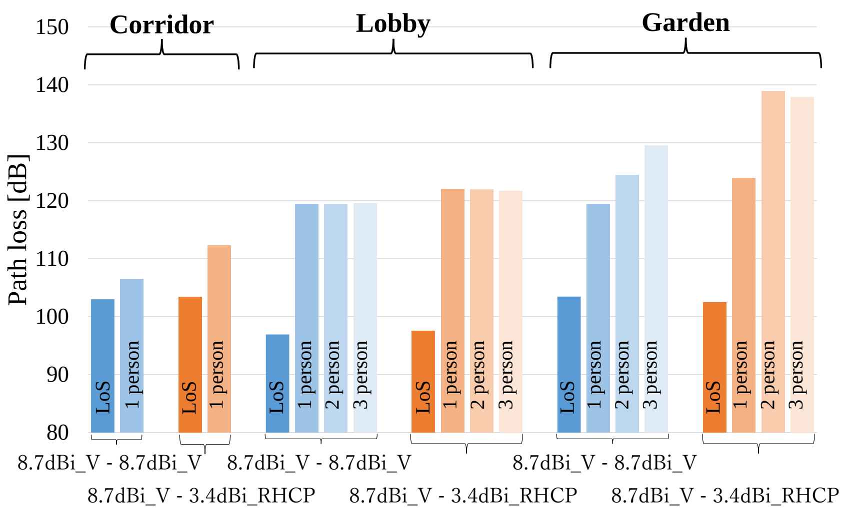

Figure 6.3-16 Location and Person Influence on Propagation Losses

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6.4 System Platform and Application

In this section, in accordance with "envisioned around 2030" as described in Chapter 4, we consider to realize various services to respond to the diverse needs of users based on the technology related to the Beyond 5G communication infrastructure explained below.

Especially in Japan, Beyond 5G is regarded as a way to advance towards the realization of Society 5.0 [1]. Society 5.0 is a human-centered society that achieves both economic development and solution of social issues through a system that brings about a high degree of integration between cyberspace (virtual space) and physical space (real space), i.e., the Cyber-Physical System (CPS).

On the basis of the blueprint for Society 5.0, we need to consider not only the technologies directly related to the communication infrastructure, but also the platform and application technologies that accompany them, as shown in Figure 6.4-1.

For example, in order to realize services such as Robotics-as-a-Service (RaaS), Mobility-as-a-Service (MaaS) and XR (as a Service) based on CPS, the following platform and application technologies will be required:

- RaaS:

  The purpose of RaaS is to make it easy for anyone to introduce robots and to support various social activities through the collaboration of many robots and people. For example, in logistics warehouses, workers and robots can work together to perform various tasks such as picking, inspection, packing, and transportation, which will significantly improve the efficiency of logistics operations. Likewise, at construction sites, site supervisors can set daily goals, and in accordance with these goals, multiple autonomous construction machines can work together to achieve efficient and injury-free operations.

  To realize these services, a platform should be developed to enable comprehension of the real world conditions and simulation of real world transition in the future. The platform should enable those processes in real time because control of robots can be carried out safely and efficiently. Furthermore, the platform should enable the formulation of an optimal operation plan for robots for the entire working area through sharing of operation plans and status of each robot. With these functions, the platform is able to control a large number of robots at various sites.

- MaaS:

  MaaS improves the efficiency of transportation by seamlessly connecting various means of transport including public transport.

  In this service, for example, we can use “across services” traversing across different transportation systems to move to a certain place. We can automatically make a reservation for dispatch by simply searching for a destination on our smartphones or registering the travel route in the schedule. Furthermore, once our location information is ascertained, we can automatically dispatch a vehicle to meet us when we arrive at the target location.

Making these services a reality entails a platform that has access functions to other platforms, such as authentication, search, reservation, and payment, as this will enable applications to be quickly developed to meet the needs of each region. Furthermore, each function (*) should be broken down into microservices that can be used in any combination as a service API in accordance with the needs of each region (*Not only functions such as location estimation, map infrastructure, data management, and data governance (privacy management infrastructure), but also MaaS-specific functions such as route search and vehicle allocation calculation).

- XR (as a Service):

  XR is a generic term for technologies that take the results of the fusion of cyberspace and physical space to and make them available for human perception, such as VR, AR, etc. There are several services utilizing these XR technologies, for example, safe driving support by AR etc. (section 4.7.1), remote direct teaching through AR/VR space in fields such as machine tool and agriculture (sections 4.8.1 and 4.10.1, etc.), remote haptic feedback in medical field (section 4.12.1), entertainment services in the virtual space (section 4.14.1, etc.) and disaster prevention training using VR space (section 4.15.3), etc.

  Making these services a reality entails physical space reconstruction/ augmentation (which not only reproduces but also superimposes virtual landscapes and objects on the real world), estimation of object location/posture, object recognition/identification, multimodal interaction (which combines various perceptions to understand surrounding environment and give users the sensation). And to realize information services and interaction services according to human recognition, reflex speed, the platform is required to have high-efficiency, ultra-low-latency 3D space data transmission technologies.

As described in Figure 6.4-1, "digital twin," which is one example of a "platform," is a virtual model designed to accurately reflect a physical object (physical space) and has access functions, such as authentication, search, and data management, for use of the digital twin by applications, services, and functions (transfer, recognition, etc.). Sensor data are then applied to the digital twin, and application technologies use the data in the platform so that various forms of services are embodied in the physical space. Such a system will provide users with environments optimized for their individual needs, furnish service providers with technologies and infrastructures to facilitate system construction (based on Beyond 5G communication infrastructure), and provide society with a group of fundamental technologies for accelerating the realization of CPS.

In the following section, the fundamental technologies described here will be explained except for those described in other sections, such as security and privacy technologies.

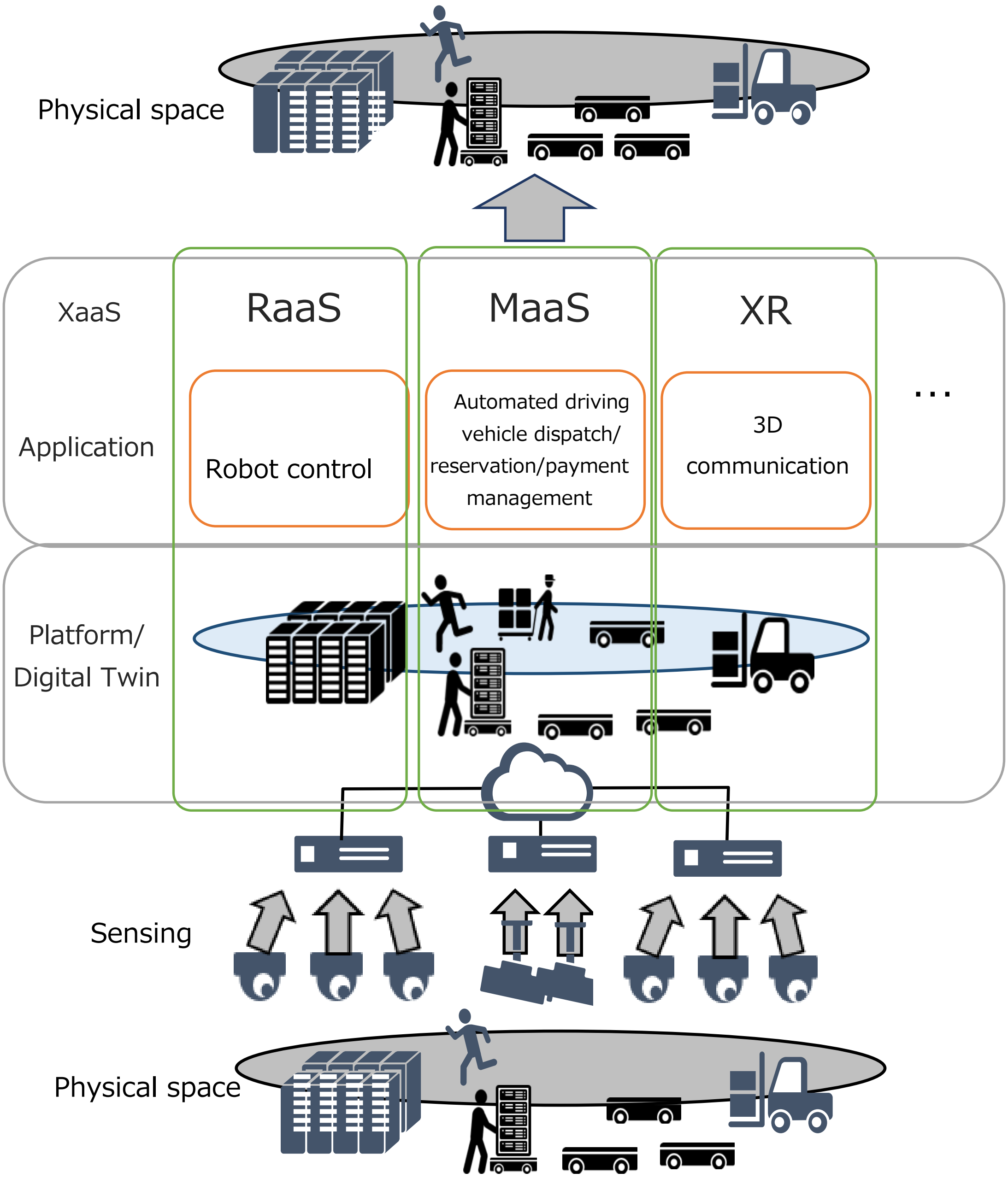

Figure 6.4-1 Service (XaaS) and Platform/Application technologies in CPS [17]

[17] A part of figures is provided by NEC.

6.4.1 Examples of fundamental technologies for XaaS, etc.

- Estimation of object location and posture with the digital twin

  Efficient and safe operation of robots requires understanding the distance and posture of objects in the digital twin. For example, in picking operations, a robot needs to know the distance and posture of the target object to minimize failure of picking. In addition, for a transport robot, knowing the exact distance and posture of an obstacle enables the robot to predict its future position with high accuracy and to avoid collisions. Therefore, the position and posture of objects must be estimated with high accuracy. Moreover, distributed estimation should be carried out at the edge to be able to estimate a large number of objects.

- Object recognition/identification with the digital twin

  For the robot to work efficiently, objects must be recognized in the digital twin to understand their characteristics. For example, understanding the characteristics of the object will enable grasping it appropriately in accordance with its hardness and weight. Also, by identifying the object, the robot can track the object at all times, enabling the omission of inspection and other tasks. Also, to facilitate introduction of robots, it is important to have a technology that can recognize and identify objects without prior learning, in addition to a method that uses prior learning with a large amount of data. It is also important to have a technology that can uniquely identify an object from its features even when tracking of the object is temporarily interrupted.

- Real-world prediction using the digital twin

  Objects in the real world are accurately reproduced in cyberspace through the digital twin. The main purpose of constructing the digital twin is to predict the future of the real world. For example, if we can predict the 5-second future of the real world in advance, we can prevent or avoid various dangerous accidents that may occur in the workplace, and we can also work more efficiently by being one step ahead. This kind of future prediction can be achieved by combining time-series analysis of the position and posture of objects in the virtual world, which continually change, and probabilistic model analysis based on the results of discriminating the types and individual characteristics of the objects.

- Robot control for safety, acceptability, and efficiency

  For robots to coexist with people, for example, by supporting users in their daily lives and tasks, it is important for them to be socially and economically acceptable in terms of safety and cost of service. For example, robots can provide community support services by understanding the user's health status and temperament and by casually encouraging the user to take a walk. Also, in business support services, robots can perform simple tasks of carrying cargo in warehouse operations, while the workers are engaged in complex tasks.

Both cases require robot control that meets safety as well as service-specific requirements, such as service acceptability and efficiency.

Realizing this kind of robot control entails estimating the situation and future changes in the physical space through the digital twin; evaluating robot behavior in terms of safety assurance, service acceptability, and work efficiency; and selecting suitable behavior.

- Physical space reconstruction and augmentation

  In this technology, IoT devices and sensors installed everywhere will be able to scan information in the real world and reproduce it in cyberspace. Physical space reconstruction and augmentation will not only reproduce but also superimpose virtual landscapes and objects on the real world. A mechanism for "highly efficient, ultra-low-latency 3D space data transmission" is needed to efficiently realize such a rich experience. Information in the real world and contents expanded in cyberspace will be transmitted back and forth without any time lag as highly efficiently compressed data, resulting in a seamless experience in CPS.

- Multimodal interaction

  The "multimodal interactions" technology will combine various perceptual expressions. This combination is not limited to the display of flat images, but images can be combined with a variety of perceptual expressions, such as stereoscopic images (through VR/AR glasses), holography (which displays highly realistic 3D images), spatial acoustics (which can be felt even at the edges of the field), and force feedback (which gives users the sensation of touching an object).

- High-efficiency, Ultra-low-latency 3D space data transmission

  As XR permeates our daily lives, the visual experience will be extended from 2D displays to (physical) space itself, and the subject of the information handled there will also change from 2D video information to 3D space information. Point cloud information representing 3D space is much larger than conventional 2D video information. Therefore, point cloud compression (PCC) technology [2], which is a coding method for highly efficient compression and transmission of point cloud data, and its successor technologies, have been established to enable stable handling of 3D space information even on mobile network. In addition, the ability to reproduce and transmit 3D space will increase the need for highly interactive applications, such as remote surgery and robot control. In such applications, ultra-low-latency transmission technology is utilized for instantaneous transmission in 3D space while maintaining the compression performance.

REFERENCES

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[2] MPEG-3DG: "MPEG Point Cloud Compression". http://www.mpeg-pcc.org/

6.5 Trust-enabling technologies (security, privacy, reliability, resilience)

In order to respond to the diversified needs of customers in the Beyond 5G era, in addition to technological innovation in terms of functionality and performance, it is essential to provide network infrastructures that can be used safely and securely by all stakeholders. These infrastructures include technologies related to security, privacy, reliability, and resilience[18].

For example, ensuring the ultra-security and reliability of Beyond 5G networks requires the establishment of a variety of technologies. They include quantum-resistant public key cryptography (post-quantum cryptography) and quantum-resistant symmetric key cryptography technologies for confidentiality and integrity; trust-enabling technologies for authentication and authorization; technologies to ensure resistance to attacks and failures due to cyberattacks; operational automation technologies for centralized management of incident information and incident response & recovery; and advanced threat and risk analysis technologies. Also, to support the establishment of these technologies, it is required to individually promote the advanced utilization of technologies such as AI, confidential computing, and multi-party computation. Analysis and management techniques for privacy protection, such as homomorphic encryption, should also be studied.

Herein, these trust-enabling technologies in line with Japan's Beyond 5G strategy are considered. Japan has defined the seven functions required for Beyond 5G. The technologies mentioned in this section particularly contribute to "ultra-security and reliability." In addition, various security requirements are envisaged for each of the seven functions, as shown in Table 6.5-1. In consideration of these factors and in recognition of the implications for the Beyond 5G era, the following technologies are foreseen to become necessary:

- Network trust-enabling technologies (ultra-secure and reliable network technologies) (6.5.1)

  Based on the various functions related to Beyond 5G networks, there are various trust-enabling technologies that should be integrated into the network. In section 6.5.1 below, various trust-enabling technologies can be classified into the categories of "design," "operation," and "management." Under these categories, individual technologies related to enabling trust in Beyond 5G networks are discussed. These technologies contribute to enabling trust throughout the life cycle of Beyond 5G networks.

- Other trust-enabling technologies (other Beyond 5G features) (6.5.2)

  The technologies to enable trust in relation to the features of Beyond 5G other than ultra-security and reliability are summarized in section 6.5.2. The section mainly discusses the technical elements mentioned in the discussion of network ultra-security and reliability technologies from the viewpoint of the features of Beyond 5G.

[18] The reliability of the network is discussed in section 6.8.4.

For example, since AI/ML (machine learning) (hereinafter referred to as AI) is evolving along with Beyond 5G, in addition to AI-based (autonomous) security technologies, the security of AI used in each element of the network, as well as the evolution of AI-based network attacks should also be considered.

These will contribute to ensuring the reliability of the entire system, including the networks in the Beyond 5G era.

Below, the technologies and infrastructures mentioned here will be explained.

Table 6.5-1 Requirements for enabling trust for the seven functions of Beyond 5G (Revised from reference [1])

Function	Requirements related to trust enablement
Ultra-fast and large capacity	• Quantum-resistant symmetric key cryptography (ultra-fast encryption/decryption) • Ultra-fast processing logic for traffic surveillance, intrusion detection, etc. • Storage and management methods, such as advanced compression technology and distributed storage technology for stored data
Ultra-low latency	• Lightweight security • Beyond 5G blockchain utilization
Ultra-massive connectivity	• Efficient authentication and authorization (aggregate authentication, broadcast authentication, etc.) • Efficient security surveillance and processing techniques
Ultra-low power consumption	• Hardware implementation of security features • Lightweight security architecture
Ultra-security, resiliency and reliability	• Ensuring confidentiality and integrity (Quantum-resistant public key/symmetric key cryptography, confidential computing, etc.) • Authentication/authorization technology and trust model • Ensuring traceability (collection and management of log, event, and flow information) • Resistance to attack and failure • Ensuring security coordination • Advanced log, event, and traffic analysis • Centralized management of information originating from incidents • Operational automation for integrated response and recovery • Privacy protection function • Beyond 5G user/device reliability diagnosis • Advanced threat and risk analysis • Dynamic policy enforcement • Automated health audits (automated soundness checking)
Autonomy	• Automation/autonomy of operation and audit • Autonomy to ensure resistance to attacks and failures • Trust-enabling mechanisms from an AI perspective
Scalability	• Integrated management of devices and systems to enable trust • As-needed monitoring of advanced configuration modules and integrated configuration management system

6.5.1 Trust-enabling technologies for ultra-secure and reliable networks

Technologies that complement the ultra-security and reliability features of Beyond 5G are crucial in enabling trust in the Beyond 5G network. The following sections describe each of these technologies from the three perspectives of design, operation, and security management..

6.5.1.1 Technologies related to the design of Beyond 5G networks to enable trust

(1) Ensuring confidentiality and integrity

As a function provided by the Beyond 5G network, ensuring a very high level of confidentiality and integrity is an important requirement to ensure sufficient trust. To ensure the confidentiality (concealment of data to non-legitimate users) and integrity (preventing data from being maliciously tampered with) of all management and user data handled in Beyond 5G, it will be essential to construct a cryptographic system that takes into account not only the current computing environment but also the network environment using quantum computers (quantum technology), which is expected to be utilized in Beyond 5G.

Quantum computers leveraging the physical properties of matter and energy have been researched for more than 20 years. They can now perform prime factorization of integers and computation of discrete logarithm problems, which are difficult to solve with conventional computers. Current public-key algorithms, such as RSA and Elliptic Curve Cryptography (ECC), point to security as a mathematical problem that is difficult to solve, but quantum computers are said to be able to easily solve it using Shor's algorithm [2]. Also, since decryption of current symmetric key cyphers, such as AES, will be significantly accelerated through quantum computers using Grover's algorithm [3], there is a need to increase the required key length in anticipation of the advent of the era of quantum computing.

Based on the above assumptions, it is important to develop the cryptographic infrastructures shown in A) and B) below as confidentiality and integrity functions that can appropriately respond to the requirements in the era of quantum computing. Likewise, it is important to promote the development of infrastructures (incorporation into protocols and APIs) for enabling trust in Beyond 5G. Also, before constructing the cryptographic infrastructures for the quantum computing era described above, the following technologies, such as C) quantum key distribution technology and D) secure computing, should be developed as fundamental technologies for enabling trust in Beyond 5G.

A) Quantum-resistant public key cryptography

Quantum-resistant public key cryptography (simply called "quantum-resistant cryptography") technologies have been attracting attention as the public key cryptography technology for the era of quantum computers. Because these technologies require computational time, they cannot be used similarly as symmetric-key cryptography, which encrypts data in real time, and they are basically used as a key encapsulation mechanism (KEM) to encapsulate and share "cryptographic keys" used in symmetric-key cryptography. Nevertheless, many schemes (algorithms) have been proposed for quantum-resistant public key cryptography, and each algorithm possesses features that support the sophistication of the following quantum-resistant public key cryptography technologies.

- Attribute-based encryption (only those with access privileges can decrypt information)
- Searchable encryption (can be searched while encrypted)
- Homomorphic encryption (operations can be performed while encrypted)
- Proxy re-encryption method (can change the authorized person who can decrypt data while encrypted)
- Broadcast encryption (allows a single sender to communicate with many recipients)
- Threshold encryption (data above the threshold can be decrypted)

Therefore, in the Beyond 5G network, KEM will be provided as a fundamental technology for networks. And, algorithms possessing features that support the sophistication of the above quantum-resistant public key cryptography technologies will be used for the diverse applications for utilizing Beyond 5G.

B) Quantum-resistant symmetric key cryptography

Confidentiality and integrity of management data and user data in the Beyond 5G network environment will be ensured through quantum-resistant symmetric key cryptography using cryptographic keys configured with KEM via the above quantum-resistant cryptography (public key). From the viewpoint of the security of symmetric encryption, it is necessary to double their key size in order to ensure at least the same level of security in a quantum computing environment as that of the 128-bit key of symmetric keys (AES) currently in use. As described in section 6.5.2.1, in order to approach the Beyond 5G communication speed of 100 Gbps, there is a need to study methods to carry out ultra-high speed encryption processing. Further, even in Beyond 5G edge systems, where computing resources are relatively scarce compared with those of Beyond 5G core systems, there is also a need for ultra-high-speed encryption and decryption. Investigations need to be carried out on the premise of the deployment of quantum-resistant symmetric key cryptography to achieve ultra-high speed for Beyond 5G networks as a whole.

C) Quantum key distribution

Quantum key distribution (QKD) is a technology for securely sharing cryptographic keys between two parties by transmitting key information on one photon per bit over an optical fiber transmission line. By applying the principles of quantum mechanics, this method can form a communication channel that can detect eavesdropping. Once eavesdropping is detected, the transmitted encryption key is discarded and sent securely on another channel.

Thus, despite limitations in transmission distance, before a complete quantum computer will be used, this technology may be utilized as a secure way to deliver encryption keys, from the viewpoint of detecting and preventing eavesdropping.

D) Technologies for computing data while protected

In response to many external and internal attacks, a normal network system ensures the confidentiality of data by encrypting the data. In many cases, data are encrypted while on storage or as data pass through the transmission line over the network. However, if the network system is compromised by any means, the data in use (being processed) may be exposed. In other words, when data are processed on the computer, they are decompressed into the computer's memory to perform the calculations, but encrypted data are generally decrypted before the calculations. Since the data are converted to plain text, the data in the memory become exposed through memory dumping and other methods used by an attacker that has penetrated the system.

Confidential computing is a computing technology that is designed to provide solutions for processing sensitive data to counter the above threat. For example, while protection of transmitted data within a mobile system is usually achieved through hop-by-hop encryption between network functions, data processed or held within a network node can be protected by confidential computing. It is, thus, effective in ensuring the confidentiality of the total network system. This protection is achieved by using a hardware protection mechanism called Trusted Execution Environment (TEE) [4] to ensure safe processing in an isolated environment.

When combined with hop-by-hop security, confidential computing provides an end-to-end, isolated network slice from the terminal to the end of the slice in the network. TEE is implemented in Intel SGX, AMD SEV, as well as in Intel TDX. These hardware security solutions are based on a remote authentication framework, allowing end users to verify that their applications run reliably on legitimate and properly configured hardware. In addition, sensitive data or keys can be written only if authentication is successful. This approach is said to be fully compliant with the NIST Zero Trust Principles [5].

Also, methods known as fully homomorphic cryptography and multi-party calculation are being considered in relation to confidential computing. In particular, fully homomorphic encryption, as described in section 6.5.1.1(1) A), can process encrypted data (arbitrary operations). This method requires a framework to encrypt or decrypt the data, and also requires that the processing algorithm be adapted to the processing of the encrypted data. Since the computation of these processes takes time, the use of hardware acceleration technology will likely lead to the first step toward the realization of fully homomorphic cryptography.

(2) Authentication and authorization technologies and trust model

It is required to ensure that the system components (node, cloud, etc.) that underpin the Beyond 5G network are authenticated and authorized by appropriate mechanisms. Specifically, there is a need to build a mechanism to manage the IDs (identifiers) set for each component in an integrated manner and to appropriately manage each access right (what each component can do). Further, real-time mutual authentication between components is required when access occurs within the network.

Moreover, in order to properly eliminate malicious Beyond 5G users and applications, the infrastructure needs to be built to guarantee their authentication and authorization. In particular, considering the massive simultaneous connectivity feature described in section 6.5.2.3, authentication and authorization of many users are required to be performed in real time, pointing to the importance of developing a mechanism to support authentication and authorization.

In particular, it would be interesting to organize a multifaceted trust model [6] in an environment implementing the authentication and authorization technologies. The Beyond 5G multifaceted trust model proposed in reference [6] is organized into three different modes for satisfying the trust requirements. The existing modes include the Bridge mode based on centralized authentication and authorization and the Endorsement mode based on third-party verification, evaluation, and authentication, and the new mode is the Consensus mode based on multi-party flat negotiation. Based on the Consensus mode, all native trust attributes can more effectively meet the architecture and service requirements of distributed and decentralized networks.

(3) Ensuring traceability - technologies for collecting and managing log, event, and traffic flow information

There are a wide variety of system modules for configuring and operating Beyond 5G networks, and a wide variety of log information is outputted from a large number of modules. It is, therefore, important to utilize log information to contribute to the sound operation of Beyond 5G networks. However, a log management system that can be integrated and centrally managed is required to be built in order to centrally manage log information and ensure the necessary traceability of log information. It is also necessary to thoroughly integrate and centrally manage event information outputted by monitoring modules and fraud detection modules deployed in Beyond 5G networks. Efficient management and operation of traffic flow information will also contribute to the sound operation of Beyond 5G networks.

In other words, to contribute to the sound operation of the Beyond 5G network, it is required to collect sufficient log information, event information, and traffic flow information. By establishing a collection and management infrastructure for appropriate management, the traceability of information used in network operations can be ensured and sound operations can be implemented. Moreover, these should be premised on compliance with the legal systems and privacy protection laws of each country (section 6.5.1.2 (1) and (2)).

(4) Ensuring resistance to attacks and failures (ensuring availability)

Even in the event of an attack on the Beyond 5G network or a system failure, the network system needs to continue to operate to ensure availability. Conventional technologies have also been developed to properly duplicate network systems, such as duplication of network resources (memory, configuration information, etc.), of network computing resources (switches, etc.), and of network storage resources (information resources necessary to maintain the network). In the Beyond 5G network, it is important to ensure resilience that enables the integration of existing duplication technologies in a more sophisticated manner. In particular, with regard to resistance to cyberattacks, it is likely that the duplicated portion will be targeted by advanced attacks. Therefore, it is required to establish a mechanism for detecting predictive attack behavior at an early stage and for dynamic response and recovery. This will be achieved through sophisticated analysis of the information obtained from the collection and management infrastructure for log and event information established in (3) above.

Also, unlike in the conventional "passive" system, which starts responding after a cyberattack, it is important to collect and analyze information such as open-source intelligence (OSINT) and dark web information in advance. These pieces of information should then be matched with the attack signs visible from logs, events, and flow information to more actively ensure resistance to attacks.

Distributed denial of service (DDoS) attacks are one of the most difficult cyberattacks for network administrators. Thus, it is also necessary to introduce a DoS monitoring system over a wide area to detect DoS attack target information at an early stage, and identify and eliminate DoS traffic. It is required to build a network that is resistant to DoS by preparing ample alternative resources (memory, etc.), such as by absorbing traffic through decentralization.

(5) Ensuring security coordination

Since different Beyond 5G networks and services/applications require specific implementation to enable different types of trust, it is necessary to coordinate between different types of trust-enabling mechanisms to avoid conflicts in protection. This is important for enabling trust in the entire Beyond 5G system, which is premised on the interconnection of different Beyond 5G networks. For example, the level of control enforced by trust enablement mechanisms is required to be adjusted appropriately in accordance with the physical and virtual resources (edge, network core, cloud, etc.) needed by the managers of Beyond 5G components and with the services running on those resources. In other words, in an environment for construction and operation in which these different parties involved in

Beyond 5G coexist, various physical and virtual resources, as well as various trust-enabling mechanisms, should ideally be designed, constructed, deployed, and operated in a coordinated manner as a whole system. Coordination functions should, therefore, be deployed to coordinate different trust-enabling mechanisms between different parties. Coordination of trust-enabling functions, including security, should be aimed at the interoperability and harmony of diverse protection mechanisms.

6.5.1.2 Technologies related to the operation of Beyond 5G networks to enable trust

Trust-enabling functions are crucial for the day-to-day operation and maintenance of Beyond 5G network infrastructures. For example, when monitoring the wide variety and effectiveness of trust-enabling functions being implemented in Beyond 5G environments and appropriately reporting to the administrator the protection functions or components that impact the maintenance of a healthy Beyond 5G operation, such as in an attack, or when changing the trust-enabling functions for any reason, there will also be a need to notify and warn the lower-level trust-enabling functions associated with those protection functions of the changes made. This means that Beyond 5G operators need to check the appropriate incident report, audit information, and configuration data related to Beyond 5G networks on the basis of reports and alerts, such as on logs and events that occur during operations, in order to maintain sound Beyond 5G operations.

(1) Advanced log, event, and traffic analysis

Unlike previous network environments that focused on perimeter defense, in Beyond 5G, the wide variety of functions are distributed across the network. Moreover, since network configuration based on virtualization technology expands the scope of security measures, the vulnerability points (attack vectors) that evoke attacks are also widened, making it necessary to deploy more advanced trust-enabling functions. Therefore, the detection technologies for abnormalities and unauthorized communications need to be improved to detect the wide variety of attacks, abnormalities, and unauthorized communications, and prevent intrusion by unauthorized users. Advanced analysis (cross-sectional correlation analysis, multi-factor deep analysis, etc.) of collected logs, events, and traffic flow information is required to be carried out by utilizing the log collection and management mechanism described in 6.3.1.1 (3) above. The knowledge and data obtained from other Beyond 5G networks should be considered for use in advanced analysis (see section 6.5.1.2 (2) regarding centralized information management).

(2) Centralized management of information originating from incidents

In addition to the log, event, and flow information collection and management infrastructure described in section 6.5.1.1 (3), incident information related to network operations (location, cause, impact, recovery method, issues, etc.) is also required to be centrally managed for the entire Beyond 5G environment and utilized for individual Beyond 5G network operations. In other words, sharing information related to the operation of Beyond 5G networks among network operators and application providers will contribute to the prevention of and swift response to similar incidents.

(3) Operational automation technologies for integrated response and recovery

Security functions required to ensure network trust include intrusion detection systems (IDS), firewalls (FW), patching and management, network configuration management, and log management. There are a wide variety of relevant functions, and they have conventionally been manually operated to manage IDS signatures, FW filter rules, patch management modules, and patches. Fully automating the operation and management of these diversified security functions will minimize the needed human resources and enable implementing highly accurate operations. Also, after a new attack is discovered, signatures and rules can be automatically updated by deriving in advance the generation mechanism for each new signature and rule. Moreover, analysis of the current attack behavior using log and event information should also enable deriving a mechanism to automatically detect signs of new attacks.

Patch processing needs to be conducted as an operational and routine process, wherein equipment (including firmware), software (including virtual), middleware, OS, etc. that need patch management in the Beyond 5G network environment are required to be thoroughly monitored and managed. Thus, there is a need to update the information subject to patch management using information from relevant vendors, OSINT, and the latest vulnerability information. Automatic patching (such as managed updates) based on updated information should, therefore, be carried out. However, depending on the content of the patches provided, there are target devices and software that need to be evaluated regarding the extent to which the patch application affects the current operation. In such cases, it is necessary to check whether the provided patch can be applied using a test environment. Whether the entire process can be fully automated, including the confirmation of patch applicability, depends on how the logic of AI, etc. will be assembled in the future (see section 6.5.2.5).

(4) Privacy protection functions

Personally identifiable information (PII) is handled in the Beyond 5G network environment, with some of these pieces of information being subject to privacy protection. Functions that provide privacy protection need to be used in designing and building network services in the Beyond 5G environment. Also, when analyzing the characteristics of communications and conducting user analysis to improve network functions using log information obtained from actual communications, such analysis operations should be carried out while protecting privacy. The fully homomorphic cryptography described in section 6.5.1.1 (1) D) is a possible mechanism for this.

Further, since data use in Beyond 5G environments where multiple service providers exist is complex, there is a need to flexibly respond to the intentions of users regarding data use. In other words, Beyond 5G users should be able to set PII preferences (specific choices on how PII should be processed for a specific purpose), and network/service providers should be able to collect and share PII accordingly and provide users with a history of how user information is shared with other operators. Beyond 5G network/service providers are required to implement collection, management, and operation to enable the above. This kind of framework has been standardized in ITU-T Recommendation X.1363 for IoT [7], which is also useful in Beyond 5G environments.

(5) Beyond 5G user/device reliability diagnosis

In the Beyond 5G era, where communication networks are more closely integrated into various social activities, it will become increasingly important for people to take appropriate security measures. Therefore, support for taking appropriate security measures needs to be provided to users participating in Beyond 5G services, as part of service operation. Specifically, as a technology to ensure network trust, a mechanism is required to be established to quantify the reliability of the people using the service and the devices used, and to control the connection to the network based on the trust relationship, in order to prevent unauthorized users and vulnerable devices from connecting to the network. These technologies are also closely related to the authentication and authorization technologies described in section 6.5.1.1 (2), and analysis at the design stage is important.

6.5.1.3 Technologies related to 5G network security management to enable trust

Beyond 5G network security management refers to a framework for Beyond 5G network service providers to design, implement, operate, and improve appropriate security functions. Essentially, the requirements and guidelines specified in ISO/IEC 27001, ISO/IEC 27002, ISO/IEC 27011 (ITU-T Recommendation X.1051) should be followed. For Beyond 5G, studies on the sophistication of security management as shown below are required.

(1) Advanced threat and risk analysis

The basic challenge of security management is how to calculate the assumed risks of the target Beyond 5G business operators, how to prepare for the risks, and how to reduce and avoid the risks for the business operators. Therefore, it is very critical for business operators to be able to identify the foreseeable threats for their organization (cyberattacks, etc.), calculate the degree of impact of the identified threats on the organization (whether or not such attacks will cause tremendous damage, etc.), and identify the anticipated risks based on the threats that have high impact. Recent trends in cyberattacks indicate that attack methods have become more diverse, complex, and sophisticated, and the attacks are changing not by year, but on a monthly and weekly basis. Therefore, threat analysis, impact analysis, and risk analysis need to be performed frequently within the organization. Furthermore, analysis is required to be carried out promptly, including concrete penetration tests, in addition to desk reviews.

(2) Dynamic policy enforcement technologies

When business risks as a Beyond 5G operator are calculated according to the results of the risk analysis described in (1) above, a "high-level policy" is formulated to implement security management in accordance with the calculations. The high-level policy, which is typically formulated in a meeting of security officers from each organization, serves as a guideline that the organization needs to follow to comprehensively ensure trust (security). However, separate policy documents exist under the high-level policy, such as access policies (password management, etc.) and intrusion detection policies (setting detection levels, etc.). Given the need to adapt to an environment with rapidly evolving cyberattacks in the Beyond 5G era, as a minimum, individual policies should be dynamically improved on the basis of the results of short-term risk analysis such as the penetration test described in (1) above. Processing needs to be carried out in accordance with the revised and improved policy, such as filtering out unauthorized access through a near real-time process. This dynamic policy enforcement is an activity that leads to ensuring attack resistance as described in section 6.5.1.1 (4).

(3) Automated health audit technologies

Auditing whether trust is adequately ensured is considered part of security management, wherein it is also important to regularly audit whether the function to enable trust has been designed, implemented, and operated in a sound manner. Usually, audits are conducted along with the review of security management, but as mentioned in (2) above, it is important to audit and verify the soundness of the Beyond 5G environment from a comprehensive perspective in keeping with the changes in cyberattacks. Thus, technologies that can automatically generate audit scenarios and perform frequent automated health audits need to be developed and operated. This automatic health audit is linked to the above-mentioned risk analysis and related to automation of operations discussed in section 6.5.1.2 (3).

6.5.2 Trust-enabling technologies related to other Beyond 5G features

6.5.2.1 Ultra-fast and large capacity

As mentioned in the discussion on quantum-resistant symmetric key cryptography in section 6.5.1.1 (1) B), communication speed in Beyond 5G will exceed 100 Gbps, pointing to the need for R&D of faster and lighter encryption methods that can meet this requirement in various devices. In order to maintain the same level of security as the 128-bit key currently used (in AES), the key length is required to be at least 256 bits [8]. In other words, a cryptosystem that uses 256-bit keys and can handle throughput of more than 100 Gbps need to be developed in consideration of communication speed in the Beyond 5G era. Realizing such ultra-high-speed processing will make it possible to transmit large amounts of data and enable trust in processing.

On the other hand, in relation with the transmission and reception of large volumes of data, monitoring large volumes of traffic and securing large volumes of data storage resources are also important requirements. For example, in the Beyond 5G environment where large-volume traffic is processed at ultra-high speed, the processing logic for monitoring traffic information and detecting unauthorized intrusions is also required to be processed at ultra-high speed. In other words, conventional perimeter security devices (IDS, FW, etc.) need to have ultra-high performance to withstand ultra-high speeds.

Further, storage devices that store large volumes of transmission/reception data and management data, need to be thoroughly studied, along with methods for their management. For example, assuming that the size of data to be collected and stored on a daily basis will increase by at least 100 times, R&D of storage and management methods, such as advanced compression and distributed storage technologies for stored data, need to be carried out

6.5.2.2 Ultra-low latency

Technologies for enabling trust to support the ultra-low latency feature of Beyond 5G entail the development of the cryptographic infrastructure discussed in section 6.5.1.1 (1). In a quantum computing environment, quantum cryptography providing public keys cannot satisfy the ultra-low latency feature of Beyond 5G, considering the processing response for authentication based on KEM. However, after configuring the cryptographic environment, such as for authentication and authorization, ultra-low latency can be ensured by using ultra-high-speed quantum symmetric key cryptography.

On the other hand, in order to enable the blockchain to be adaptable to the ultra-low latency capabilities of Beyond 5G wireless networks, the blockchain needs to overcome several issues such as high-speed consensus algorithm and the integration of the distributed blockchain with the centralized network architecture, which are the areas for studies.

6.5.2.3 Ultra-massive connectivity

In regard to the feature of Beyond 5G enabling a large number of edge systems to be connected at the same time, authentication and authorization processing with the connected edge systems (users, devices, etc.) needs to be carried out at the same time. Therefore, when simultaneous connections are made, the processing load on the system side that provides authentication increases because heavy authentication and authorization processes run at the same time, pointing to the need for certain countermeasures.

For example, by setting authentication to be carried out in multiple units, aggregate authentication can be used to authenticate multiple edge systems at the same time, or priority levels can be set for simultaneously connected edge systems. In such cases, it is necessary to come up with a mechanism for prioritizing authentication of edge systems as a subset of simultaneous connections, through broadcast authentication and other schemes.

6.5.2.4 Ultra-low power consumption

As mentioned in the discussion on confidential computing in section 6.5.1.1 (1) D), methods that rely on hardware processing for the core part of trust-enabling mechanisms are being studied. A technology for implementing the high processing load (high power consumption portion) related to enabling trust through hardware can be considered in relation to the ultra-low power consumption feature of Beyond 5G. Further, technologies that contribute to reducing power consumption can be developed by reducing the weight of the protection mechanism with the least possible reduction in the level of trust enablement.

6.5.2.5 Autonomy

As mentioned in the discussion on automation of operations in section 6.5.1.2 (3) and automated health audit in section 6.5.1.3 (3), there are many scenarios for autonomously enabling trust in Beyond 5G. Other than the automation and autonomy of operations and audits, it is crucial to introduce an autonomous security mechanism to also ensure resistance to attacks and failures as discussed in section 6.5.1.1 (4). Realizing this kind of automation/autonomy entails the use of AI. Trust-enabling mechanisms are discussed below from the viewpoint of AI.

The widespread use of AI in the architecture, process, and technology domains enables effectively reducing the two major factors for security weaknesses; namely, vulnerable software and insecure operational practices. AI contributes to improving network reliability through the automation of attack detection and response, improvement of accuracy and accountability of attack detection, and sophistication of hardware and software safety verification. For example, in the WarpDrive[19] project [9], a large amount of web access information has been collected and accumulated, and an infrastructure for analysis and research using AI has been constructed and operated through the cooperation of seven security research institutes in Japan. A number of promising results have thus far been produced through the project.

[19] Web-based Attack Response with Practical and Deployable Research InitiatiVE.

Also, the use of AI in Beyond 5G technologies will open up new prospects for self-monitoring, self-optimizing, and self-configuring networks. Integrating Beyond 5G network architecture with key technologies such as AI should make it possible to configure fully automated systems with intelligent defense mechanisms. Further, the massive amount of data generated will be continuously analyzed using AI to enable robust real-time monitoring and real-time threat detection, which will be essential for future Beyond 5G networks. However, designing such systems requires addressing several challenges, such as the reliability of AI components, security and privacy issues in deep learning models, and recoverability of data.

6.5.2.6 Scalability

Since it will be easier to dynamically expand the system components in the Beyond 5G environment, there will be a need to add security devices related to enabling trust and to expand the security system. These additions and functional enhancements will also lead to changes in the configuration for providing trust enablement, as well as to the enhancement and modification of the mechanisms for collecting, analyzing, and managing log and event information. Therefore, guaranteeing the scalability of Beyond 5G entails not only implementing integrated management of devices and systems for enabling trust, but also introducing a framework for the integrated configuration management system that can automatically grasp the correspondence between the expanded Beyond 5G configuration modules and the devices and systems for enabling trust.

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6.6 Network energy efficiency enhancement

Background & motivation

The increasing number of connected devices, base stations, and objects will not only create unprecedented growth of data traffic and massive connections, but also create a substantial increase in energy consumption across all parts of the network. Energy efficiency, defined as bits/Joule, has long been one important design target in 5G, and will continue to be an even more important requirement for Beyond 5G network design. It will no longer be a nice-to-have feature but a make-or-break requirement for Beyond 5G mobile networks. In addition to energy efficiency, reduction of life-cycle energy consumption of the networks should be taken into consideration as an effective way to cut down the electricity bill and, at the same time, as an important social obligation to reduce the greenhouse gas emissions. While the energy-efficient network design drives the ICT industry towards sustainable development, the ICT industry as a whole can play an important role in cutting the global CO_2 emission for a cleaner and healthier living environment for mankind. ICT is expected to enable a 20% reduction of global CO_2 emissions by 2030 compared with that of 2015. Meanwhile, Beyond 5G communication systems should also be leveraged to find new business use cases and expand the application scenarios to benefit other industries. There is a need to work towards achieving the bigger picture of overall sustainable social development.

Goal of energy efficiency for Beyond 5G

In light of this, green and sustainable development is, therefore, the core requirement and ultimate goal of network and terminal designs in Beyond 5G. By introducing the green design concept and native AI capability, Beyond 5G will improve the overall energy efficiency (defined in bits per Joule), e.g., 100-fold, across the network and keep the total energy consumption (in unit of Joules) lower than that of 5G, while also ensuring optimal service performance and experience. As the core infrastructure of the digital economy, Beyond 5G will have to make unique contributions to the sustainable development of humankind.

Technologies and research directions

1) Framework for designing and evaluating the energy efficiency of networks

In terms of the research directions for green end-to-end Beyond 5G network design, the potential technologies to achieve energy efficiency span architectures, materials, hardware components, algorithms, software, and protocols. Industry consensus needs to be established regarding the methodology used to evaluate energy efficiency across the entire ecosystem. Dense network deployment (leading to shorter propagation distance), centralized RAN architecture (resulting in fewer cell sites and higher resource efficiency), energy-aware protocol design, and cooperation between users and base stations are some factors that need to be carefully considered in order to achieve an energy-efficient Beyond 5G communication system. A framework for green network design has been proposed in [1], in which four fundamental trade-offs are described for the design and evaluation of the network; namely, deployment efficiency–energy efficiency trade-off, spectrum efficiency–energy efficiency trade-off, bandwidth–power trade-off, and delay–power trade-off. Key network performance and cost indicators under different transmission and networking schemes are woven together with these four trade-offs.

2) Hardware aspect (especially power amplifier efficiency)

As we move toward using increasingly higher frequencies, finding innovative ways to have higher hardware efficiency also becomes a key factor for energy efficient network design. For instance, dealing with reduced power amplifier (PA) efficiency becomes a major challenge [2]. Since each RF chain has a PA, as the number of radio frequency (RF) chains goes up, achieving efficient radio network energy consumption becomes even more challenging. Novel antenna and RF architectures that exploit less RF chains but still achieve performance close to a full RF chain case would be one direction worthy of investigating.

3) Network aspect (service provision in accordance with traffic dynamics in time and space)

From the network aspect, improving the overall energy efficiency entails making the service provision conform to the traffic dynamics in time and space, avoiding waste of energy radiation into areas and durations that have no traffic requirement [3]. There should be, of course, balance between fast service access and maximizing energy consumption reduction. Network architecture design with multiple layers of heterogeneous coverage that supports dynamic switching off would be beneficial to achieve the above goal. On top of the architecture, algorithms for co-coverage identification and traffic prediction leveraging AI technologies are promising solutions. The wide application of AI technologies in wireless networks offers new opportunities to optimize network resource management using tools such as deep reinforcement learning, instead of solving complicated non-convex optimization problems.

4) Renewable energy, passive transmission, etc.

In addition, the use of renewable energy and the application of all kinds of energy-harvesting technologies should also be considered as potential directions for green network design. Solar power is one example that has been widely used for operating micro and even macro base stations. On the other hand, low-power-transmission schemes by optical wireless, passive meta-surface, or backscattering communications are novel candidates for Beyond 5G communications in different application scenarios.

5) Distributed network to solve the centralized AI training and inference power problem

Another significant challenge centers on computing power consumption due to the rise of AI. We can speculate that, on average, the human brain achieves data rates of 20,000 Tbit/s and can store 200 TB of information while consuming only 20 Watts. Conversely, the computing power of AI is doubling every two or three months, far in excess of Moore's law. For a neural center to achieve the same capabilities as the human brain, there is a 1,000 times gap at a point of time near the end of Moore's law. In order for neural centers to replace data centers and fully leverage the potential of AI, it is imperative to use significantly advanced ML technologies that facilitate sustainable AI-based Beyond 5G [4]. A standardized approach to implementing a distributed computing architecture and software orchestration will enable the Beyond 5G network to be an efficient platform for a diversified ecosystem.

In regard to items 3) and 4) described above, section 6.8.5 also gives further elaboration of similar technologies or ideas for Beyond 5G networks.

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6.7 Network coverage extension via non-terrestrial networks (NTN)

Non-terrestrial networks (NTN) enhance the coverage of future IMT from ground through the air toward space, which enables ubiquity of communications, and is expected to enable new use cases, such as effective connection with unmanned systems, monitoring (video and data), mobile eMBB, IoT, logistics systems, and backhaul (especially for emergencies), and smartphone integration.

Communications networks in the future IMT, defined as a network to be realized by around 2030 and beyond, will be premised on a network that is connected from space to the ground on a multi-layered basis. The following research and development initiatives with a view to realizing this communication network will need to be undertaken.

Regarding NTN, Scalability Working Group of the Beyond 5G Promotion Consortium conducted detailed studies and documented the technology roadmap, use cases, and efforts to resolve issues. These documents were revised by NTN Promotion Project of XGMF and published on the XGMF website [1-3]. If you are interested in more details about NTN, please refer to these documents.

1. High throughput and capacity

   Enhanced broadband and large capacity are required for NTN communications.

   For instance, the latest technological studies and trends in satellite communications show that dynamic beamforming, flexible beam hopping, on-board processing, and frequency reuse are already underway in efforts to provide throughput of several hundred Gbps to 1 Tbps in the next development. In addition, higher frequencies like millimeter wave, terahertz, and optical technologies provide higher speed and larger capacity services. However, such high frequency bands are easily affected by weather conditions like clouds and rainfall, making countermeasures necessary for communications to be more robust against climate. In terms of capacity increase, advanced signal processing is required to handle all data using higher speed and multi-thread technologies.

2. Low latency

   There is an unavoidable delay of about 120 msec one way due to the distance of geostationary satellites in orbit. Low-earth orbit satellites (about 100 km to 1000 km altitude) or HAPS (about 20 km altitude) are promising NTN components for delay-sensitive applications because they shorten the delay to the order of several msec. In particular, the latency of HAPS-to-ground communications can be regarded as equivalent to terrestrial IMT. Optimized NTN combinations will be required to adapt to applications that have varied necessary conditions and requirements. In terms of location of data centers or servers, multi-access edge computing (MEC) is another solution for delay reduction.

3. Massive connection for IoT

More people and things will be connected in Beyond 5G. When operating from space, it is possible to communicate with many things simultaneously under one satellite coverage, which will be a big advantage for applications that require accurate synchronized processing. In addition, distributed processing or network technologies like multi-hop communication are also effective if there are limited communication resources for NTN components due to battery or power supply equipment. Combination of different types of NTN, for instance, wide-area geostationary satellites and NGSO satellites with low propagation delay, will enable a more efficient network.

4. Optical laser communications

Optical laser technology is also important, and laser communication terminals (LCT) must be developed. Applying this technology to communications between NTN platforms (e.g. satellite-to-satellite, satellite-to-HAPS, and HAPS-to-HAPS) should enable large-capacity and high-speed communications.

5. Optimal route selection and multi-connectivity technology

Optimal route connection via multiple terrestrial networks and NTN components with multi-connectivity technology are also required. Multi-routing with optimal route selection and simultaneous multi-connections provide better reliability and extension coverage, especially for higher demand areas. Routing and multi-connectivity optimized and customized for each application or use case are dependent on varied conditions and requirements, such as delay and desired quality.

6. Quantum cryptography communications

In Beyond 5G, every piece of information and data will be downloaded, processed, and utilized so that the data obtained or processed in space, such as earth monitoring data like meteorological or geomorphological data, and location or movement of everything including people, will be vital and, therefore, require security. Reliability, integrity, security, and scalability are required as much as, or even more than, for data stored in ground servers. Therefore, in order to improve the security conditions for information exchange via intercontinental communications and mobile communications, future communication methods based on quantum cryptography keys using optical communications are highly desired. Inter-satellite links will also require these technologies for security.

7. Autonomous operations

For NTN infrastructures, a large number of NTN components are deployed in the sky and space, and they are connected physically and logically to each other in a complex manner. Operations will also become more complicated; therefore, human operations for selecting and connecting optimized routes will be difficult to carry out. Moreover, diagnosis, troubleshooting, and recovery from failures will become impossible tasks for humans. All optimal and timely operations, decisions, and service provision to users will be performed by AI. For example, all NTN components will have a grasp of the geographical and operational environment, including internal communications and other NTN components. They will then set the optimum communication parameters autonomously while interacting with other NTN components and terrestrial components.

8. Edge computing technology

A huge amount of data from IoT, such as drones and CubeSat, and delay-sensitive information, like real-time automatic operation of vehicles, will be exchanged by NTN components with terrestrial networks, so that NTNs must be able to handle the huge volume of data at low latency. Shortening delay will require not only enhancing the NTN components like LEO or HAPS, but also the edge computing technologies installed in the NTN components.

6.7.1 High Altitude Platform Station (HAPS)

High Altitude Platform Station (HAPS) is a radio station located on a platform that flies and stays in the stratosphere at an altitude of about 20 km. The stratosphere is a layer of the atmosphere far above the clouds, unaffected by rain or snow and less affected by air currents. These characteristics enable the flight of stratospheric platforms to be steadier compared with flight in other layers of the atmosphere.

Since HAPS operates at an altitude much closer to the ground than satellites, it can provide services with the same latency as terrestrial mobile networks, among other features. When HAPS is used as an IMT base station, it provides the following advantages.

- A single HAPS can cover a service area radius of up to 100 km, making it more efficient than ground base stations in providing wide area coverage.
- Unlike mobile satellite communications, which require dedicated terminals, normal mobile phones (smartphones, etc.) can be used without modification.
- Robust and resilient networks that are not affected by power outages or damage due to natural disasters (earthquakes, tsunamis, etc.) can be deployed.
- Mobile communications can be provided in the sky (for flying cars, drones, etc.) and at sea (for ships, etc.), which are difficult to cover by on-ground base stations.

There are two types of HAPS platforms, airplane type and airship type (including balloons), and each type has its own advantages and disadvantages.

Airplane type has the advantage of high operability during flight. In particular, there are many companies that are developing small and medium-sized airplanes because of their ease of operation. On the other hand, larger airplanes require a high level of safety, which increases the difficulty of development. However, since the solar panels attached to the wings are relatively larger and generate more electricity than those of the small and medium types, they can fly more quickly to the destination and supply more power to the communication payloads and sensors mounted on the aircraft.

Airship type can generate a large amount of energy due to their massive buoyancy and expansive light-collecting area on the sphere. However, in terms of fixed-point flight performance, airships are inferior to airplanes because they generate more air resistance. Therefore, they require measures such as auxiliary propulsion systems for operation.

The advancement of HAPS evidently depends on improving the performance of batteries and solar panels. The significant increase in battery capacity and solar panel power-generation efficiency in recent years has made it possible to fly for long periods in the stratosphere. The performance of batteries and solar panels will likely continue to improve in the future; thus, HAPS is guaranteed to make further progress and become an essential infrastructure for humankind.

6.7.2 Satellite communications

Communication satellites are among the critical NTN components for implementing a future network that is connected from space to the ground on a multilayered basis for vertical network extension. Satellites serve as essential platforms to support areas outside of cellular service on the ground, and cover air, ocean, as well as outer space, which is not covered by terrestrial networks.

There are two types of satellites; namely, GSO and NGSO, with their own pros and cons.

GSO satellites are able to cover a large area from a fixed point with respect to the earth, with an approximately 250-msec delay (RTT is 500 msec) due to their long distance, around 36000 km, above the ground.

GSO satellites can accommodate a large number of NTN components of LEO/HAPS with continuous communications due to its large-area advantage. GSO satellites can also support areas not covered by NGSO satellites, such as LEO/HAPS.

NGSO satellites have lower orbits than geostationary satellites and are useful for delay-sensitive applications. For continuous service, constellation is required to provide seamless and continuous communications.

The number of satellites per constellation plane is critical for constant throughput.

The user terminal on the ground needs handover technologies for tracking the moving satellite and switching to the next satellite with no interruption. Seamless handover requires catching and preparing connection with the next satellite before the connection release of the current satellite.

Communication satellites have been used for cellular backhaul services, emergencies, direct communications with mobile terminals and vehicles on sea or air, and for IoT.

In the future of NTN, satellites are absolutely required platforms for providing IMT connectivity everywhere through multilayer and vertical extension.

6.7.3 UAV-assisted wireless communications

Unmanned aerial vehicles (UAV), which are also commonly referred to as drones, are a type of aircraft without a human pilot onboard. They can be remotely controlled by an operator via a UAV controller. They have a certain range of autonomous flight capabilities, which will likely achieve fully autonomous flight in the future. UAVs vary widely in terms of size and weight, and can be used in varied business sectors in future smart cities and lifestyles. For instance, UAVs have been widely used for aerial photography, logistics, aerial inspection for constructions, as well as for environmental monitoring and precise agriculture. According to Keystone's forecast, the UAV technology market will reach $41 – 114 billion globally in a few years [4]. In these applications, UAVs are mainly acting as a special type of mobile terminals within the network.

However, by leveraging the fundamental features of UAVs, i.e. mobility in the air and a natural platform to carry certain load, in the future, they can also be used as a base station or relay to form a temporary network and to extend mobile communications. The benefits provided by such UAV-assisted wireless communications are flexibility and agility to provide on-demand deployment of network coverage within a short time. These are very important in complementing fixed infrastructures in particular scenarios, such as during natural disasters or during short-term events like concerts or big games in crowded stadiums.

Moreover, UAV-assisted wireless communications can also bring the base station closer to the user with shorter distance and possibly light-of-sight (LOS) communication links, which can help improve the service quality and reduce power consumption for users. For instance, it can be used to collect IoT data from less-covered areas such as farms or forests, saving power for both fixed base stations and IoT devices. Moreover, UAV base stations can also serve as extended mobile sensors to enhance the sensing capability of Beyond 5G, obtaining better information of the environment for communications, as well as for 4D city mapping for autonomous driving.

Realizing the functions mentioned above entails overcoming many technical challenges ahead. Similar to HAPS, one big challenge pertains to the power supply (limited onboard battery) and energy efficiency of the UAVs, which will certainly limit its application range and scenarios. Likewise, technologies such as UAV 3D trajectory planning to form flexible radio network architecture, channel modeling between UAV moving base stations and terrestrial user terminals, interference management and cancellation using advanced antenna and signal processing algorithms, efficient and ubiquitous wireless backhauling, as well as onboard sensing and communication co-design are directions that are worth further study.

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6.8 Wireless and optical

6.8.1 New Radio Network Topology

(1) Features and strengths

In contrast to conventional cell-based radio network topology, a feature of the New Radio Network Topology is to create and control new radio network topology utilizing distributed antennas, repeaters/relays, reflectors, and virtual mobile terminals, in addition to the usual base stations and mobile terminals. This enables high capacity, coverage extension, highly stable communication, and low power consumption.

(2) Value provided

For end-users, this technology provides highly stable services and applications regardless of users' locations. It addresses environmental problems by contributing to low power consumption of mobile terminals and radio network. It benefits service providers by contributing to high flexibility in designing radio network systems and their operation.

(3) Role to play

The topology can provide 100 times high-capacity communications than 5G required for services and applications in Beyond 5G era regardless of users' locations.

(4) Description of technologies

The New Radio Network Topology realizes stable, high-capacity communications and coverage extension regardless of users' locations by utilizing a large number of spatially distributed antennas, repeaters/relays, and reflectors such as Reconfigurable Intelligent Surface (RIS) installed between base stations and mobile terminals and by virtually increasing the number of terminal antennas through inter-terminal cooperation.

(a) RIS technology

RIS technology uses programmable new sub-wavelength two-dimensional metamaterials to actively and intelligently regulate electromagnetic waves through digital coding; forming electromagnetic fields with controllable amplitude, phase, polarization, and frequency; and providing an interface between the physical electromagnetic world and the digital world of information science. RIS can break through the uncontrollable characteristics of traditional wireless communication and realize active control of the wireless propagation environment; intelligently realize the regulation, enhancement or elimination of signal propagation direction in three-dimensional space; suppress interference and enhance signals; and build a new paradigm for Beyond 5G intelligent programmable wireless environment.

RIS will improve the communication quality, enhance the high frequency coverage, improve performance for edge users, etc. For example, RIS can enhance signal of blind users. The direct link between the user and its serving base station is severely blocked by obstacles. In this case, the deployment of an RIS that has a clear connection with the base station and the user helps to bypass obstacles through intelligent signal reflection, thereby creating a virtual visual link between them, which is useful for expanding the millimeter that is easily blocked.

RIS will become a new kind of transceiver that may replace the traditional transceiver. RIS can further improve the performance in new areas: high-precision positioning, wireless power transmission, and integration of sensing and communication. RIS technology meets at least two requirements of Beyond 5G:

- RIS can significantly improve the transmission performance between communication devices, enhance the coverage in the communication system, as well as improve the transmission rate, coverage, and energy efficiency of Beyond 5G.
- RIS can actively customize the wireless communication environment and flexibly regulate the wireless signal in accordance with the required wireless functions, such as ensuring Beyond 5G network security and reducing electromagnetic pollution and auxiliary positioning perception, in order to realize intelligent regulation of the wireless communication environment.

Toward the development of Beyond 5G, the challenges and difficulties faced by RIS technology include: channel state information acquisition, channel modeling, beamforming design, passive information transmission, AI-enabling design, prototype system verification, deployment, and networking design.

As a new and potential basic key technology, RIS has the characteristics of low cost, low power consumption, and easy deployment. It will be able to support green communication, enable intelligent wireless environment, and realize more new capabilities. RIS will bring a new network paradigm and open a new era of Beyond 5G in the future.

(b) Large-scale distributed MIMO

One of the most important features in wireless industry is multi-antenna systems used to provide coverage and high throughput. As a start, MIMO system focused on enhancing multi-user transmission, later massive MIMO systems is a key component in 5G. To formulate the next evolution in multi-antenna systems, we should define the needs that Beyond 5G networks should deliver to satisfy the dynamic requirements of future use-cases considering connectivity, reliability, adaptability, sustainability and security aspects. It is expected that Beyond 5G should provide higher data rates with uniform and reliable service quality as well as more resilient transmission schemes. Large-scale distributed MIMO (D-MIMO), aka cell free massive MIMO, is a key component- D-MIMO can be seen as a combination of ultra-dense networks, massive MIMO and coordinated multi-point transmission where devices have simultaneous physical links to a large number of tightly coordinated network transmission points. This will help us to build non-intrusive, flexible and robust networks [1]. When densification starts to suffer from interference, D-MIMO provides significant performance gains by the coordination of distributed Access Points (APs) with a Central Processing Unit (CPU) through high-capacity fronthaul links (e.g., fiber-optic cables) [2].

Network densification and wideband transmission in high frequencies along with beamforming and converged access-backhaul-fronthaul considering various deployment options and hardware impairments will be key to providing the extreme and uniform performance. Nonetheless, there is still a need to realize a robust access link that supports mobility on high frequency bands, where the propagation environment is more challenging. Spatial diversity brings the advantage of achieving the high reliability and resilience, especially in non-line-of-sight, and a D-MIMO network can benefit from a much higher degree of macro diversity to overcome radio blocking.

Nonetheless, there is a need to understand how large area that can be coordinated considering various split options that address practical beam management and transmission approaches in higher bands. Centralized processing with phase coherent transmission would give the best performance, but coordination among APs put strict requirements on transport network. Just note, joint but non-coherent transmission with high number of redundant AP links would result in inefficient resource usage. Beyond 5G MIMO should be settled to enable scalability, robustness, and high performance, but also be optimized from an energy perspective with architectural and hardware aspects. In case of large bandwidth, digital processing in the APs is power consuming and increases the size, then it needs to move into a centralized location, meaning fronthaul (FH) interface between AP & CPU becomes analog. Beyond 5G transport needs to connect distributed antennas and processing units over multiple sites via a backhaul network, and the Beyond 5G Lower Layer Split (LLS) may be built on the existing 5G solutions with certain adaptation and enhancements. Compared with collocated massive MIMO, D-MIMO requires many sites for the APs. Thus, the LLS fits for D-MIMO in terms of deployment.

(C) User-centric RAN architecture

It is important to implement user-centric networks in which a communication area is formed for each user in accordance with the communication environment and individual communication requirements.

In user-centric RAN architecture [3], instead of a specific base station providing services to users in a specific area, multiple base stations work together to provide services for each user. The technologies required for this purpose are as follows:

- To provide cell-free massive MIMO, which is a combination of distributed MIMO and massive MIMO technologies (see section 6.8.3), to reduce radio quality degradation at cell boundaries. Large numbers of base station antennas are densely deployed and each base station antenna cooperates with the others to provide service to individual users. Applying massive MIMO technology at aggregation stations, interference between users can be suppressed, and radio quality degradation at cell boundaries—an issue in conventional cellular architecture—can be reduced. For further details, please see the previous item (b).
- To expand the virtualized target to include the backhaul of the mobile communication network and the radio link between a base station and terminals to provide each users' logical network [4]. In detail, a radio processing unit and a radio unit (access point, AP) are placed for each user by using a virtualized method, and these units perform distributed processing of the radio signals between APs. Those provides mobile communication networks per users by the evolved RAN architecture, because it can place and control base station functions for adaptation both the radio environments and communication services that are different per users.
- To provide "Radio on THz" technology [5]. In this technology, a UE is connected to its peripheral devices via terahertz broadband radio, while the peripheral devices convert their terahertz radio into the different (lower) frequencies for connecting to base stations (e.g., the millimeter wave bands and the sub-6 gigahertz band) and then connect to the APs. Specifically, through the connection, it becomes possible to solve issues arising from the constraints caused by a single user device, such as power transmission and the number of integrated antennas.

6.8.2 Technology for wider bandwidth and advancement of frequency utilization

(1) Features and strengths

In the higher frequency spectrum from the millimeter waves to terahertz waves, it is possible to use a drastically wider bandwidth compared with 5G. From this reason, extremely high data rate and high-capacity communication exceeding 100 Gbps can be achieved. In addition, due to the extremely short wavelength of THz spectrum, antenna elements become much smaller than those designed at millimeter waves. Consequently, the ultra-massive MIMO system provides not only coverage extension by pencil-beamforming, but also improvement of spectrum efficiency by exploiting higher spatial resolution and frequency reuse.

(2) Value provided

When new frequency bands such as millimeter wave and terahertz wave are added to the existing frequency bands, a much wider frequency band will be available than before. Therefore, it is possible to optimize the use of multiple bands in accordance with the application, which is expected to improve the frequency utilization efficiency of existing frequency bands, expand the scope of applications to new use cases, and improve user experience everywhere.

(3) Role to play

The exchange of data between physical space and cyberspace will likely increase dramatically in the future toward 2030. By using the wide frequency bandwidth such as millimeter and terahertz waves in addition to the existing frequency bands, it will be possible to achieve a peak data rate exceeding 100 Gbps and process massive amounts of data from any location instantly and accurately.

(4) Description of technology

In the higher frequency spectrum from the millimeter waves to terahertz waves, it is possible to use a drastically wider bandwidth. However, terahertz waves tend to travel through a straight path than millimeter waves and cannot propagate over a long distance. In order to address this problem, it is necessary to carry out technical examination on terahertz waves to clarify their radio propagation characteristics, establish their propagation model and high-precision propagation simulation technique, and advance device technology. A wide range of frequency utilization technologies, such as spectrum sharing, and a review of spectrum utilization methods in low frequency bands, will also be important.

In addition to the extremely high data rates, high-resolution sensing and imaging, and high-precision positioning applications will be implemented into THz communications, whose THz spectrum has features such as wider bandwidth operation, higher gain antenna performance, and frequency-selective resonant absorption characteristics. High gain antennas, where the interference from neighboring cells can be ignored and communication is physically divided, tend to split the terahertz communication area from neighboring cells because the beam is very thin and forms a narrow area.

Due to the extremely short wavelength of THz spectrum, antenna elements can be much smaller than those designed at millimeter wave bands, and many more antenna elements can be integrated in the footprint. This ultra-massive MIMO system provides not only coverage extension by pencil-beamforming but also improvement of spectrum efficiency by exploiting higher spatial resolution and frequency reuse. Ultra-massive MIMO as well as massive MIMO systems at THz bands will be leveraged to improve system performance of future IMT systems.

As a further coverage extension technique, RIS reflectors can be applied on the wall of the room or the building to deliver THz waves to the non-covered areas like in millimeter wave RIS technics.

6.8.3 Further advancement of RAT/air interface

(1) Features and strengths

By radio access technology (RAT) and air interface specialized in Beyond 5G, such as new waveform, modulation, coding, multiple access, full duplex schemes, and advanced MIMO/massive MIMO, will enable extremely high capability and performance of Beyond 5G, such as a peak data rate of over-100 Gbps and 100 times the system capacity of 5G. They can also support use cases that are newly provided in Beyond 5G and extended from 5G.

(2) Value provided

They provide ultra-high capacity and data rate for wide area and local area communications, while addressing the challenges of signal propagation, system and hardware complexity, power consumption, and cost. They also support new use cases by leveraging network for sensing.

(3) Role to play

They will help in bridging the digital divide by enabling access to anyone, anywhere; provide better environmental awareness via sensing to improve physical resource planning and resource management; reduce wastages in logistics and transportation, leading to a more sustainable society; and enable equitable and ubiquitous access to high quality healthcare and education. Other potential use cases include short-range communications, for example, across displays and computing devices, and rack-to-rack communications.

(4) Description of technology

Study and analysis are ongoing on the waveform, modulation, and coding techniques to address radio propagation issues, numerology and frame structure for wide carrier bandwidths, and subcarrier spacing at the high bands. Advanced MIMO and antenna schemes are key for ultra-densification and ensuring energy efficiency to support high data rates.

(a) New waveform, modulation, coding, multiple access, and full duplex schemes

Extreme data rates in Beyond 5G will be made possible by leveraging large carrier bandwidths available at sub-THz bands. Operation of Beyond 5G in these bands will satisfy the high capacity demands of indoor hotspots, help in expanding urban coverage with the use of integrated access and backhaul architectures, and enable new use cases based on precision sensing.

Signal propagation characteristics at short range due to high attenuation at high frequencies, which can get blocked easily due to short wavelengths, must be accounted for in the design of the waveform for effective operation in the high frequency ranges.

Waveform design needs to not only account for signal propagation characteristics to make the most efficient use of the spectrum, but must also account for practical limitations posed by hardware and the channel, such as non-linearity of power amplifiers, low quantization resolution, very short channel coherence time and bandwidth, phase, and impulsive noise. New modulation schemes, pilot sequences, and codes need to be developed to extract the best capacity from the given spectrum.

The classical frame structure of preamble, pilots, coded bits, and cyclic-redundancy may not be best suited for transmission of short messages. Simultaneous communication and sensing will also drive the new waveform design. To minimize implementation complexity and power consumption while maximizing coverage area for high capacity, enhanced single carrier waveforms with spectral shaping will need to be analyzed.

Solutions must be investigated to address high phase noise problems, which would motivate research to explore low-PAPR modulation schemes together with coding techniques. For high data rates in high phase noise settings, large subcarrier spacing will be useful for robust operation, while reducing cyclic prefix length. Numerology aspects will also need careful analysis. Control and reference signal design, initial access, and beam management should also be studied as part of the design of the frame structure.

With advances in the field of AI for communications, the waveform, modulation, and coding techniques can be dynamically adapted and optimally designed by AI to build practical systems that not only reliably transmit bits, but also adapt to different radio environments, hardware, and data traffic needs.

(b) Advanced MIMO/massive MIMO

Advanced MIMO techniques will be key to extracting the best performance from the available spectrum in lower (< 6 GHz), mid (2.5 – 4.9 GHz) and mmW (24 – 71 GHz) bands. Massive MIMO will be key to ensuring that power consumption per transmitted bit remains in control while trying to maximize coverage at sub-THz bands. AI/ML techniques for beam management and prediction, CSI compression, prediction and feedback along with reduction of reference signal overhead must be investigated for better performance and simpler system design.

Ultra-dense deployments at mmW and sub-THz frequencies will require scalable and distributed signal processing capabilities provided by distributed MIMO techniques. Enhancements to CSI and SRS framework for improved CSI acquisition will complement advanced algorithms for distributed signal processing.

Use of MIMO for coverage and capacity enhancements including support for larger array sizes is already being investigated in the context of 5G FR1/FR2 bands. The gains from these techniques need to be analyzed. Further enhancements in this area, as well as the role of intelligent reflective surfaces, are interesting topics for future research. On the UE side, techniques for multiple subpanels and their management need to be studied for operation in the new bands.

6.8.4 Technology to support extreme ultra-reliable and low latency communications

(1) Features and strengths

Each node realizes multiple synchronization methods (phase synchronization at carrier frequency or autonomous synchronization to a virtual common clock) depending on the required precision. The virtual common clock is obtained by an autonomous distributed clock scheme, which is based on the atomic clocks in network nodes including UE. By exploiting the above space-time synchronization technology, extremely low latency communication can realize extremely low latency of 1 msec or less at end-to-end. In addition, extremely ultra-reliable and low latency communications (URLLC) in Beyond 5G should realize a higher level of reliability than 5G URLLC, and for Beyond 5G, the improvement by one digit (reliability of 10^{-6} - 10^{-7}) is assumed as the target value in comparison with 5G.

(2) Value provided

Besides the various pre-existing technologies, space-time synchronization technology will provide clocks synchronized at the picosecond level between two short-range nodes, and also a clock timescale that can be shared at the nanosecond level in a local terrestrial network. Extremely low latency communication can provide more advanced real-time interactive AI services without the 'sense of incongruity' by the low latency feedback from cyberspace. Extremely ultra-reliable communication can support mission-critical industries. In the future, with the wide popularization of robots and drones and the expansion of radio coverage to air, sea, and space, realization of reliable communication will be required in a wider area.

(3) Role to play

In short-range communications, a precise and stable clock infrastructure realizes the low-latency and high-capacity communications beyond the 5G level, enabling strong interactions between the edge servers and UE. This infrastructure also enables a synchronous operation among base stations, power transmitters, as well as UE, which contributes to the reduction of energy as well as frequency resources through the efficient transfer of power and communication packets.

Industrial use cases are characterized by their wide range of requirements, which vary among industries and applications. Low latency is not always required; however, it is necessary to anticipate use cases that would require very demanding conditions and not be simply satisfied with an average low latency but demand stable low latency that will never fluctuate. Automation systems in factories are predicted to use different applications to make their automated operation more effective. Beyond 5G needs to support “Mixed Traffic,” in which different systems with different communication requirements coexist. It is necessary to realize Beyond 5G systems that can respond to a wide range of requirements, such as achieving extremely high-capacity communication while maintaining extremely high reliability and low latency.

(4) Description of technology

A plurality of synchronization techniques are implemented in accordance with the time synchronization accuracy required for each node (phase synchronization at a carrier frequency or autonomous synchronization to a virtual common clock). In order to realize a high level of real-time and interactive services in cyber-physical fusion, it is important to always have stable end-to-end low latency. Enhanced URLLC technologies for Beyond 5G realize an extremely low latency of about 1 msec or less on the end-to-end basis, by utilizing high-precision space-time synchronization, etc. In addition, a higher level of reliability (e.g., 10^{-6} - 10^{-7}) is achieved than 5G URLLC. In the space-time synchronization technology, an atomic clock is arranged at each node including user terminal, and an autonomously distributed clock scheme is implemented.

6.8.5 Technology to enhance energy efficiency and low power consumption

(1) Features and strengths

Achieving carbon neutrality is a universal subject not limited to the information and communications field. In the case of Beyond 5G systems, providing high-speed and large-capacity communication services at the expense of power consumption is not acceptable.

The mobile communication industry has a long history of improving spectral efficiency and power consumption of its devices and facilities and has been providing low power consumption user devices that allow longer battery operations in the field. Toward Beyond 5G era, these legacy technologies are to be further improved and applied together with several expected breakthrough technologies to achieve carbon neutrality.

(2) Value provided

Communication and data processing services must be provided in a sustainable and carbon-neutral way by improving the energy efficiency of communication systems 10 times compared with 5G.

(3) Role to play

On top of providing ICT services without generating excess carbon dioxide, the technology could contribute to carbon neutrality by eliminating unnecessary energy consumption in every social or economic activity.

(4) Description of technology

Further higher power efficiency and lower power consumption compared with 5G will be realized by utilizing energy harvesting technology for converting energy such as light, heat, vibration, and electromagnetic waves into electric power; ambient backscatter communication technology for transmitting and receiving existing signals without using a battery; and wireless power supply technology from base stations deployed in high density [6], [7].

As for the reduction of power consumption of the hardware devices used as the infrastructure of the communication system, there is a possibility that the reduction of power consumption can be achieved by applying optical data transmission between a set of equipment placed in a single site or even devices in single equipment, rather than using electric signals. Empirically, it has been said that the boundary between transmission of electrical signals using metal conductors and transmission of signals using optical fibers was "1 Gbps·km" [8]. However, in the future, application of optical signal transmission technology to closer distances may promote further reduction in power consumption [9].

Improvement in efficiency of the communication infrastructure as a whole can be achieved, for example, by applying appropriate and advanced resource management in the system in accordance with the communication traffic volume.

Furthermore, "local production for local consumption" of information at edge nodes using the edge data processing function of Beyond 5G system could help achieve carbon neutrality by reducing unnecessary data transfer and eliminating redundant data processing.

6.8.6 Integrated sensing & communications and high- accuracy localization

(1) Integrated sensing and communications (ISAC)

(a) Features and strengths

Beyond 5G will move beyond simple positioning and will feature a networked sensing capability [10]. Driven by the continuous increase in frequency bands, bandwidths, and antennas, communications systems will integrate wireless sensing capabilities to explore the physical world through radio wave transmission, echo, reflection, and scattering. The integrated design allows for better communication performance in terms of medium-aware communication through more efficient beamforming and interference suppression techniques when sensing information is made available. Meanwhile, the ISAC network also creates new usage scenarios that allow for efficient, on-demand sensing services such as localization, imaging, mapping, and activity detection. Within such context, several new key performance indicators (KPIs) are introduced for sensing capability such as sensing accuracy, sensing resolution and detection/false alarm probabilities.

(b) Value provided

High-resolution and high-accuracy sensing, localization [20] (including positioning), imaging, and environment reconstruction capabilities will improve communication performance and support a broader range of network service scenarios, laying a data foundation for building an intelligent digital world. Potential new services that could be supported by future ISAC systems can be classified into four categories [11], namely: high-accuracy localization and tracking; simultaneous imaging, mapping, and localization; augmented human sense; and gesture and activity recognition. The ISAC system can provide both device-based positioning and device-free localization services for Beyond 5G, which leads to supporting use cases requiring high-accuracy localization such as automatic docking for drones and collaboration between robots for complex tasks. In addition, Beyond 5G based sensing capabilities in simultaneous imaging, mapping, and localization enable the mutual performance improvements of these functions which opens up the realm of possibilities in 3D indoor/outdoor non-line-of-sight imaging and mapping. Using much higher frequency bands, the ISAC system can be implemented in portable devices to augment human senses and enable people to "see" beyond the limits of human eyes, e.g. in future smart hospitals to obtain information on vascular/organ status and other vital signs. Device-free gesture and activity recognition based on the joint capability of sensing and machine learning is another promising aspect of ISAC applications to promote contactless user interfaces and camera-free supervision of the patients or elderly people so that emergences can be timely identified.

(c) Role to play

In the ISAC system, sensing and communication functions will mutually benefit each other within the same system. On one hand, the communication network as a whole can

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[20] In this section, positioning defines the device coordinates while localization provides information about the device, objects, and environment.

serve as a sensor. On the other hand, the capabilities of high-accuracy localization, imaging, and environment reconstruction obtained from sensing will facilitate and improve the performance of communication through more accurate beamforming, faster beam failure recovery, and less overhead to track the channel state information (CSI). Moreover, sensing can be seen as a “new channel” observing, sampling, and linking the physical and biological worlds to a cyber world. Real-time sensing combined with advanced AI technologies is thus essential to implement the concept of digital twin, a true and real-time replica of the physical world, a reality in the future.

(d) Description of technology

The integration of sensing and communication functions can happen at different levels, from loosely coupled to fully integrated, from shared spectrum and shared hardware, to shared signal processing and protocol stacks, and even cross-module, cross-layer information sharing, benefiting one another. ISAC in Beyond 5G network will empower technological innovations that make use of large-scale cooperation between base stations and user devices, joint design of communication and sensing waveforms, as well as advanced signal processing techniques. The integrated ISAC system design allows for efficient resource sharing between both sensing and communication. As such, the main benefit of the integrated design will be the avoidance or mitigation of interference between the two systems when temporal, spectral and spatial resources are shared. Power utilization can also be much more efficient if the systems are integrated to a certain degree, sharing the same RF, IF and digitization sub-systems. In addition, the integration allows more opportunistic and predictive communication based on the sensed knowledge of the historical and real-time channel environment characterization.

There are still major challenges in the practical implementations for the design and evaluation of ISAC as a core technology in future communication system. First and foremost, a theoretical framework is necessary to analyze and evaluate the performance of current ISAC solutions in order to identify the benefits and any short comings. Current design of the ISAC system calls for the baseband and RF hardware to be functionally shared and as a trade-off, the impact of distortion parameters on sensing performance needs to be carefully considered. The challenge for the joint waveform design is the very different KPIs for communication and sensing where optimizing both might not be so straight forward. ISAC in the mobile communication network provides great opportunities and benefits for synchronized multi-static sensing where the technology challenges here would lie in the synchronization, joint processing and network resource allocation in order to achieve the optimum fusion sensing results. As such, the key technology directions for ISAC will be on the performance analysis of general ISAC networks, radio access network design for ISAC, sensing-assisted/-enabled communication,

communication-assisted sensing and sensing-assisted positioning, which will take us closer to integrating sensing and communication.

(2) Wireless space-time synchronization for high-precision positioning

(a) Features and strengths

Although current GNSS fail to provide pico-second level synchronization accuracy to base stations, wireless space-time synchronization can offer that level of accuracy, enabling the phase-locked synchronization in mm waves between base stations. This new level of precision of synchronization is critical for positioning technologies that are based on time-of-flight (ToF) measurement of traveling waves, such as ultrasonic sound, light, and radio wave. Another positioning technology that requires synchronization is stereo vision-based positioning.

(b) Value provided

Wireless space-time synchronization enables measurement of the relative positions of the devices at centimeter or more accuracy.

(c) Role to play

As the synchronization technology matures more toward 2030, Wireless space-time synchronization will likely become available in future IMT by around 2030, enabling location-based services to be fully equipped with higher precision localization capability.

(d) Description of technology

Wireless space-time synchronization is an implementation of (carrier phase) two-way time and frequency transfer. It measures the transmission delay of electro-magnetic waves at picosecond accuracy, resulting in measurement of the relative positions of the devices at centimeter or more accuracy while also synchronizing the local clocks of remote devices.

6.8.7 Management of radio access/core network and other wireless systems

(1) Features and strengths

Technologies based on the prospect of using radio waves in various applications include radio resource management technology to effectively use finite radio resources, integration of various wireless signals/systems, and mobile core network management. These technologies can provide values such as large capacity and low latency communications.

(2) Value provided

Management technologies enable users to enjoy flexible services, and allow service providers to make effective use of finite radio resources.

(3) Role to play

It is possible to provide ultra-fast and large-capacity communication required for services and applications in the Beyond 5G era based on radio resources available at the corresponding location.

(4) Description of technology

(a) Integration of various wireless technologies

This technology integrates and controls various types of other wireless systems other than mobile communications with mobile communications. It effectively utilizes limited radio resources by exploiting the other wireless systems in the right place in accordance with the needs of users and the intentions of mobile network operators.

(b) Core network management

This includes a multi-session communication technology that simultaneously uses multiple communication connections to increase capacity and a technology that simplifies terminal location management to promote simultaneous multiple connections.

6.8.8 Technology for native AI-based communication

(1) Features and strengths

Native AI-based communication will make a breakthrough from the incumbent modular-based air interface design by deeply integrating AI and improving the overall system performance. Further, the ultimate air interface will be able to perform end-to-end intelligent communications to meet the ambitious Beyond 5G requirements.

(2) Value provided

AI will be a built-in feature of native AI-based communication. It will be more efficient in terms of power consumption and spectrum utilization, and will support efficient integration of communications and sensing, and provide a simpler protocol and signaling mechanism with low overhead and complexity.

(3) Role to play

For Beyond 5G, AI is the design tablet of the future communication system, and it will be the cornerstone to create intelligence everywhere. To meet the diverse service demands and new KPIs in Beyond 5G, the integration of AI in communications is envisioned as a key technology to revolutionize wireless network architecture and air interface design.

(4) Description of technology

The AI native air interface aims to ensure that the network delivers the desired bandwidth and latency KPIs to the application, by dynamically adapting to the constraints and variability of radio environment and hardware imperfections. For this purpose, the classical air interface procedures such as channel and source coding will have to function with complete awareness of the characteristics of the data it needs to carry. With advances in field of AI for communications, the AI native air interface will not only reliably transmit bits, but also adapt to different radio environments, hardware, and data traffic needs. Such an end-to-end optimization of the air interface will be critical to support verticals e.g., industrial communication systems for sensing and robotic control, where resource prioritization with knowledge of application specifics will be necessary to guarantee performance and predictable degradation of operation.

(a) AI-enabled intelligent PHY and MAC controller

With massive collected data, AI is able to solve the nonlinear mapping problems and provide intelligent prediction and decision optimization, which facilitate the design of intelligent PHY and MAC controller. In physical layer, the modules can be replaced by AI models, such as deep neural networks, and a huge amount of channel and environment data collected by sensing can be utilized to enhance the performance in channel acquisition, beamforming and beam-tracking, sensing, and positioning, etc. In MAC layer, AI models can be an intelligent MAC controller to support intelligent transmission reception points (TRP) management, enables massive data processing and zero-latency intelligent control. It can coordinate the load of the network center and edges, and perform real-time beam management and dynamic spectrum configuration. Further, it can promote the modulation and coding scheme (MCS), hybrid automatic repeat request (HARQ) mechanisms, interference management, and power control.

Further, use of Machine Learning (ML) to enhance some receiver processing blocks such as physical layer RACH detection, channel estimation, and symbol demapping can be expected as one of the first steps towards AI-AI with hybrid systems containing a mix of ML and non-ML processing blocks. The next phase is expected to see ML models combining multiple functions such as joint channel estimation, equalization and demapping. With improvements in hardware acceleration capabilities, and increased confidence in ML models, ML-only systems will become feasible.

(b) AI-enabled intelligent protocol and signaling

Intelligent protocols and signaling mechanisms are important components of AI-enabled personalized air interfaces, which provide sufficient room to enable intelligent PHY and MAC control. They are expected to reduce signaling overheads and improve system efficiency through self-learning, self-operation, and self-maintenance. In terms of frame structure, more flexible waveform parameters and transmission duration should be designed to meet the diverse requirements in Beyond 5G, such as the 0.1 msec latency requirement for localized communication if specified. In terms of control signaling, more flexible size and fewer formats of control signaling are required to realize a simplified, agile, and forward compatible mechanism.

Further, AI/ML will be used to design the protocol, leading to solutions that are well-suited for native AI/ML processing. Hence, it is not necessary to fix all aspects in advance, but instead insert hooks for online training and refining of the models. Signaling procedures will need to enable distributed end-to-end training, without the need to specify modulation schemes and waveforms, which can be optimized at deployment time. In addition, the specifications can include AI/ML-driven waveforms and modulation schemes that have been designed or learned in advance, to be used alongside fully learned counterparts when online learning is not feasible.

(c) End-to-End intelligent post-Shannon communications

Traditional Shannon's communication framework focuses on bit transmission to deliver and restore messages without errors. In future wireless communications systems, radio-link procedure and AI technology will be jointly designed to realize efficient information processing, transmission environment sensing, and intelligent air interface capabilities. The neural network at the transmitter will intelligently adapt to the real-time changes of the information source, while the neural network at the receiver will extract effective information from the received data according to specific tasks. By this means, information can be exchanged based on its content and semantic communications can be realized.

6.8.9 Optical communication technology

(1) Features and strengths

Optical communication technology is suitable for long-distance, high-speed, and high-capacity communications.

In contrast to terrestrial mobile communication systems in which the radio propagation loss in the UHF to SHF band (300MHz to 30GHz) increases rapidly in proportion to the 3.5th to 4th power of the propagation distance, optical fibers have transmission loss (in dB) that is simply proportional to the transmission distance (Figure 6.8-2).

The minimum inherent attenuation of single-mode fiber is about 0.2 dB/km [12]. In practical transmission systems using light and thin optical fiber cables, 0.3 dB/km is achieved, and high-speed, large-capacity communications over several 10 km is possible [13].

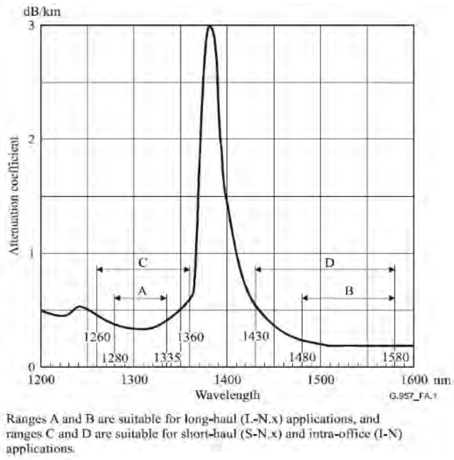

Figure 6.8-1 Typical spectral attenuation coefficient for the installed fiber cable [13]

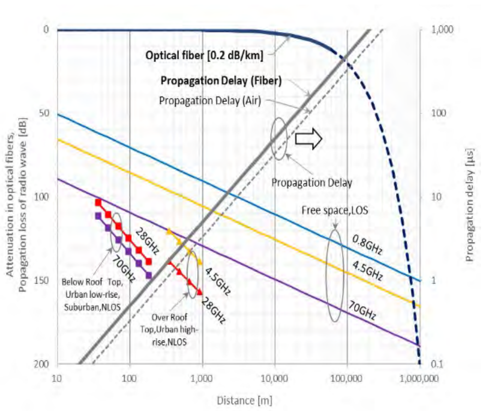

Figure 6.8-2 Attenuation of optical fiber and propagation loss of radio wave [13][14]

In Japan, we have a decades-long history of technological development since the dawn of optical fiber communications, and a high-speed optical communications network has been deployed nationwide. Utilizing these optical communication infrastructures together with state-of-the-art communication technologies either for wired and wireless systems could present a good opportunity to demonstrate how the Beyond 5G system works and supports a variety of use cases in an efficient manner.

(2) Value provided

By appropriately applying optical transmission to the connection between each Beyond 5G communication node, more efficient and large-capacity communication could be stably realized to provide comfortable and stress-free communication services that address the increasing demands of greedy communication traffic.

(3) Role to play

To support a sustainable society as part of the advanced communication infrastructure, optical fiber communication technologies that are being developed for the Beyond 5G era should not only provide more advanced communication utilizing existing optical fiber networks, but also provide high-speed, large capacity, and stable communication links using the latest technology in fronthauls and backhauls of wireless communication networks, as well as in the entirety of long-haul communication networks.

In addition, they play an important role in the realization of carbon-neutral communication services, for example, by providing low-power broadcast transmission or active route and resource management in response to communication traffic behavior.

(4) Description of technology

Advancement of optical communication technology is also important in order to support wireless communication technology, which is increasingly advancing toward Beyond 5G. More flexible and low-power-consumption optical communication network is made possible by photonics-electronics convergence technology, in addition to the enhancement of fiber technology, including multi-core fiber and next-generation optical communication technology for realizing higher data rate communications [10], [15]-[17].

It should be noted that, in technical studies and system construction in the case where low-delay transmission is an important key performance factor, in addition to the transmission processing delay and information processing delay at Beyond 5G transmitting/receiving nodes and relay nodes, an additional delay time due to a physical transmission distance is added and would not be negligible in some cases (see right axis in Figure 6.8-2)

6.8.10 Radio over Fiber

(1) Features and strengths

Radio over Fiber is a technology for large-capacity mobile fronthaul transmission to accommodate the user data rates required in the Beyond 5G era, as well as avoid power and space problems in the arrangement of large numbers of distributed base station antennas (see section 6.8.1).

(2) Value provided

Large-capacity mobile fronthaul transmission technology can provide users with high data rate communications. On the other hand, for the service provider, it is possible to avoid power and space problems in the arrangement of distributed base station antennas.

(3) Role to play

- To provide the ultra-high capacity and data rate required in the Beyond 5G era
- To save power and space when installing large numbers of distributed base station antennas

(4) Description of technology

Radio over Fiber: A technology that generates and demodulates radio signals at a central station and transmits radio signal waveforms as is over optical fiber in the mobile fronthaul section.

- Intermediate Frequency over Fiber (IFoF) [18]: A technology that transmits high-capacity radio signals efficiently by multiplexing radio signals for base station antennas on the frequency axis without transmitting radio signals one channel at a time.

6.8.11 Optical wireless and acoustic communications

(1) Features and strengths

The radio frequency spectrum is a limited resource; due to the increasing demand for high data rates and communication capacity, spectrum resources are facing an increasingly serious shortage. Optical wireless and acoustic communications using ultra-wide spectral ranges have become a promising solution to overcome the RF spectrum crisis for some scenarios. At the same time, light can also be used for positioning or sensing.

(2) Value provided

Optical wireless and acoustic communication systems exhibit more benefits (unlicensed spectrum, low cost, low-power-consumption communication, security, etc.) when compared with RF-based communications. It can be used to expand both communication and service areas (e.g. underwater). Meanwhile, it also faces several challenges, especially the fusion of communication and related light positioning and sensing technologies.

(3) Role to play

Optical wireless and acoustic communications using ultra-wide spectral ranges have become a promising solution to overcome the RF spectrum crisis for some scenarios.

(4) Description of technology

- The technology uses a new high-bandwidth modulator to increase the emission bandwidth of a single light source, while considering multi-channel technologies such as MIMO and wavelength division technology.
- At the physical layer, it is necessary to consider the reuse of existing OFDM technology, but at the same time, it is also necessary to consider the characteristics of the optical wireless communication system to design OFDM modulation technology.
- Because of the direct line-of-sight communication of optical communication, the system needs to consider a technology that will enable the alignment between transmitter and receiver.

The optical frequency band has huge spectrum resources and sub-micrometer wavelengths available for communication and sensing. Therefore, optical spectrum-based communication and sensing technology can meet many future Beyond 5G application scenarios. The architecture and technology of Integrated Sensing and Communication with Optical Wireless (ISAC-OW) need to be considered to support the ultra-high data rate (e.g., Tbps rate), high-precision positioning, and high-precision sensing in the Beyond 5G era [10].

(a) Key requirements and scenarios

To meet the ultra-high transmission data rate (e.g., Tbps), some technologies need to be researched, including optical components and materials, PHY layer technologies, and uplink chain implementation techniques. Meanwhile, the architecture and operation schemes of ISAC-OW system also need to be investigated.

ISAC-OW system exhibits ultra-wide spectral ranges, freedom from electromagnetic interference, and high security features, along with high-precision positioning and sensing features. Hence, it is suitable for hospital, factory, flight carbine, and vehicles. In the hospital scenario, ISAC-OW can be used to monitor users' medical conditions, for gesture recognition, indoor positioning, and navigation, and to provide reliable, ultra-high-data-rate communication service. In the factory scenario, by means of waveform design, one optical beam can be used to illuminate, transmit signals, and furthermore, to sense the vibration of machines. By means of ISAC-OW techniques, vehicle-to-vehicle communication and object identification can also be performed.

(b) Joint communication and sensing architecture design for ISAC-OW

In many indoor scenarios, illumination is done deliberately by reflection or refraction and are covered by lamp shades and covers, and are turned towards walls or other objects. Thus, there is a need to develop techniques for high-speed communication even if the receiver is not in direct view of the transmitter.

Optical-based localization can provide great improvements in metrics such as precision and accuracy, although there are still open issues in addressing robustness, scalability, and complexity. Infrastructure sensing techniques have been used for air condition monitoring, and gesture and picture recognition. However, sensing techniques by means of other wavelength signals, such as visible light signals, have to be developed.

Furthermore, in order to support integrated sensing and communication features, novel system architectures, along with operation schemes, light sources, receiver-placement optimization, and waveform design for simultaneous communication and sensing need to be investigated.

(c) Optical component and material for ISAC-OW

In order to provide an ultra-high data rate, the corresponding components and materials need to be considered.

Wideband LED:

Light-emitting diode (LED) is one of the most important light sources due to its low power consumption and long lifetime; increasing the LED bandwidth helps improve the data rate at the transmitter. Wide use of the OWC system based on LED light source should be promoted.

High sensitivity PD:

Photodetectors (PDs) are indispensable components in optical sensors, communication systems, and photonic interconnects.

Integrated micro-optical array:

Massive parallelization of micro-optical array system supports space diversity and multiplexing technologies, enabling a significant increase of throughput. Both micro-LED technologies and spatial multiplexing techniques will mature and become cost effective, and white light based on different wavelengths will unlock throughput, thanks to wavelength division.

Passive optical device:

Passive optical components are the key components of optical systems, including optical waveguide, optical filter, diffraction grating, and optical antenna. Many new achievements have emerged by combining silicon technology and new materials and structures.

Reconfigurable optical device:

Electro-optic modulation and beam adjustment can be realized by changing the amplitude and phase of light. It helps to expand the application of OWC, including non-line-of-sight (NLOS), multi-user access, high-precision positioning, etc.

(d) Technology for physical layer of ISAC-OW

At the same time, standard organizations also need to attract more industrial partners to invest in future technology research, and to promote technology research and industrial applications. The main research points for standardization include the following:

Channel Model and Capacity:

The Optical Wireless Communication (OWC) receiver receives the line-of-sight (LOS) optical signal and many copies of NLOS coming from reflections. Meanwhile, the channel gain for OWC is modeled after the Lambertian model, which is time-invariant but affected by geometrical parameters such as the locations of the transmitter and receiver. Practical channel characteristics should be considered. Unlike the RF, the channel capacity of OWC should consider: (i) dimming requirements, (ii) peak optical intensity constraints, (iii) illumination requirements and the LED dynamic range, and (iv) necessity for the input signal to be non-negative and real-valued.

Modulation:

The modulation in OWC is implemented by varying the light intensity of the LED, where the light signal is a real non-negative signal. Due to the non-linear OWC channel response, the aforementioned modulation schemes suffer from inter-symbol interference. To combat this impairment, the OFDM scheme is modified to become a real non-negative signal after IFFT, such as DC-biased optical OFDM (DCO-OFDM), asymmetrically-clipped optical OFDM (ACO-OFDM), and mixed OFDM (X-OFDM), which does not need DC-bias and possess more spectrum efficiency than ACO-OFDM.

Multiple access:

For example, the NOMA technology enables multiple users to share a single resource component, whether it is a sub-carrier, a time slot, or a spreading code. In OWC networks, power domain NOMA (PD-NOMA) has attracted wide attention, wherein different power levels are set for different users. Cooperative NOMA techniques can offer advantages to the network because users with higher power (better channel conditions) can decode messages and act as relays.

MIMO:

Hybridization of micro-LED matrices and CMOS driver arrays on a single chip may be required to increase the data rate to support the ultra-high data rate (e.g., one Tbps). The MIMO algorithms used in OWC include repetition coding, spatial multiplexing, and spatial modulation.

OAM:

Orbital angular momentum (OAM), which has different topological charges that are orthogonal with each other, is an important technology for OWC.

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7. CONCLUSION

7. Conclusion

In this White Paper, we considered the daily life of users and the wide range of usage scenarios that span many industries to delve into Beyond 5G, which is foreseen to be commercialized by around 2030. Through this process, we examined from a multilateral perspective the requirements for communication systems to serve as social infrastructures. In addition, in light of the trends on user demands for high quality and advanced services, we envisioned usage scenarios and applications for the 2030 era through research and analysis of social and market trends. On the basis of these typical usage scenarios, we examined the key concepts, frequencies, network requirements, capabilities, architecture, and key technologies for Beyond 5G. Furthermore, with the aim of international appeal of Japanese technological capabilities and contribution to the global standardization activities, we have compiled the results of research on technical topics that are "Japan's selling points," such as Japan's strengths and high-profile themes, and released them as supplementary volumes in conjunction with the release of the version 3.0. These are ongoing studies, and the White Paper will be updated as needed in accordance with the results of the studies.

On the basis of the results of this study, the Beyond 5G Promotion Consortium White Paper Subcommittee supported the preparation of Japanese contributions to standardization activities in ITU-R WP5D on the IMT for 2030 and beyond. The Beyond 5G Promotion Consortium was merged with the 5G Mobile Promotion Forum and began activities as the XG Mobile Promotion Forum (XGMF) from April 1, 2024. In the future, collaborating with the 6G-related projects of the XGMF, we intend to endeavors to contribute to frequency coordination and standardization activities in ITU and 3GPP, as well as to the building of international cooperative relations with groups involved in Beyond 5G/6G. Furthermore, we intend to promote Beyond 5G to various industries, and to promote collaboration and co-creation among industries. We plan to further study and enhance the contents of the White Paper on the basis of the many insights gained through these activities. We would like to ask those who read this White Paper to send their opinions to the 6G-related projects of XGMF. We hope that the discussions made through this White Paper will contribute to the strengthening and expansion of international partnerships on research and development, standardization, radio frequency coordination, and dissemination activities, as well as to the building of cooperative relationships with industries to take advantage of the unique capabilities of Beyond 5G/6G.

ABBREVIATION LIST

Abbreviation List

Abbreviation	Explanation
6DoF	Six Degrees of Freedom
3GPP	Third Generation Partnership Project
ACO-OFDM	Asymmetrically Clipped Optical OFDM
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AIaaS	Artificial Intelligence as a Service
API	Application Programming Interface
APN	All Photonic Network
APs	Access Points
AR	Augmented Reality
ASIC	Application Specific Integrated Circuit
BaaS	Banking as a Service
BMI	Brain Machine Interface
BtoBtoC	Business to Business to Consumer
BtoC	Business to Customer
BW	Band Width
BWA	Broadband Wireless Access
CASE	Connected, Autonomous/Automated, Shared, Electric
CAPEX	Capital Expenditure
CMOS	Complementary Metal Oxide Semiconductor
CPRI	Common Public Radio Interface
CPS	Cyber Physical System
CPU	Central Processing Unit
CSI	Channel State Information
DaaS	Data as a Service
DCO-OFDM	Direct Current biased Optical OFDM
DDoS	Distributed Denial of Service
D-MIMO	Distributed MIMO
DMM	Distributed Mobility Management
DNA	Deoxyribonucleic Acid

Abbreviation	Explanation
DRAM	Dynamic Random Access Memory
DSRC	Dedicated Short Range Communication
DT	Digital Twins
DTC	Digital Twin Computing
DX	Digital Transformation
ECC	Elliptic Curve Cryptography
eCPRI	enhanced CPRI
EESS	Earth Exploration Satellite Service
eMBB	enhanced Mobile Broadband
EC	Electronic Commerce
ECC	Elliptic Curve Cryptography
ECU	Engine Control Unit
EHF	Extremely High Frequency
ETC	Electronic Toll Collection System
EV	Electric Vehicle
FA	Factory Automation
FDD	Frequency Division Duplex
FG-AN	Focus Group on Autonomous Networks
FH	Fronthaul
FPGA	Field Programmable Gate Array
FR	Frequency Range
FS	Fixed Service
FSPL	Free Space Path Loss
FW	Firewall
GDP	Gross Domestic Product
GEO	Geostationary Orbit
GPU	Graphics Processing Unit
GPS	Global Positioning System
GSO	Geostationary Earth Orbit
HAPS	High Altitude Platform Station
HARQ	Hybrid Automatic Repeat Request

Abbreviation	Explanation
HEMS	Home Energy Management System
HMD	Head Mounted Display
HMI	Human Machine Interface
HUD	Head-up Display
I/F	Interface
IC	Integrated Circuit
ICDT	Information, Communication, and Data Technology
ICT	Information and Communication Technology
IDS	Intrusion Detection System
IFFT	Inverse Fast Fourier Transform
IFoF	Intermediate Frequency over Fiber
IoT	Internet of Things
IP	Internet Protocol
IPS	Induced Pluripotent Stem
IPv6	Internet Protocol version 6
ISAC	Integrated Sensing and Communication
ISAC-OW	Integrated Sensing and Communication with Optical Wireless
ISRU	In-Situ Resource Utilization
ISS	International Space Station
IT	Information Technology
ITS	Intelligent Transport Systems
KEM	Key Encapsulation Mechanism
KPI	Key Performance Indicator
LCT	Laser Communication Terminals
LED	Light-Emitting Diode
LEO	Low Earth Orbit Satellite
LiDAR	Light Detection and Ranging
LLS	Lower Layer Split
LOS	Light of Sight
LTE	Long Tern Evolution
MaaS	Mobility as a service

Abbreviation	Explanation
MAC	Media Access Control
MCS	Modulation and Coding Scheme
MEC	Multi-access Edge Computing
MIMO	Multiple-Input and Multiple-Output
ML	Machine Learning
m**MTC**	massive Machine Type Communication
MR	Mixed Reality
MS	Mobile Service
MTP	Motion to Photon
MUP	Mobile User Plane
NBI	Northbound Interface
NGSO	Non-Geostationary Orbit
NIST	National Institute of Standards and Technology
NLOS	Non-Line of Sight
NOMA	Non-Orthogonal Multiple Access
NPU	Neural network Processing Unit
NR	New Radio
NTN	Non-Terrestrial Network
O&M	Operation and Maintenance
OAM	Orbital Angular Momentum
ODD	Operational Design Domain
OFDM	Orthogonal Frequency Division Multiplexing
ONAP	Open Network Automation Platform
OPEX	Operating Expense
O-RAN	Open Radio Access Network
OSINT	Open-Source INTelligence
OTA	Over The Air
OWC	Optical Wireless Communication
PA	Process Automation
PA	Power Amplifier
PCB	Printed Circuit Board

Abbreviation	Explanation
PCR	Polymerase Chain Reaction
PD-NOMA	Power Domain Non-Orthogonal Multiple Access
PDs	Photodetectors
PF	Platform
PHR	Personal Healthcare Record
PHV	Plug-in Hybrid Vehicle
PHY	Physical Layer
PII	Personally Identifiable Information
PMIPv6	Proxy Mobile IPv6
PPM	Privacy Policy Manager
PPP	Purchasing Power Parity
PUE	Power Usage Efficiency
QKD	Quantum Key Distribution
QoE	Quality of Experience
RaaS	Retail as a Service
RaaS	Robotics as a Service
RACH	Random Access Channel
RAN	Radio Access Network
RAS	Radio Astronomy Service
RAT	Radio Access Technology
RF	Radio Frequency
RIS	Reconfigurable Intelligent Surface
RMSE	Root Mean Square Error
RoF	Radio over Fiber
RSA	Rivest-Shamir-Adleman
RTT	Round Trip Time
SDGs	Sustainable Development Goals
SDN	Software Defined Networking
SEAL	Service Enabler Architecture Layer for Verticals
SISO	Single-Input Single-Output
SNS	Social Networking Services

Abbreviation	Explanation
SPOF	Single Point of Failure
SR	Segment Routing
SRS	Sounding Reference Signal
SRv6	Segment Routing version 6
SRv6 MUP	Segment Routing IPv6 Mobile User Plane
TAT	Turn-around-Time
TCO	Total Cost of Ownership
TDD	Time Division Duplex
TEE	Trusted Execution Environment
ToF	Time-of-Flight
TRP	Transmission Reception Points
UAV	Unmanned Aerial Vehicle
UCN	User Centric Network
UE	User Equipment
UI	User Interface
UMTS	Universal Traffic Management System
URLLC	Ultra-Reliable and Low Latency Communications
UX	User Experience
V2X	Vehicle To Everything
VHTS	Very High Throughput Satellite
VR	Virtual Reality
vRAN	Virtual Radio Access Network
XaaS	X as a Service
X-OFDM	Mixed OFDM
XR	Extended Reality
ZSM	Zero-touch network and Service Management