Beyond 5G White Paper (ver.3.0)
～Message to the 2030s～
【Overview】

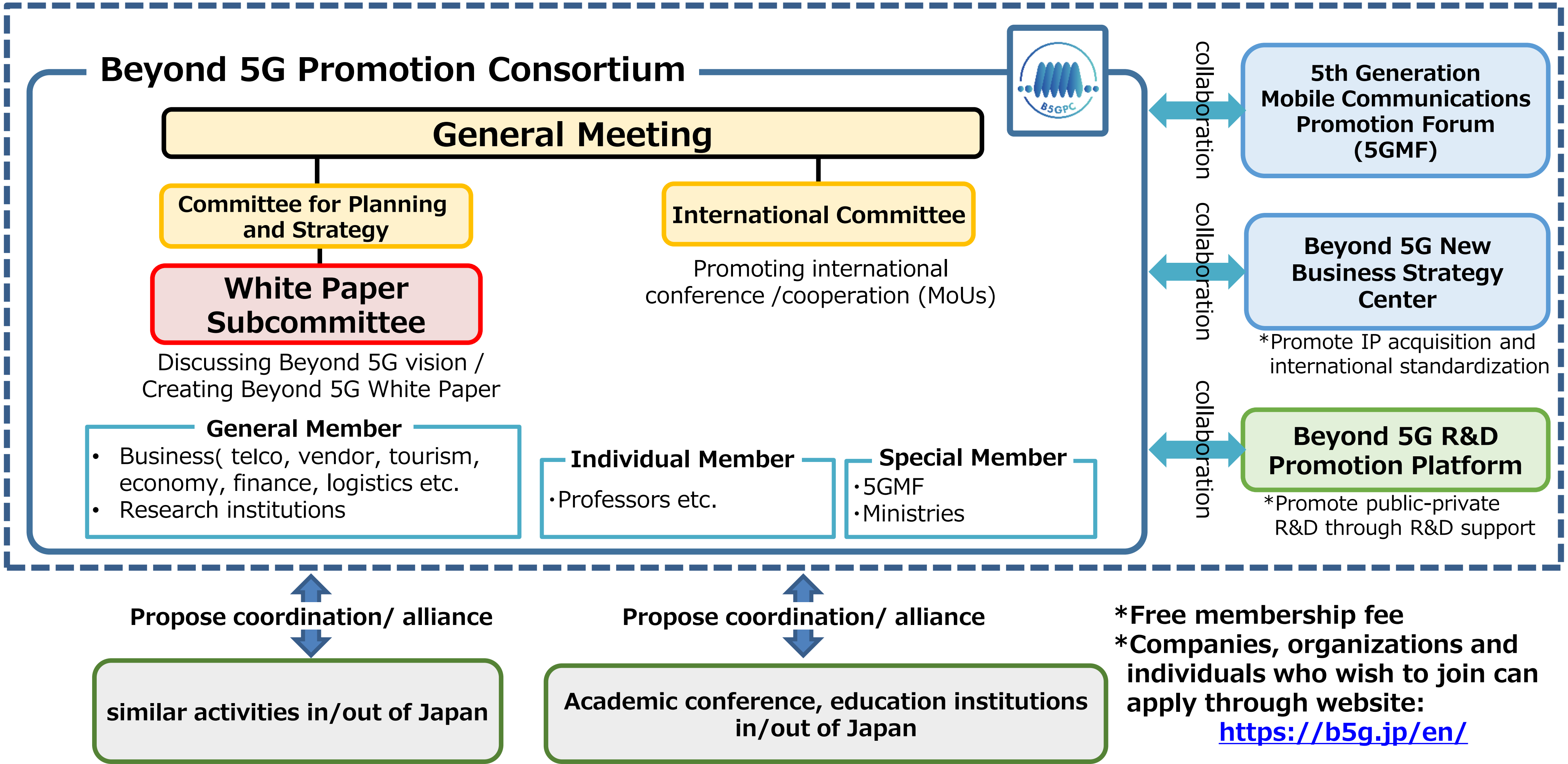
White Paper Subcommittee, B5GPC

Mar. 7, 2024

Beyond 5G Promotion Consortium

UPDATE on Version 3.0

- Established “Beyond 5G Promotion Consortium” to promote Beyond 5G Promotion Strategy through industry-academia-government collaboration.
  - International conference for international cooperation
  - Vision for Beyond 5G, White Paper etc.
  - Open RAN Promotion



***Free membership fee**
***Companies, organizations and individuals who wish to join can apply through website:**
https://b5g.jp/en/

Structure of White Paper Subcommittee

UPDATE on Version 3.0

Committee for Planning and Strategy

White Paper Subcommittee

Chair : Nakamura (NTT DOCOMO)

- Forecast strong and lively society expected in the 2030's and clarify use cases and requirements of Beyond 5G
- Take international leadership by developing concept of Beyond 5G early on and reflecting it to international standardizations including ITU
- Contribute to strengthen international competitiveness by capturing and reflecting views from various industries and developing meaningful concept of Beyond 5G for all industries

Vision Working Group

Leader : KONISHI (KDDI), Sub leader: NAGATA(NTT DOCOMO)

- Develop the vision part of the white paper with forecasting our society around 2030 and studying use cases and requirements of Beyond 5G

Technology Working Group

Leader : SAKUMOTO (FUJITSU), Sub-leader: SHIMONISHI(NEC)

- Develop the technology parts of the white paper with studying technology trends of Beyond 5G and clarifying roles and expectations of functions and values for users and markets

Spectrum Working Group

Leader : HONDA (ERICSSON JAPAN)

- Develop the spectrum related information with conducting survey on spectrum for Beyond 5G

WP5D Ad Hoc

Leader : AGATA (KDDI), Sub-leader: TAKETSUGU (NEC)

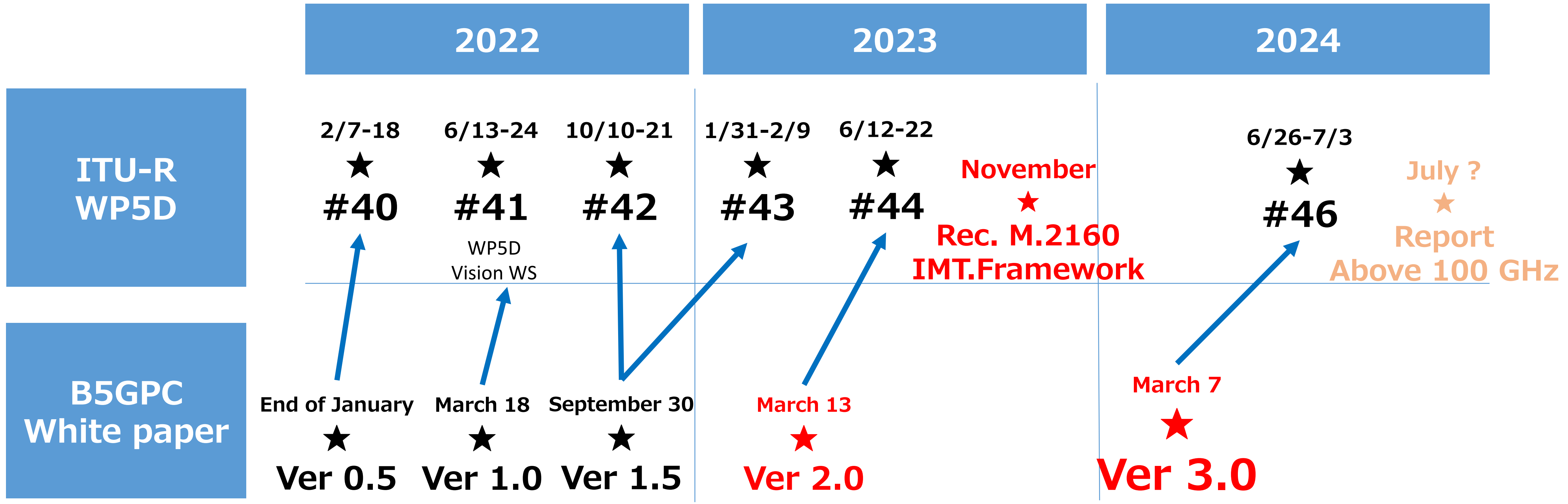
- Action planning and contribution to ITU-R WP5D based on studies in the subcommittee

Path to publication toward White paper Ver 3.0

UPDATE on Version 3.0

Version 3.0 published on 7 March 2024

White paper have been contributing to ITU-R and several reports.



Structure of white paper

UPDATE on Version 3.0

Chapter 1. Introduction

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.

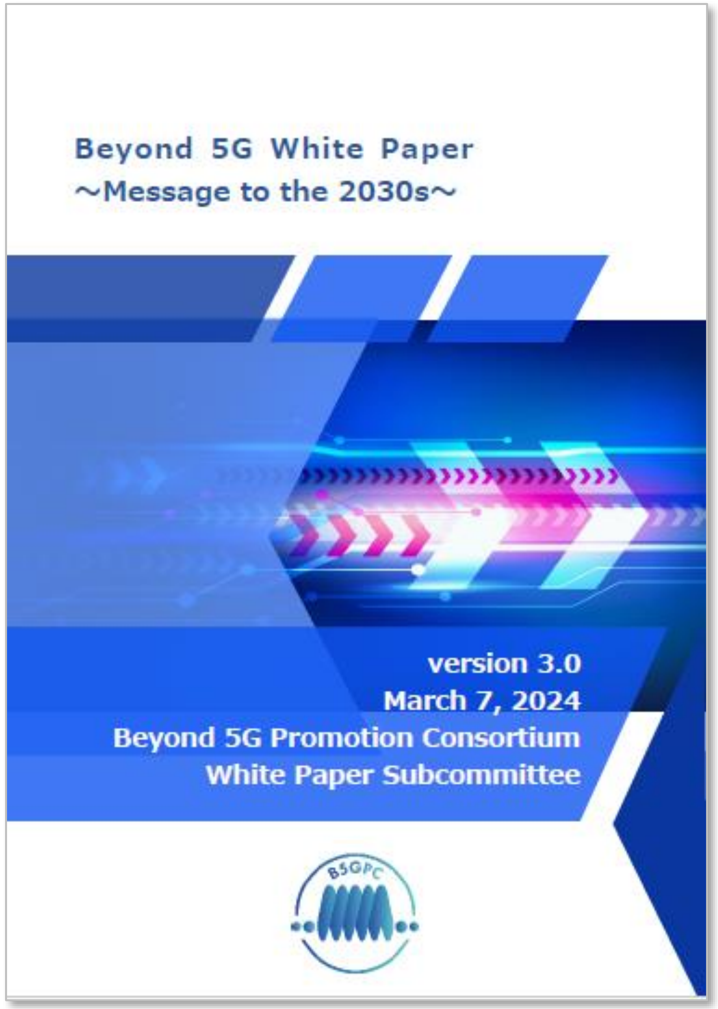
Chapter 5. Capabilities and KPIs required in Beyond 5G

- 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, together with the symbol figure of Beyond 5G, the six usage scenarios and the target KPI (Quantitative and Qualitative).

Chapter 6. Technology trends

- This chapter examines the trends in 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.

Chapter 7. Conclusion



https://b5g.jp/en/output/

Main Updates

Version 1.5

- **5.2 Add a symbol figure and usage scenario**
- **5.3 Add a figure of target KPI**
- **Improvement of contents**
  - ✓ 4.7 (Automotive) Add 5G use cases and requirements
  - ✓ 4.8 (Machines) update of main texts
  - ✓ 6.1.3.2 Add some study results on radio propagation

Version 2.0

- **Section4 (Trends from other industries) Improvement of readability and contents**
  - ✓ Improvement of consistency of each section, Add summary
  - ✓ Add examples of 5G usage and table of capability, Add figures for expectations of Beyond 5G
- **Section5 (Technology trends) Improvements of contents on sections below**
  - ✓ 6.1.3.1 Add and update contents for trends of spectrum usage study
  - ✓ 6.3 Add and update contents for trustworthiness (Security, Privacy, and Resilience)
  - ✓ 6.6, 6.6.1, 6.6.3 Add network architecture and optimum computing resource, network autonomous operation
  - ✓ 6.6.4 Add contents on resilience

Main Updates

Version 3.0

- **Chapter 1: Updated description for version 3.0 and supplementary volumes.**
- **Chapter 5: Adding comparison between B5GPC WP and IMT-2030 Framework**
  - ✓ 5.2.2: Adding comparison between the conceptual figure of B5GPC WP and IMT-2030 Framework
  - ✓ 5.3.3: Adding comparison between the target KPIs of B5GPC WP and IMT-2030 Framework capabilities
  - ✓ 6.1.3.2 Add some study results on radio propagation
- **Chapter 6:**
  - ✓ Section 6.2 (formerly 6.6) "Beyond 5G Architecture" section updated to describe the new architecture and add reference to a supplementary volume published at the same time
  - ✓ Section 6.1, "Technology Trends Toward Beyond 5G," was reorganized, frequency resource utilization technology was separated as Section 6.3, and "Deployment Status of Mobile Phone Systems" was moved to Section 2.5 of Chapter 2.
  - ✓ Section 6.3.1.2 “Identification of spectrum in WRC for IMT terrestrial component”, Section 6.3.1.3 “Survey on radio frequency on the range of 7125 MHz to 15.35 GHz”, and Section 6.3.1.4 “Status of the range 6425 MHz - 7125 MHz” were added.

Next steps and invitation toward collaboration

UPDATE on Version 2.0

- This white pater contains useful information which promote to study on new future business and solutions for social issues among all industries not limited to communication industry. It is expected that the white paper helps shape better future society and promote global activities.
- This group is contributing to spectrum study and standardization activities in ITU/3GPP and conducting collaborations among industry, academia, government based on the white paper.
- Any related organizations are invited to give us an opportunity to exchange views on this white paper.

Beyond 5G White Paper (ver.3.0)
～Message to the 2030s～
【Beyond 5G use case and requirement】

Vision Working Group,
White Paper Subcommittee, B5GPC

Mar. 7, 2024

Establishment of "Workshop on Society in 2030s"

UPDATE on Version 2.0

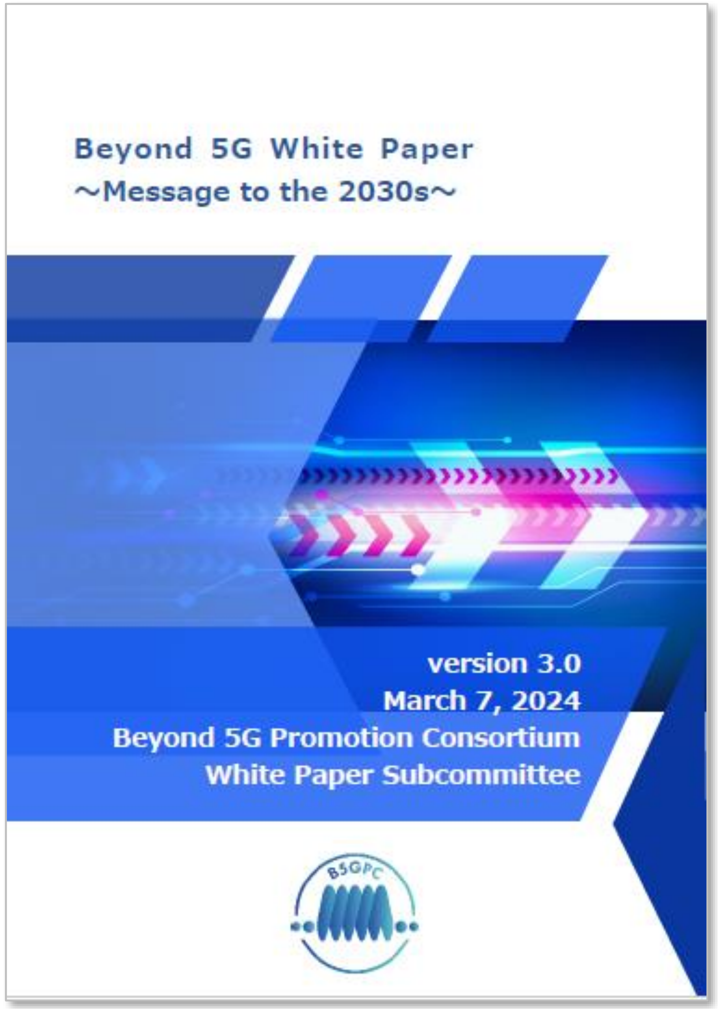
- **Speakers from various industries and discussions in Vision working group for vision and use cases in 2030s.**

List of 24 presenters in total at the workshop

Meeting	Presenter
June 15, 2021 1st Meeting	Telecom Services Association
	National Institute of Advanced Industrial Science and Technology
July 20, 2021 2nd Meeting	Social Welfare Corporation, Zenkoukai
	East Japan Railway Company
	CFA Society Japan
	Fuji Television Network
	Medical futurist Dr. Oku
Aug. 3, 2021 3rd Meeting	National Institute of Science and Technology Policy
	PREVENT Inc.
	Telexistence Inc.
	Arch Inc.
	Asratec Corp.
Sep. 14, 2021 4th Meeting	Toshiba Corporation
	Quora Inc.
	Japan Aerospace Exploration Agency
	Japan Science and Technology Agency
	Mach Corporation Co., Ltd.
Oct. 12, 2021 5th Meeting	Yamato Transport Co., Ltd.
	Shiftall Inc.
	Toyota Motor Corporation
Dec. 14, 2021 6th Meeting	Obayashi Corporation
	Mr. Tokue (Founder of Radishbo-ya)
Jul 12, 2022 7th Meeting	Kyoto University
Nov 8, 2022 8th Meeting	UNIADEX

Chapters in White Paper written by Vision Working Group

UPDATE on Version 2.0



https://b5g.jp/en/output/

Expectations from various industries for Beyond 5G

~ Examples from Section 4.x in the White Paper ~

4.3.1 Warehousing/Logistics

Current Situation and Challenges

- Demographic Trends and Labor Shortage
- Safety and security against increasing natural disasters
- Strengthening digitalization and innovation for Society5.0
- Ensuring the sustainability of the global environment the SDGs
- Response to pandemics

Future Vision

- Fully optimized supply chain through Logistics DX and standardization (Simple and smooth logistics)
- Logistics structural reforms against Labor shortage (Labor friendly Logistics)
- Robust and sustainable Logistics Network (realizing strong and flexible logistics)

What is required for Beyond 5G

Evolution of Application (Now → Future)

The future Industry with 4G/5G

- **IoT**
- **Local communication**
- **Cyber ports**
- **Logistics DX**
- **Drone**

The Future Industry with Beyond 5G

- **Advanced AI/ML（incl. radio IF)**
- **Digital twin**
- **Full automation**
- **Fast automated delivery**
- **NTN/HAPS**

The current Industry 4G/5G

- **RF tag**
- **Logistics IT**

The Current Industry with Beyond 5G

- **Partial automated driving, delivery and tracking**
- **Basic AI/ML (e.g. delivery scheduling)**
- **Big data**
- **Cloud**

4G/5G Beyond 5G

Evolution of Capability

Latency requirement is on **the order of milliseconds** in the local network, and time synchronization is required to **support PTP (microseconds)** as the accuracy of the internal clock including the radio section.

4.5 Media (1)

In 2030, people can enjoy more immersive media experiences utilizing virtual space and holographic communication, e.g., “the metaverse”.

Current Situation

- Various multi-media contents including TV/radio, publishing and advertise business, SNS, etc.
- Due to pandemic, the digitalization has been accelerated, e.g., online live events.

What is required for Beyond 5G

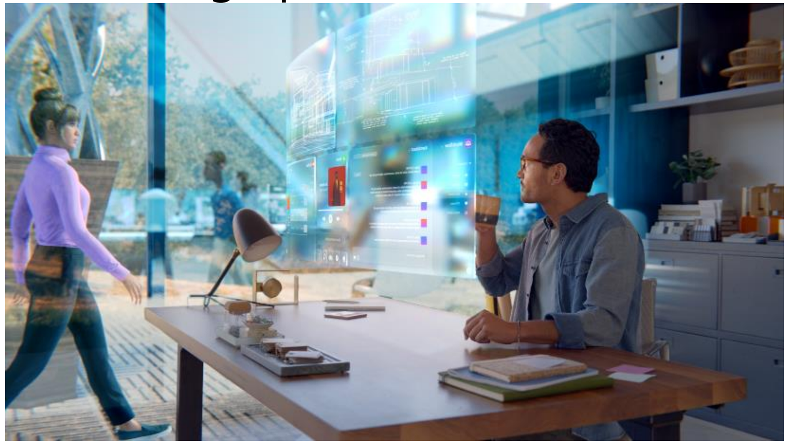
- All the contents can be accessed online via internet. Likewise, richer user-created contents can be delivered more easily regardless of time, place and device type.
- Utilization of virtual space and Holographic communication.
- Personalization/customization for more efficient contents delivery.

Online live event

Source: https://lineblog.me/livepress/archives/13261786.html

Entertainment in virtual space

Holographic communication

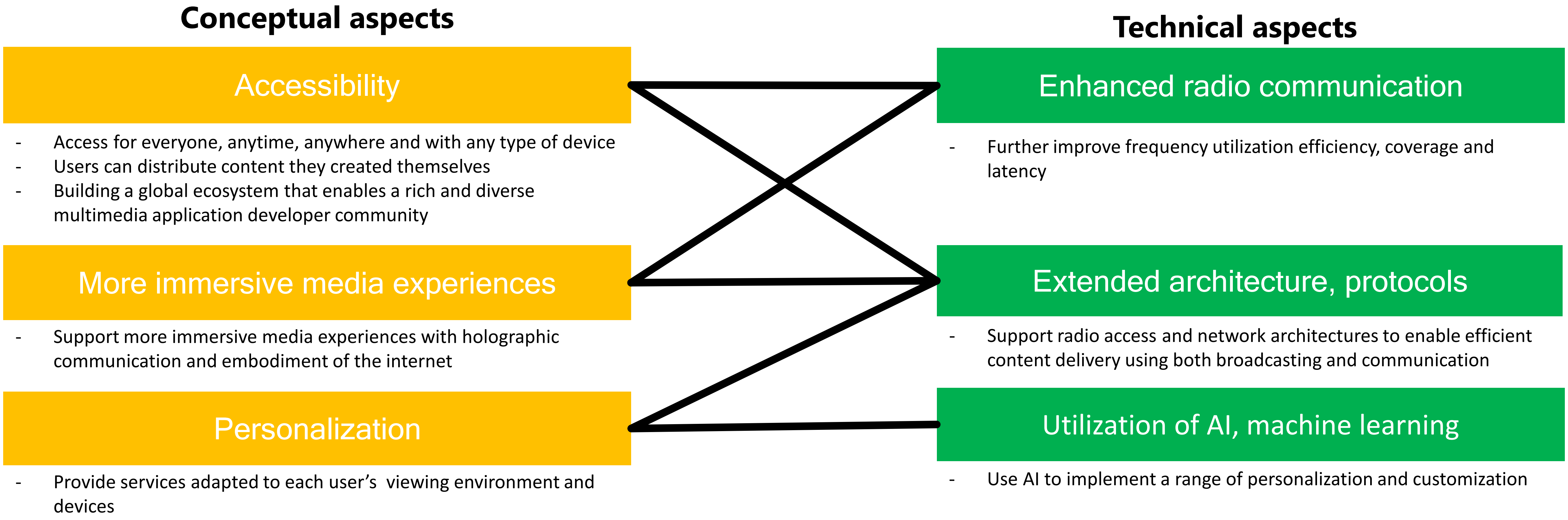


Source: https://about.meta.com/what-is-the-metaverse/?utm_source=about.facebook.com&utm_medium=redirect

4.5 Media (2)

- **The figure below summarizes the high-level requirements (Conceptual / Technical aspect) for beyond 5G.**
- **<u>A few tens ~ hundreds Gbps</u> of peak throughput can be expected for Holographic communication, as an example of performance for Beyond 5G.**

The black lines between the boxes represent what technical aspects will be relevant to the conceptual aspects



4.7 Automotive (1)

The aging society restricts people's mobility in rural areas, and population concentration in urban areas causes traffic congestion. A future society is envisioned in which all people can be ensured with unconstrained and efficient mobility irrespective of their living areas.

Current Situation and Challenges

- Lack of drivers negatively affects the sustainability of public transportation in rural areas, while population concentration in urban areas causes traffic jam. Both adversely affect the quality of people's lives.
- Increased awareness of societal crisis on energy and environmental issues, and problems of traffic-accident caused by the aging society.

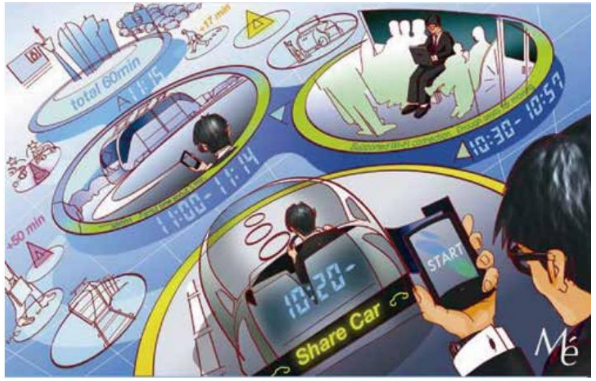
- Realize a mobility-inclusive society that provides unconstrained and efficient mobility for all people
- Build a robust infrastructure for automated driving and safety driving assistance, and a low carbon-emission society

Future Vision

1. A society all people can move freely and efficiently

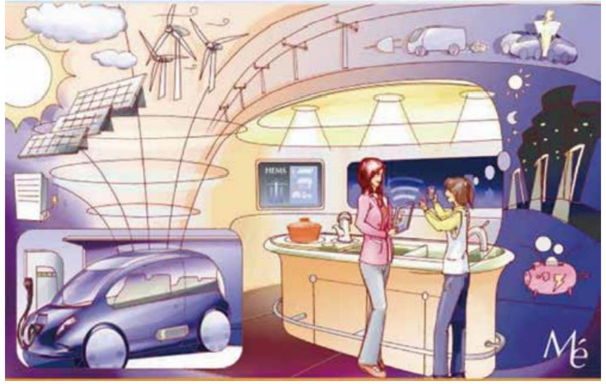
Source: ITS Japan

2. MaaS Platform allowing the Multi-modal mobility of people



Source: ITS Japan

3. Collaboration between vehicles with Smart Cities



Source: ITS Japan

4. Enabling digital society to realize Mobility-inclusive

Source: The Government of Japan, ITS Roadmap

4.7 Automotive (2)

UPDATE on Version 1.5

Towards Automotive Society in 2030 Era, Beyond 5G shall require the integration of highly accurate sensing and communication, distributed AI learning & inference, and ultra reliability

What is required for Beyond 5G

Safety Driving Assistance

Beyond 5G sensing and enhanced connectivity are required so as to support Safety Driving under extreme conditions, e.g., driving at intersections without a signal, under bad weather or in the event of a disaster.

Evolution of Applications (Now → Future) / Evolution of Capability (4G/5G → Beyond 5G)

	4G/5G	Beyond 5G
Future	**Applying 4G/5G** ● Look-ahead information via cloud-based coordination ● See-through, AR/VR Navigation	**Beyond 5G Era.** ● Complement V2I cooperation by sensing (Sensing Fusion, Sensing capability) ● Enhanced connectivity and availability (ultra low latency, ultra high reliability, VLEO/HAPS)
Now	**Present Industry** ● Data Volume: 50MB/Car monthly ● Probe data retrieval with V2N	**Beyond 5G if applied** ● 88% of new car sales are connected cars ● Active utilization of V2V communication (Sidelink)

Automated Driving

Integrated sensing and communication, distributed AI learning & inference, and quantum-cryptography-based security are required to accelerate the implementation of automated driving

Evolution of Applications (Now → Future) / Evolution of Capability (4G/5G → Beyond 5G)

	4G/5G	Beyond 5G
Future	**Applying 4G/5G** ● Dynamic Map, SW downloading with OTA ● Improved Connectivity utilizing V2I, V2V and V2P communications	**Beyond 5G Era.** ● Sensing and distributed AI learning & inference (sensing accuracy at cm level) ● Remote monitoring and remote driving (data speed at 50 Gbps, E2E latency at 1 ms, reliability at 10-6 or higher)
Now	**Present Industry** ● Autonomous Level-3 ● Expressway ● L3 Cars Sales: 70K/Year	**Beyond 5G if applied** ● Cooperative automated driving Level-5 ● Data Volume: 5GB/Car monthly ● L3-5 Sales: 8Mil./Year (30% of new car)

4.12.1 Healthcare (1)

Current Situation and Challenges

- Coexistence of various people in super-aging society
  - achieving harmony with a super-aging society, and to fulfill the role of presenting the world with solutions
- New solutions to unknown diseases
  - putting systems and measures in place to respond and resolve them promptly when they occur.
- Further development of medicine and medical device
  - achieving the world's highest medical technology standards and take the lead in the industry

Future Vision

1. Support and reproduction of physical functions and abilities

Source: Ministry of Health, Labor and Welfare (Home page)

2. Immediate response to unknown infectious diseases

Source: Cabinet Secretariat (COVID-19 Information and Resources)

3. Development of medical technologies

Source: Japan Agency for Medical Research and Development (Achievements)

4. Support for super-aging society

Source: Ministry of Health, Labor and Welfare (Home page)

5. Extension of healthy lifespan

Source: Ministry of Health, Labor and Welfare

4.12.1 Healthcare (2)

What is required for Beyond 5G

Use cases with Beyond 5G

1-1 Assisting perceptual abilities
Augmented human, Brain machine

2-1 Minimum contact, monitoring infections
Positioning, Centralized management of health status

3-1 DB of genome analysis
Personalized medicine, AI-based drug discovery

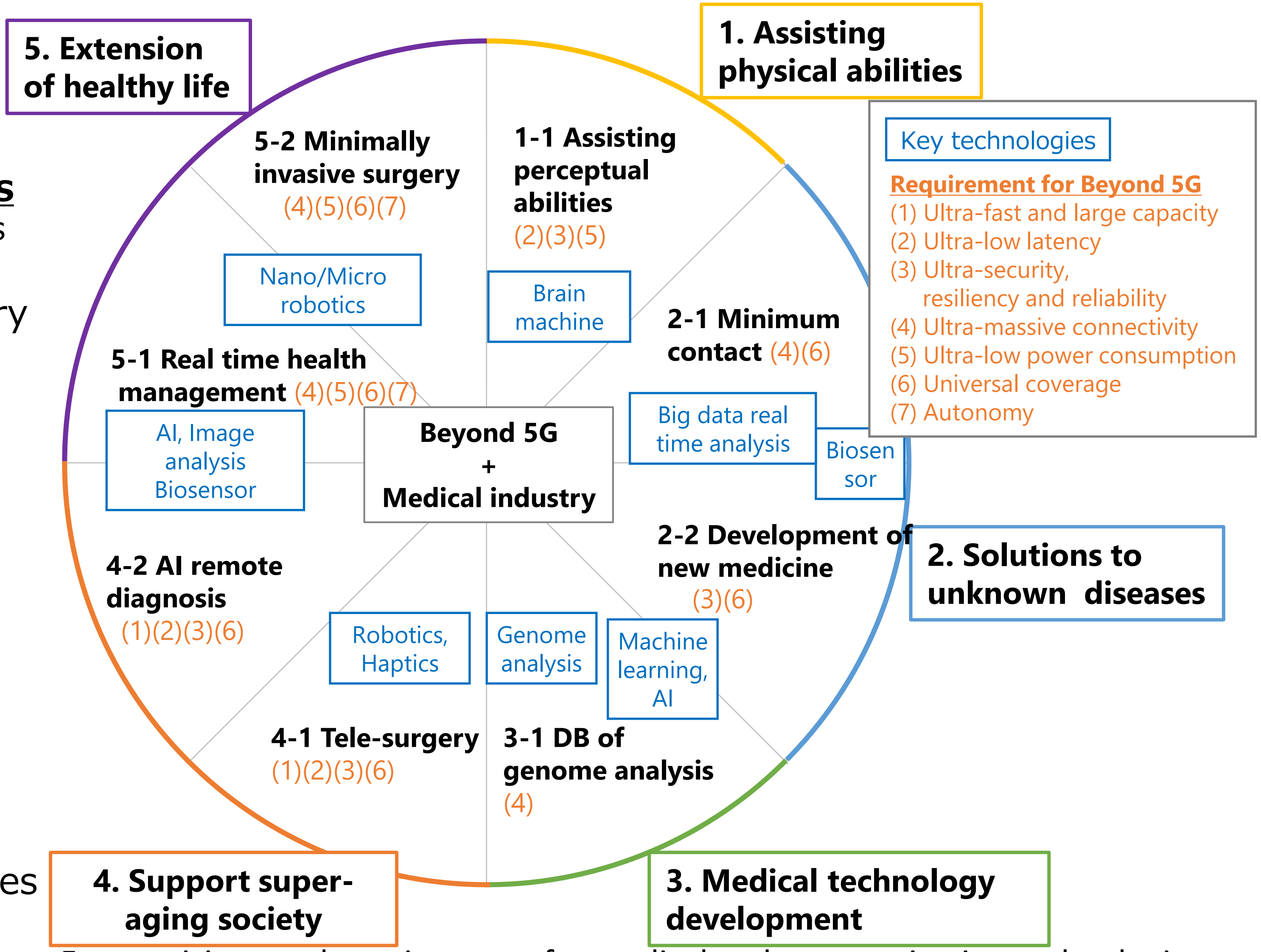
4-1 Tele-surgery
Robotics, AI based surgery

5-2 Minimally invasive surgery
Nano/Micro robotics, Energy harvesting

Beyond 5G requirements

Tele-surgery
- **Tens of Gbps** throughput
- **10^{-7}** reliability

Minimally invasive surgery
- **up to tens of millions/km²** connectivity
- Autonomous communication control of devices



Future visions and requirements for medical and communication technologies

4.15.1 Space (1)

To protect the people's lives on earth, it is required to contribute to solving social issues by space utilization. By developing of space utilization technology, efforts to expand the living area and activity area to space are required.

Current Situation

- Space utilization is mainly preceded by national government, specific industries, R&D and satellite broadcasting
- New efforts are required by utilizing space and space development technology to solve social issues.

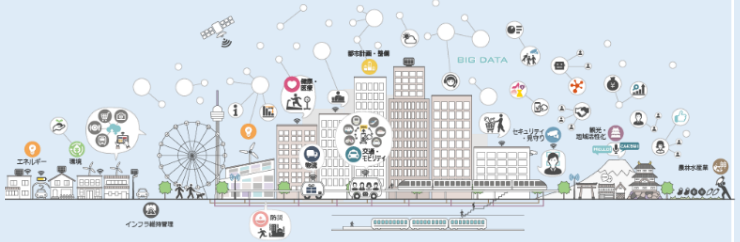
Challenges

- Japan's aging society and population decline
- Global warming, intensification of natural disasters
- Shift to clean energy, energy competition
- Increased pandemic risk and realization of "New normal"
- Realization of a society that affirms diverse ways of life

Future Vision

1. Communication to protect life

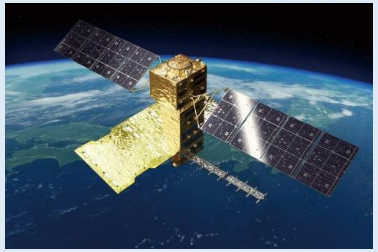
Smart communication infrastructure using space



Source: Smart City Public-Private Partnership Platform HP

2. Protect life by space data

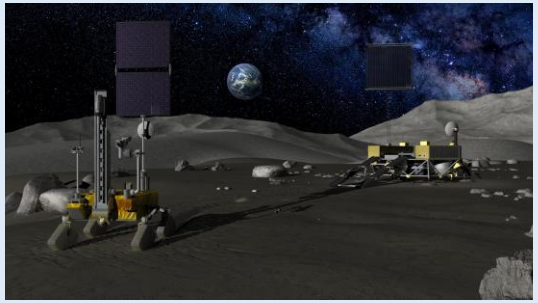
Space-generated data from a secure and resilient environment



Source: JAXA observation satellite HP

3. Utilization of space environment

Expanding the area of human activity to space



Source: JAXA

4. Adapt space to lifestyle

Realizing each diverse lifestyle using space

Source:JAXA/Adobe.stock.com

4.15.1 Space (2)

Ultra-fast and large capacity, universal coverage, ultra-security, resiliency and reliability, autonomy and ultra-low latency are required as requirements for 5G and beyond toward expected future image to protect the people's lives on earth.

What is required for Beyond 5G

Coverage extension to the sky, sea and space

Ultra-fast and large capacity(approximately several dozens of Gbps by low/medium earth orbit satellite), universal coverage, ultra-security, resiliency and reliability and autonomy as Beyond 5G's performance are required for smart cities and autonomous driving support.

Evolution of Application (vertical axis) / Evolution of Capability (horizontal axis)

	4G/5G	Beyond 5G
Future	**4G/5G's Future** ✓ **For specific industries such as aircraft**	**Beyond 5G's Future** ✓ **Universal coverage extension** ✓ **For all industries and integrates with terrestrial networks, or independent of terrestrial networks** (Ultra-fast and large capacity, Universal coverage, Ultra-security, resiliency and reliability, Autonomy)
Now	**4G/5G's Current** ✓ **For mobile backhaul, for sea and air**	**Beyond 5G's Current** ✓ **For specific apps such as wide area robotics in spot areas**

Utilization platform for space data

Universal coverage, ultra-security, resiliency and reliability, autonomy and ultra-low latency as Beyond 5G's performance are required for utilization platform for data observed and generated in space.

Evolution of Application (vertical axis) / Evolution of Capability (horizontal axis)

	4G/5G	Beyond 5G
Future	**4G/5G's Future** ✓ **Past data processed from the terrestrial cloud using AES for individuals**	**Beyond 5G's Future** ✓ **Enhanced security with quantum cryptography technology** (Ultra-security, resiliency and reliability) ✓ **Beyond space real-time data by AI processing on the space data utilization platform for personal use** (Universal coverage, Ultra-security, resiliency and reliability, Autonomy, Ultra-low latency)
Now	**4G/5G's Current** ✓ **Past data processed on the ground for enterprises**	**Beyond 5G's Current** ✓ **Beyond space slightly delayed enterprise data processed in a terrestrial cloud with stronger security than AES for corporate use**

AES(Advanced Encryption Standard)

4.15.1 Space (3)

Ultra-fast and large capacity, ultra-security, resiliency and reliability, ultra-low latency, universal coverage and ultra-low power consumption are required as requirements for 5G and beyond toward expanding the area of human activity to space and realizing each various lifestyle using space.

What is required for Beyond 5G

Utilizing space as a sustainable activity area

Ultra-fast and large capacity, ultra-security, resiliency and reliability as Beyond 5G's performance are required for utilization space as a human activity area (moon and/or planets) sustainably. In addition, since the installed resources are limited, it is vital to realize ultra-low power consumption.

Evolution of Application	4G/5G	Beyond 5G
Future	**4G/5G's Future** ✓ Generalization of space travel ✓ Exploration and Utilization of space resource	**Beyond 5G's Future** ✓ Workcation at space, Emergency evacuation to space ✓ Autonomic operation of Space infrastructure, construction of space factory (Ultra-fast and large capacity, Ultra-security and resiliency, Ultra-low power consumption)
Now	**4G/5G's Current** ✓ R&D at ISS(*) ✓ Observation and reduction of space debris	**Beyond 5G's Current** ✓ Control space objects ✓ Detection of space debris and Collision avoidance by spacecraft

Evolution of Capability

***ISS(International Space Station)**

Incorporating space/cyber into our lifestyle

Ultra-fast and large capacity, ultra-low latency, universal coverage as Beyond 5G's performance are required for cross-cultural communication by using space/cyber which has no border.

Evolution of Application	4G/5G	Beyond 5G
Future	**4G/5G's Future** ✓ Constant internet access at spaceship ✓ Lunar trip by using avatar	**Beyond 5G's Future** ✓ Diverse lifestyle without affects of real world ✓ Simulated experience of life on the moon using VR Haptics (Ultra-fast and large capacity, Ultra-low latency, Universal coverage)
Now	**4G/5G's Future** ✓ Live broadcast from ISS ✓ Space trip by VR	**Beyond 5G's Current** ✓ Cross-cultural community formation without affects of place and/or time ✓ School trip to cyber "space"

Evolution of Capability

Capabilities required in Beyond 5G

~ Section 5.1 in the White Paper ~

Summary in Sec. 5.1 “Capabilities required to Beyond 5G” (1)

Category	Requirements	Capabilities required by each industry
Quantitative requirements	Ultra-fast and large capacity	• **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 ms* (Immersive remote-control system (Energy resources)) • **1 ms** (Remote monitoring and remote control (Automotive)) • **100 micro sec*** for local communications (Motion control (Machinery)) • 1 ms* (Robot remote control (Semiconductor)) • Motion-to-photon (MTP) 10 ms*, time-to-present (TTP) 70 ms* (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))

Summary in Sec. 5.1 “Capabilities required to Beyond 5G” (2)

Category	Requirements	Capabilities required by each industry
Quantitative requirements	Ultra-security, resiliency and reliability	• **10^{-6}** (Remote monitoring and remote control (Automotive)) • **10^{-7}** (Remote surgery (Healthcare)) (unit: block error rate)
	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)

Summary in Sec. 5.1 “Capabilities required to Beyond 5G” (3)

Category	Requirements	Capabilities required by each industry
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)

Summary in Sec. 5.1 “Capabilities required to Beyond 5G” (4)

Category	Requirements	Capabilities required by each industry
Qualitative requirements	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)) • 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)

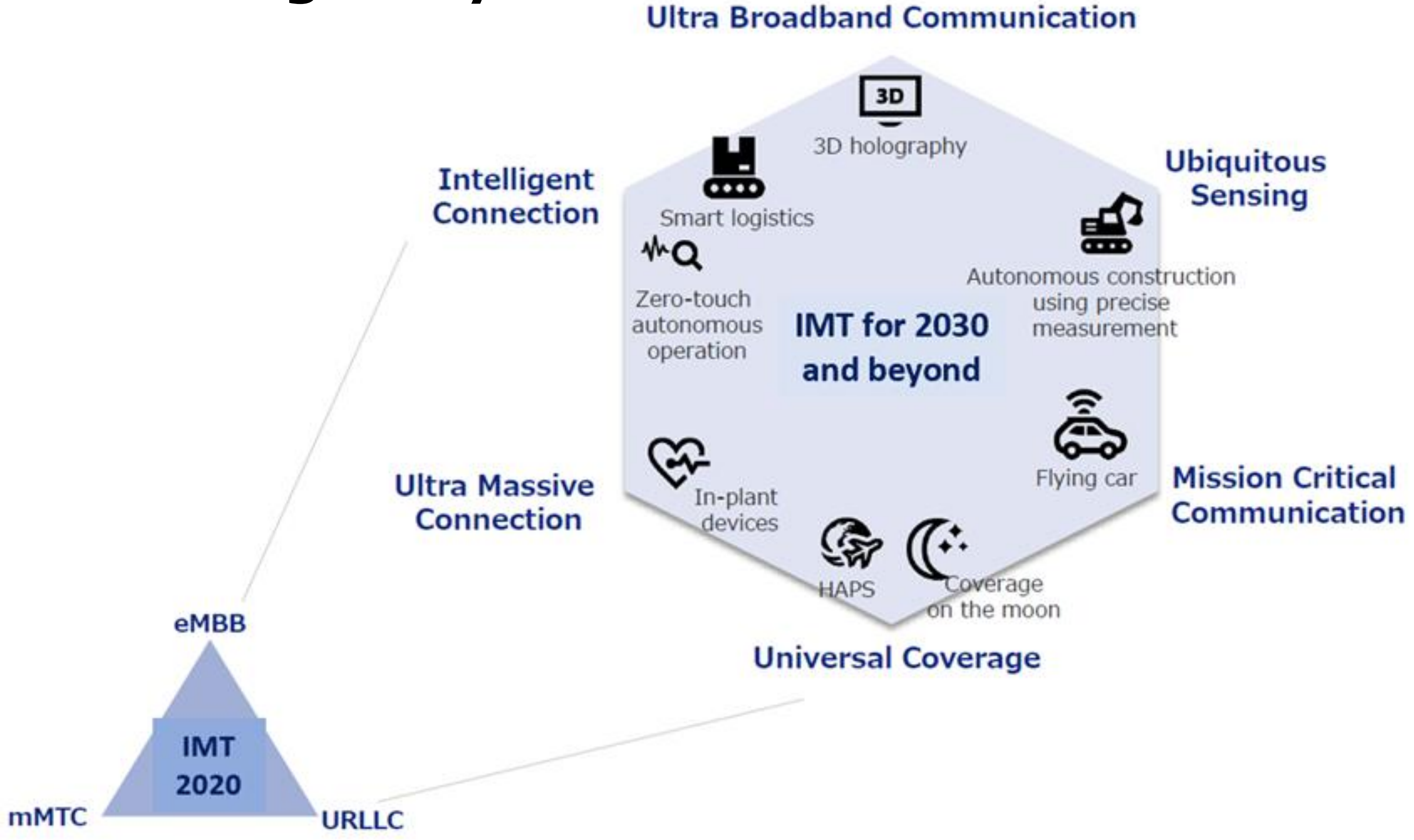
Conceptual figure of Beyond 5G and usage scenarios

~ Section 5.2 in the White Paper ~

5.2.1 Conceptual figure of Beyond 5G and usage scenarios

UPDATE on Version 1.5

Beyond 5G or "IMT for 2030 and beyond" could have six usage scenarios evolved from 5G.
This figure and the six usage scenarios in the following slide were proposed to ITU-R Working Party 5D.



5.2.1 Six usage scenarios unique to Beyond 5G

UPDATE on Version 3.0

Ultra Broadband Communication

- ✓ Extending the eMBB scenario of 5G
- ✓ Immersive XR (eXtended Reality) and holographic communications
- ✓ Extremely high data rates, lower latency and larger system capacity
- ✓ Not only for dense urban but also for some rural areas

Ubiquitous Sensing

- ✓ Integrate sensing with communication systems to realize ubiquitous sensing and receiving of those sensed data
- ✓ 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
- ✓ Facilitates interactions between virtual and physical worlds.

Mission Critical Communication

- ✓ Very stringent transmission reliability and latency characteristics by extending uRLLC of 5G
- ✓ Full automation, remote control, remote operation, robotics collaboration, autonomous driving, and remote medical surgery, etc
- ✓ 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

- ✓ Wide range services everywhere on the ground
- ✓ Mobile broadband service everywhere people live and to connect promising aerial applications such as UAV and flying cars
- ✓ Interworking between the terrestrial networks and non-terrestrial networks, such as HAPS and satellites
- ✓ Communication in the event of natural disasters as disaster-resilient infrastructures

Ultra Massive Connection

- ✓ Extending the scenario of mMTC of 5G
- ✓ 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
- ✓ Supporting the massive simultaneous connectivity

Intelligent Connection

- ✓ Incorporating AI-Native functions into Beyond-5G networks and supports AI-powered applications
- ✓ Training and inference for collaborative robots, distributed learning and inference for automated driving, and autonomous collaboration between devices with zero-touch capabilities
- ✓ Using AI/ML tools to optimize Beyond 5G systems in all network layers to improve the performance and efficiency on air-interface and network itself

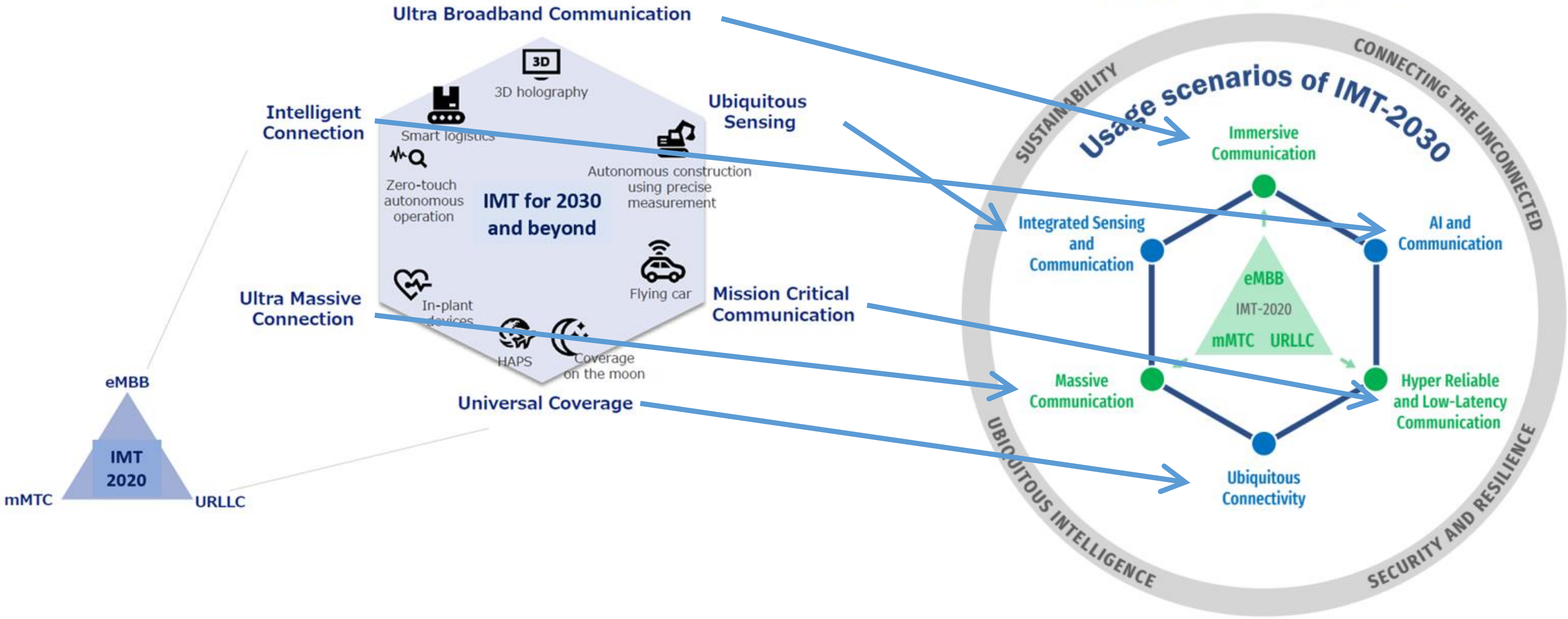
5.2.2 Comparison with ITU-R Recommendation

UPDATE on Version 3.0

Following proposals were reflected to ITU-R Rec. M.2160-0.

- **IMT-2030 is an evolution of IMT-2020**
- **Representation in a hexagonal shape**
- **Utilization scenarios at the vertices of the hexagon (with different terminologies)**

Usage scenarios and overarching aspects of IMT-2030



Common expectations from several industries

Common themes related to several industries	Expectations and dreams in industries	Expectations to Beyond 5G
(a) Decreasing birthrate and aging population	• Utilization of robots • Remote control • Autonomous driving	Ultra-fast and large capacity (up to 50Gbps) Ultra low latency (100 micro sec to 1 ms), Ultra-resiliency (10^{-7})
(b) Safe and secure	Prediction of natural disasters, life saving, and early recovery	100% coverage area with at least 10 Mbps
(c) Further wonderful life	• Flying cars • Immersive experience	Ultra-fast and large capacity (up to few 100 Gbps), Ultra low latency (1 ms), and Coverage area in outer space
(d) Exciting future	Activity supports in outer space and the moon	Communication infrastructure in outer space

Appendix

Outline of Chapter 2 to 4 in the White Paper

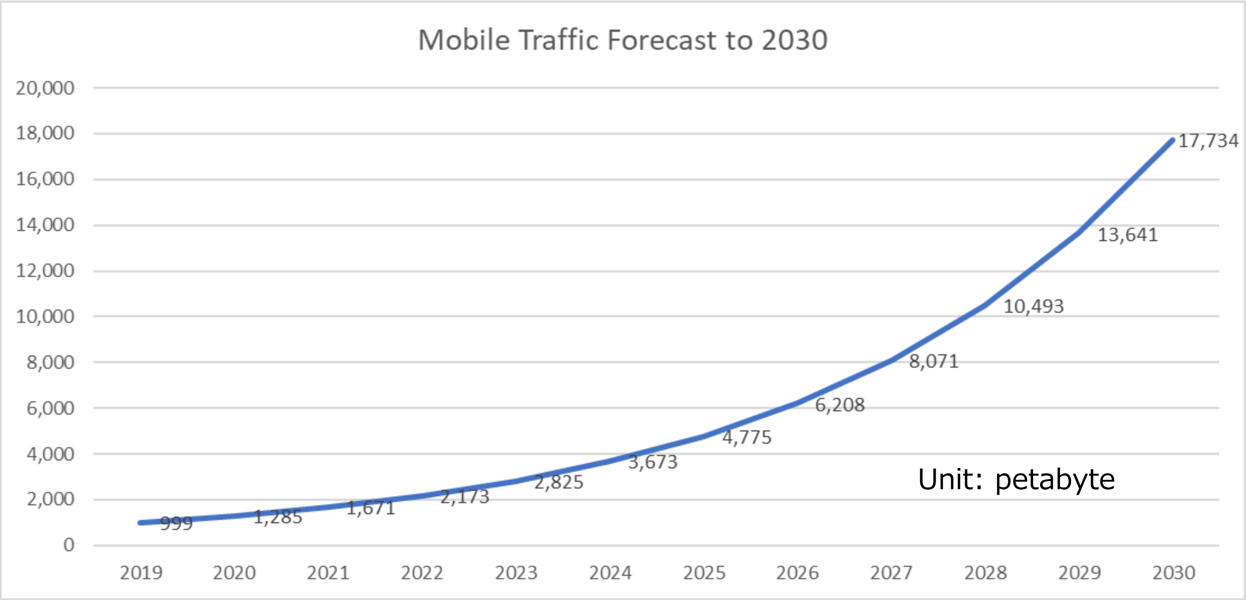
2. Traffic trends

Current Situation and Challenges

1. Stay-at-home demand with Covid-19
   - Mobile traffic increased due to mobile apps, video distribution services, online games, etc. in Covid-19.
2. 5G's trendy services unknown
   - 5G has already appeared, but 5G's trendy applications and services are unclear.

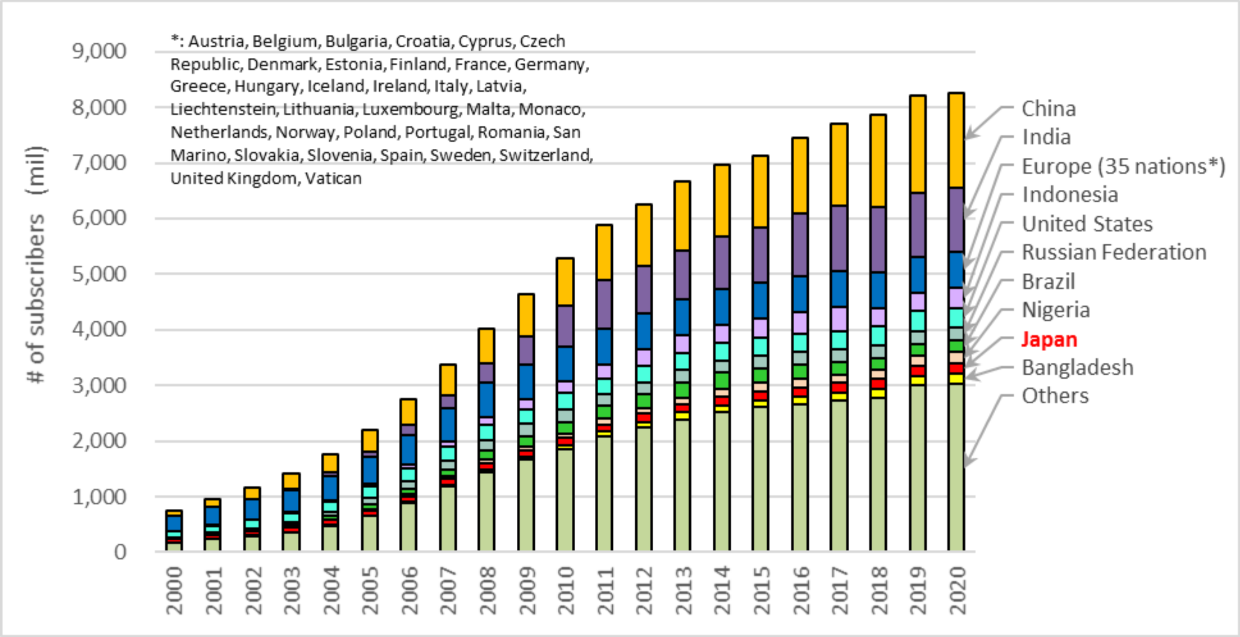
Quote : ASCII.jp VR conference / collaboration tool

Future Vision / What is required of Beyond 5G

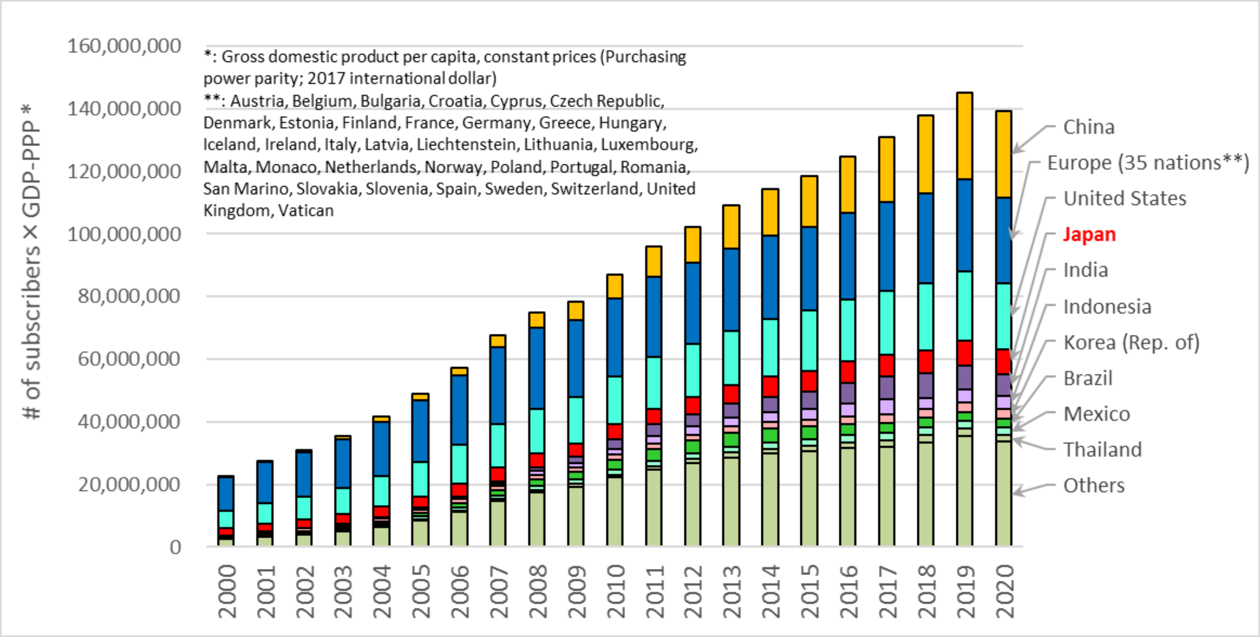


1. Expectation for new videophones and online meetings
   - Expect the arrival of videophones using new devices and online conferences using avatars.
2. Expectation for the Metaverse market
   - Expect killer apps that avatars come and go between physical space and cyberspace by the arrival of VR / AR / MR services.
3. Expansion of mobile phone usage coverage to sea, mountains and space
   - Mobile phone will improve the convenience of connecting anywhere.

UPDATE on Version 3.0



Number of mobile phone subscriptions worldwide [1]



Number of subscribers multiplied by GDP-PPP [1][2]

*Gross domestic product (GDP) per capita-purchasing power parity

[1] "Mobile-cellular subscriptions (excel)", International Telecommunication Union, Telecommunication Development Sector (ITU-D), (July 2022).

[2] "World Economic Outlook Database", International Monetary Fund, April 2022.

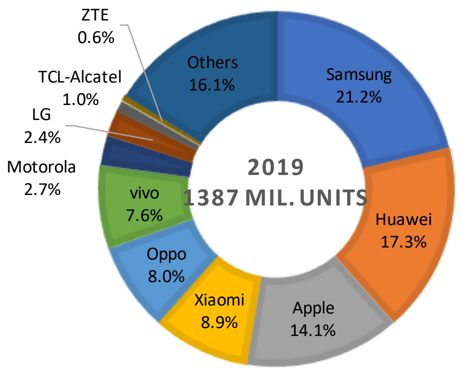
3. Market Trend of Communication Industry (1)

The market for small cell base stations and electronic components is expected to expand with the utilization of the millimeter-wave band and terahertz band, which are expected to be used in Beyond 5G.

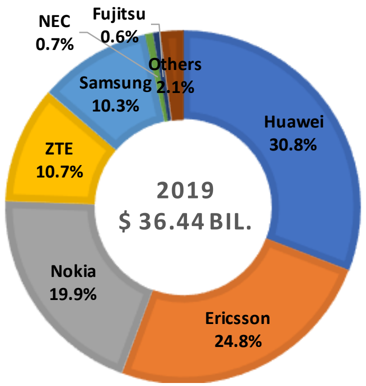
Share structure in the world market

Smartphone & Macro cell base station

While the companies that make up the market share of smartphones have changed significantly in the past 10 years, the market share of macro cell base stations has changed, but the lineup of companies has not changed significantly.



Smartphone (based on the number of units)



Macro cell base station (based on shipping value)

Beyond 5G is expected to expand the market for small cell base stations as the higher frequency bands are utilized.

Electronic components

It is expected that the number of important electronic components will increase by utilizing the high frequency band. If we can obtain a high market share, we may be able to reduce costs through mass production.

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%

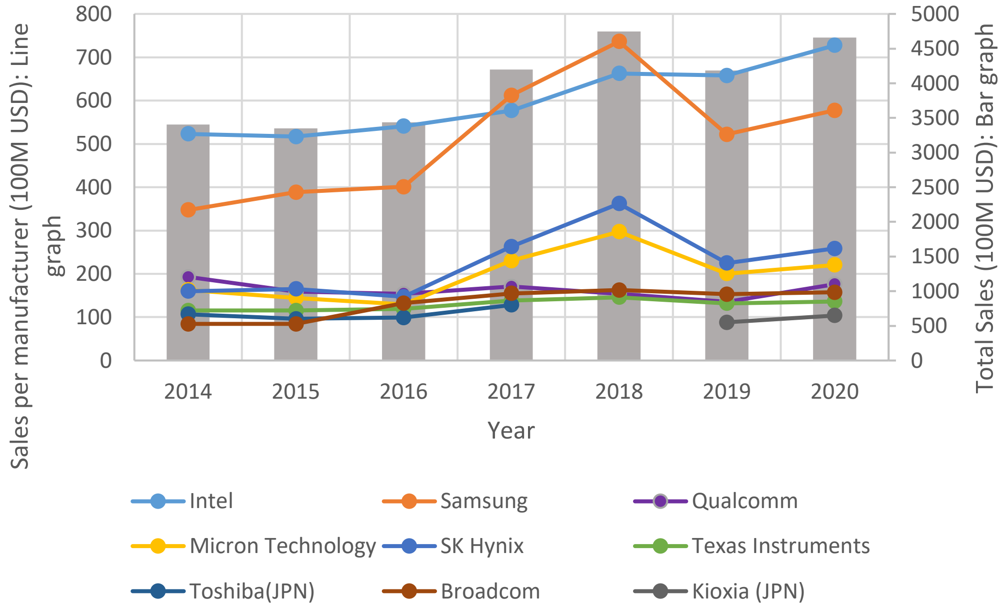
3. Market Trend of Communication Industry (2)

**The semiconductor market is expected to continue expanding in the future, and power consumption tends to increase accordingly.
For Beyond 5G, it is important to develop technologies to reduce power**

Trends related to the telecommunications industry

Semiconductor

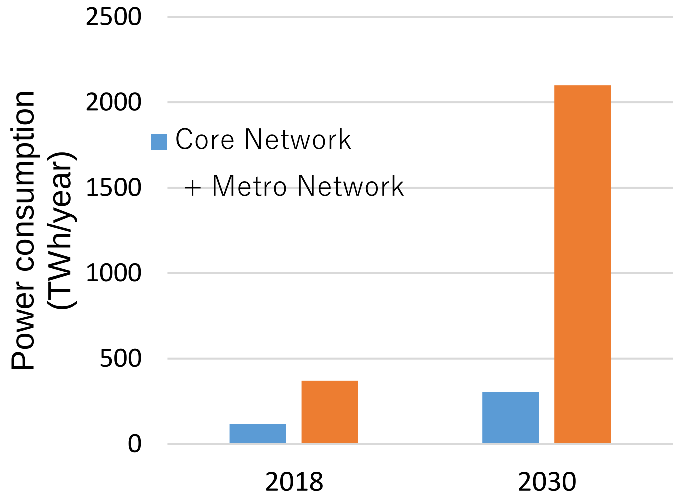
Although the semiconductor market is in a boom and bust, it is generally on a growth trend, with US and Korean companies gaining a high market share.



Semiconductor manufacturer share

Power consumption

Network-related power consumption is expected to increase about four to five times in 2030 compared to 2018. If the power consumption per base station increases, the power consumption will increase further.



Global network-related power consumption

4.1 Finance

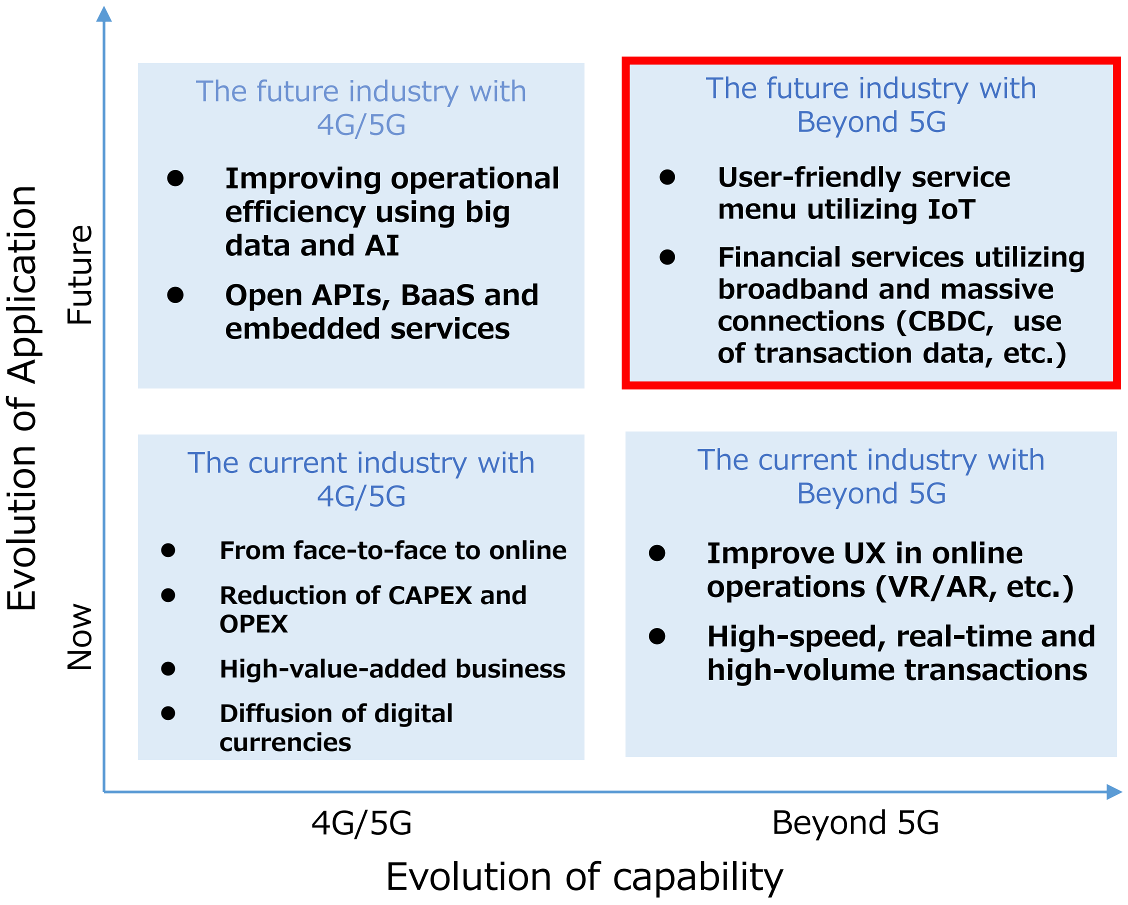
Current Situation and Challenges

- Shift from face-to-face business to online business
- Reduction of CAPEX and OPEX (Store consolidation, scale reduction, ATM reduction)
- Shift to high-value-added business (Alternative investments, advisory services, etc.)
- Diffusion of digital currencies

Future Vision

- Upgrading existing services
  - ✓ Improving operational efficiency using big data and AI
  - ✓ Service menu suitable for users
- Integrated services with other industries
  - ✓ Open APIs, BaaS
  - ✓ Embedded finance
- New financial services
  - ✓ Central Bank Digital Currency (CBDC)
  - ✓ Secondary use of transaction data, etc.

What is required for Beyond 5G



CBDC: Central Bank Digital Currency

4.2 Construction / Real estate (1)

Current Situation and Challenges

Construction

- Building a sustainable industry
- Reduced number of employees, and aging
- Workstyle reforms by improving wage levels and expanding holidays, and improved productivity through use of ICT.
- "i-Construction" aiming at drastic productivity improvement

Real estate

- Aging workforce and shortage of successors
- Idle and/or deteriorated real estate
- Support for the diversified lifestyles
- Safe and secure real estate transaction and realization of sustainable society

Future Vision

Construction

- Innovative technologies in construction/infrastructure areas
- Business efficiency and sophistication due to CIM / BIM

BIM/CIM: Building/ Construction Information Modeling, Management

i-Construction

Real estate

Utilization of new technologies such as AI, IoT and robots, improved efficiency and convenience

4.2 Construction / Real estate (2)

What is required for Beyond 5G

Achievable Applications

Construction

- Remote construction by experienced technicians
  - Collaborate with experienced technicians with VR technology
  - Remote control of construction machinery or robots with haptics and/or VR technology
- Maintenance and management of buildings or infrastructure by IoT
- Design and construction in physical and cyber space
- Fully automated construction by automated construction machines and robots

Real estate

- maintenance and management of Real estate by IoT
- Real estate management, transaction and investment by digital twin
- Online property viewing using VR

Evolution of Application	4G/5G	Beyond 5G
Future	**The future industry with 4G/5G** • IoT-based infrastructure maintenance • Automated operation of construction equipment using AI and data • Automatic assembly of construction parts performed by robots • Remote real estate transactions	**The future industry with Beyond 5G** • Using digital twins for automatic construction, infrastructure maintenance, real estate management, trading, and investment • Connecting all construction components by IoT for infrastructure and building maintenance, and real estate management • Remote construction by experienced technicians
Now	**The current industry with 4G/5G** • Acquisition and utilization of 3D surveying and design data • Remote installation management and inspection • Remote explanation of important matters (Explanation of important matters using IT)	**The current industry with Beyond 5G** • Remote construction in collaboration with experienced technicians • Online property viewing using VR

Evolution of Capability

Capabilities required in Beyond 5G

- For automatic construction using digital twins and Maintenance and management by IoT, **1 to 2 cm positioning and sending accuracy** is required.
- For remote construction by experienced technicians, **less than 100 msec ultra-low latency** is required.

4.3.1 Warehousing/Logistics

Current Situation and Challenges

- Demographic Trends and Labor Shortage
- Safety and security against increasing natural disasters
- Strengthening digitalization and innovation for Society5.0
- Ensuring the sustainability of the global environment the SDGs
- Response to pandemics

Future Vision

- Fully optimized supply chain through Logistics DX and standardization (Simple and smooth logistics)
- Logistics structural reforms against Labor shortage (Labor friendly Logistics)
- Robust and sustainable Logistics Network (realizing strong and flexible logistics)

What is required for Beyond 5G

Evolution of Application (vertical axis: Now → Future); Evolution of Capability (horizontal axis: 4G/5G → Beyond 5G)

The future industry with 4G/5G
- IoT
- Local communication
- Cyber ports
- Logistics DX
- Drone

The future industry with Beyond 5G
- Advanced AI/ML（incl. radio IF)
- Digital twin
- Full automation
- Fast automated delivery
- NTN/HAPS

The current Industry 4G/5G
- RF tag
- Logistics IT

The current industry with Beyond 5G
- Partial automated driving, delivery and tracking
- Basic AI/ML (e.g. delivery scheduling)
- Big data
- Cloud

Latency requirement is on **the order of milliseconds** in the local network, and time synchronization is required to **support PTP (microseconds)** as the accuracy of the internal clock including the radio section.

4.3.2 Aviation (1)

The number of air travelers is on an increasing trend, reflecting growth of the global economy. Safe, secure and highly efficient operation, meet diverse needs, climate and environment-friendliness are demanded.

Current Situation and Challenges

- The number of air travelers is on an increasing trend, reflecting growth of the global economy.
- The services required of the aviation industry are becoming more diverse. Services at airports and aircraft must be improved to suit diverse passenger needs.
- Realizing a decarbonized society entails the use of fuel-efficient aircraft and equipment and further weight reduction are considered.
- Advanced air traffic management systems are currently being developed, e.g. through the CARATS roadmap by the Ministry of Land, Infrastructure, Transport and Tourism in Japan.
- Safe and secure operation with increasing the rigor of security inspections while reducing the burden.

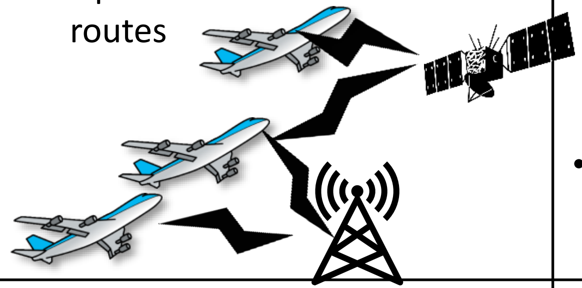
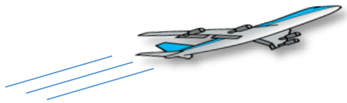
Future Vision

Services for safe, secure, convenient, and comfortable air travel	• Safe and stress-free transportation, including at the airport • Comfortable in-flight service • Support of grand operations
Advanced aircraft for sustainable air transport	• Improved fuel efficiency and achieve decarbonization • Piloting assistance and operation control
Air traffic control	• Increase density of operations through advanced air traffic control
New aviation service	• Safe and comfortable operation of drones and flying cars • Supersonic aircraft

4.3.2 Aviation (2)

Beyond 5G features contribute to the aviation industry.

What is required for Beyond 5G

	Comfortable in-flight service	Improved fuel efficiency and decarbonization	Increase density of operations through advanced air traffic control	Drones and flying cars	Supersonic aircraft
Applications	• VR / AR utilization • Provide more comfortable space and time by providing personalized environment	• Wireless avionics intra-communication (WAIC)	• Zero waiting time for takeoffs and landings • Operation on fuel-efficient routes 	• Drones for logistics, measurement, monitoring, disaster response, and infrastructure inspection  • Flaying taxi, emergency vehicles	• The comeback of supersonic aircraft • High-speed point-to-point suborbital transport 
Beyond 5Gs's contributions	• Ultra-fast and large capacity communications inside aircraft • High security to prevent unauthorized access to in- flight communications	• Ultra-fast and large capacity for IFE monitors • Ultra-low latency, ultra security, resiliency and reliability • Ultra-low power consumption sensor device	• High-precision positioning / environmental sensing • Seamless terrestrial and non terrestrial communications	• Ultra-security, resiliency and reliability, ultra-low latency communications, positioning and sensing • Ultra-fast and large capacity communications with fast-moving objects	• Expanded coverage of **high-altitude above 10km** and outer spaces (**altitudes above 100 km**)

4.3.3 Railway Industry (1)

Mobility needs have declined due to population decrease and changes working styles. Ambidexterity is required to “Exploitation” and “Exploration”.

Current Situation

- Mobility needs declined due to population decline and changes working styles.
- Ambidexterity is required to deepen the existing railway business and search for new profitable businesses.

Challenges

- Zero accidents and early restoration
- Aging and population decline
- Aging infrastructure and systems
- Distributed society

Future Vision

1. Safe and Secure

Utilization of IoT and robots

Source: Tokyo Metro, Demonstration experiment of robot

2. Automation

Self-driving and early restoration of timetable

Source: JR East, Automatic Train Operation

3. Improving Service

MaaS cooperation and all-in-one payment

Source: MLIT, Promotion of Japanese version of MaaS

4. Town Planning

Living in a new city that transcends space

Source: 4th meeting of Vision Working Group, JR East’s presentation

4.3.3 Railway Industry (2)

Capabilities required for Beyond 5G include ultra-low latency, ultra-security, resiliency and reliability, for application such as autonomous driving and smart maintenance.

Application achievable with Beyond 5G

Evolution of Application (Now → Future) / Evolution of Capability (4G/5G → Beyond 5G)

Future / 4G/5G — The future industry with 4G/5G

- **Use of IoT for operation and maintenance**
- **Touch-less and gate-less ticket gates**

Future / Beyond 5G — The future industry with Beyond 5G

- **Autonomous driving**
- **Smart maintenance**
- **Operational support by robots**
- **Seamless collaboration with MaaS**
- **Fusion of real and virtual spaces**

Now / 4G/5G — The current industry with 4G/5G

- **Trial introduction of robots**
- **Verification experiments on automated driving**
- **Verification experiments on MaaS**

Now / Beyond 5G — The current industry with Beyond 5G

- **Use of robots and XR for operation and maintenance**
- **Remote work in-transit**
- **Use of mobility and robots in various scenarios**

Capabilities required in Beyond 5G

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.

<Example of Capability>

Ultra-Low Latency	In an emergency stop of an ultra-high-speed railway, **an end-to-end delay time of about several milliseconds** is required.
Ultra-security, resiliency and reliability	In CBTC (Communications-Based Train Control) systems, **highly reliable real-time wireless communication** is required to prevent train collisions and overspeeds.

4.4 Telecommunication and IT Industries（1）

UPDATE on Version 2.0

It is necessary to realize a mechanism to find solutions by projecting events occurring in physical space into cyberspace through the promotion of smart technology based on DX and reliable and free data distribution

Current Situation and Challenges※

- Development of an advanced communications infrastructure : Safely and reliably realize extremely high-level data synchronization across both physical and cyber space everywhere.
- The construction of platforms that operate autonomously : Establishing technologies and rules for all machines to work autonomously with sensors
- Strengthen security and disaster resistance : Ensuring cyber security and a stable network that prevent communication interruptions even in times of disaster

※Review of 5G is summarized in Section 4.4.5

Future Vision

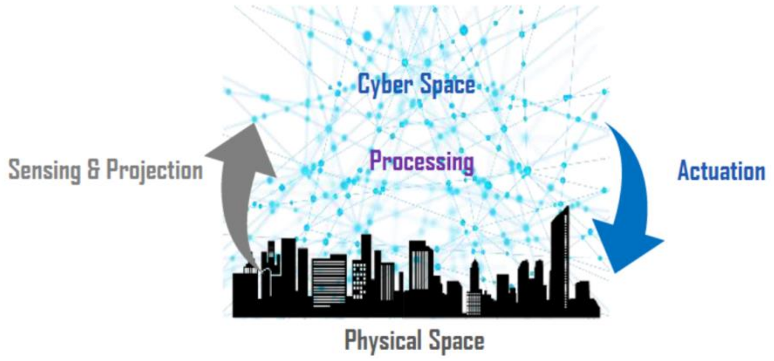
① An Inclusive Society

A society in which everyone can play an active role by the removal of differences such as age, disabilities, geographical barriers, and other differences through the expansion of physical and cognitive abilities through wearable devices and realistic experiences anywhere via robots.

Source : NICT（Beyond 5G/6G White Paper : Telepresence）

② A Sustainable Society

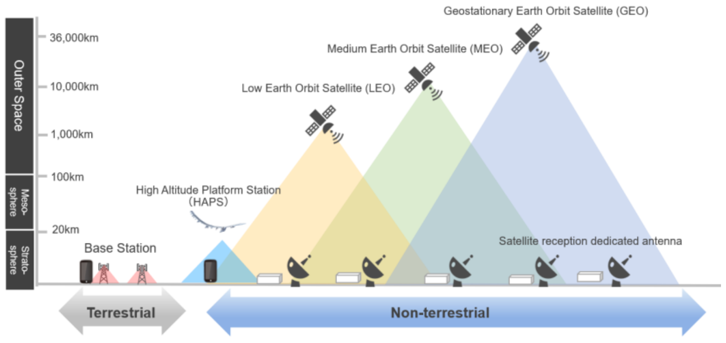
A society can achieve sustainable growth and be convenient, without any social loss, through optimization in cyberspace with real-world reproduction that can be fed back to the real world.



Source : NICT（Beyond 5G/6G White Paper : Cyber-physical system）

③ A Dependable Society

A society which will prevent communication interruptions even in times of disaster by flexibly and autonomously changing network configuration, thus everyone will be able to work with peace of mind.



Source : SoftBank Corp.（The Power of Technology "Gijutsu no Chikara" Beyond 5G／6G）

Achieving the desired future vision will require further enhancement of 5G features and new Beyond 5G features

What is required for Beyond 5G

A vigorous and resilient society through development of CPS

Autonomous optimization and future forecasting functions are required to provide the necessary goods and services to the people that need them, when they need them and only what they need

Evolution of Application (Future / Now) × Evolution of Capability (4G/5G / Beyond 5G)

Future – The future industry with 4G/5G
- Collecting data from all kinds of objects with IoT
- High-precision, AI analysis of physical space, recreated in virtual space

Future – The future industry with Beyond 5G
- **Realistic experiences using cyberspace, robots, etc., and real-time support to enhance physical and cognitive abilities** (Ultra-fast and large capacity, Ultra-low latency)
- **Eliminate economic loss through highly-accurate demand forecasting and real-time optimization using AI technology** (Ultra-fast and large capacity, Ultra-low latency, Ultra-massive connectivity, Autonomy)
- **Traffic systems without congestion or waiting for traffic signals by enabling inter-object mutual control** (Ultra-low latency, Ultra-massive connectivity, Autonomy)

Now – The current industry with 4G/5G
- Visual virtual experience with AR and VR
- Expansion of telework

Now – The current industry with Beyond 5G
- Real-time transmission of ultra-high-definition video (Ultra-fast and large capacity, Ultra-low latency)

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

The requirement for 100% land coverage by terrestrial and non-terrestrial networks will ensure that all people can benefit from digitalization and work with peace of mind

Evolution of Application (Future / Now) × Evolution of Capability (4G/5G / Beyond 5G)

Future – The future industry with 4G/5G
- Establish and coordinate a cross-sectoral information distribution platform
- Data utilization with consideration for protecting personal information and privacy

Future – The future industry with Beyond 5G
- **Seamless connectivity over land, sea, sky and space, preventing interruption by flexibly and autonomously changing network configuration.** (Universal coverage, Autonomy)
- **Use of digital technologies and services suited to individuals' needs, regardless of geographic, economic or physical constraints** (Ultra-fast and large capacity, Universal coverage)
- **Guaranteed security and privacy by using AI for automatic detection, defense, repair, etc.** (Autonomy, Ultra-security, resiliency and reliability)

Now – The current industry with 4G/5G
- Measures to counter the digital divide using optical fiber and 4G/5G

Now – The current industry with Beyond 5G
- Universal coverage using satellite and HAPS (Universal coverage)

4.5 Media (1)

In 2030, people can enjoy more immersive media experiences utilizing virtual space and holographic communication, e.g., “the metaverse”.

Current Situation

- Various multi-media contents including TV/radio, publishing and advertise business, SNS, etc.
- Due to pandemic, the digitalization has been accelerated, e.g., online live events.

Future Vision

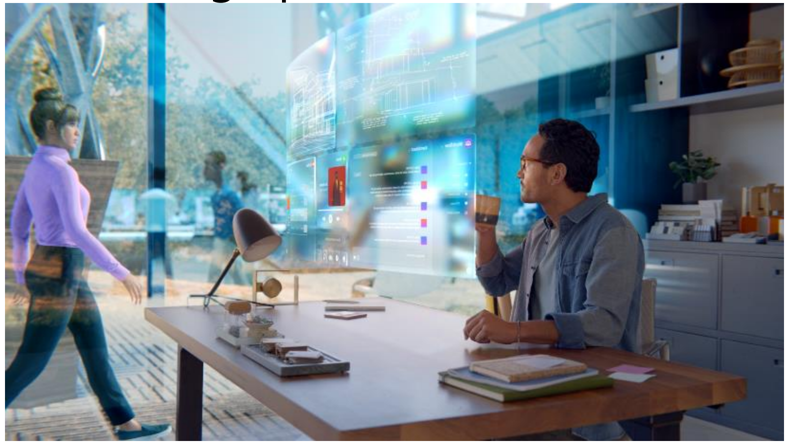
- All the contents can be accessed online via internet. Likewise, richer user-created contents can be delivered more easily regardless of time, place and device type.
- Utilization of virtual space and Holographic communication.
- Personalization/customization for more efficient contents delivery.

Online live event

Source: https://lineblog.me/livepress/archives/13261786.html

Entertainment in virtual space

Holographic communication



Source: https://about.meta.com/what-is-the-metaverse/?utm_source=about.facebook.com&utm_medium=redirect

4.5 Media (2)

- **The figure below summarizes the high-level requirements (Conceptual / Technical aspect) for beyond 5G.**
- **A few tens ~ hundreds Gbps of peak throughput can be expected for Holographic communication, as an example of performance for Beyond 5G.**

The black lines between the boxes represent what technical aspects will be relevant to the conceptual aspects

Conceptual aspects

Accessibility

- Access for everyone, anytime, anywhere and with any type of device
- Users can distribute content they created themselves
- Building a global ecosystem that enables a rich and diverse multimedia application developer community

More immersive media experiences

- Support more immersive media experiences with holographic communication and embodiment of the internet

Personalization

- Provide services adapted to each user's viewing environment and devices

Technical aspects

Enhanced radio communication

- Further improve frequency utilization efficiency, coverage and latency

Extended architecture, protocols

- Support radio access and network architectures to enable efficient content delivery using both broadcasting and communication

Utilization of AI, machine learning

- Use AI to implement a range of personalization and customization

4.6 Energy, Resource, Material (1)

Introduce new technologies such as IoT and automation, improve the working environment in mines and plantations, the efficiency of equipment and the movement to the "venous industry“ to secure stable resources and decarbonize for a sustainable society

Current Situation

- Toward a sustainable society, Mineral resources industry is focusing on recycling and marine resource development, Paper industry is focusing on new businesses related decarbonization
- Promote the study and introduction of new technologies to improve work efficiency and work environment in mines and forest plantations
- Companies in both industries, which are large-scale equipment industries, are promoting efforts for energy saving and decarbonization

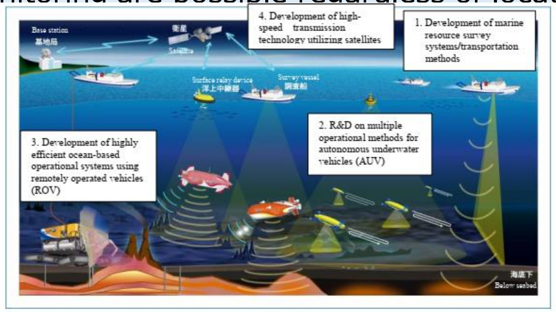
Challenges

- Promote the introduction of automated machinery and remote operation / remote monitoring regardless of location
- Promote equipment efficiency improvement and introduction of energy saving / decarbonization technology utilizing IoT / big data
- Promote "veinous industry" through IoT as a broad infrastructure base

Future Vision

Efficient, safe and secure working environment

Robot utilization and remote control / monitoring are possible regardless of location



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

Automation of logging

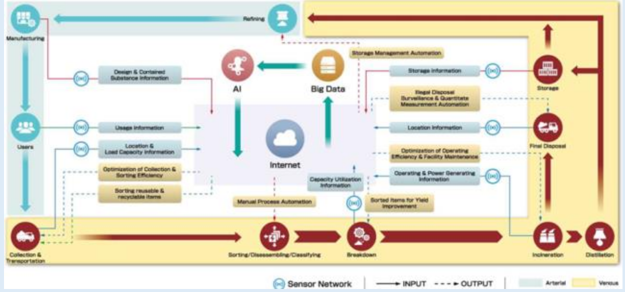
Automatic cable-yarding system

Autonomous driving Forwarder

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

Recycling as a common infrastructure

“venous industry" with a extreme-massive connectivity that is not restricted to any location



Source: “The IoT Council of Waste Management and Recycling HP”

Optimal operation of energy-saving and low-carbon equipment

Manufacturing DX/Value chain utilizing IoT and big data

4.6 Energy, Resource, Material (2)

UPDATE on Version 2.0

Requirements unique to Beyond 5G to realize the expected future are Universal coverage, ultra-low latency, Ultra-massive connectivity, ultra-low power consumption, and contactless power supply

What is required for Beyond 5G

Requirements

- **Universal coverage**
  High-speed communication in mountains and at sea
- **Ultra-low latency**
  45 ms or less for an immersive remote control system aimed at improving the working environment (example)
- **Ultra-massive connectivity**
  Realization of CPS by collecting environmental data and mobile data of all things and places
- **Ultra-low power consumption / contactless power supply**
  IoT terminals that are easy to install and operate anywhere (no power supply required, etc.)

Evolution of Application (Now → Future)

The future industry with 4G/5G

■In areas not served by 5G(quarries, oceans, forests)
Local 5G system
■In 5G service areas
More sophisticated manufacturing DX, recycling industry through collection IoT data (with restrictions on the installation location)

The future industry with Beyond 5G

■Flexible equipment installation / system
·No location restrictions
·Edge and cloud integration, virtualization, etc.
·DX across the entire value chain
·Cross-industry 'veinous industry' leveraging shared IoT data collected from all locations

The current industry with 4G/5G

■In areas not served by 5G (quarries, oceans, forests)
Individual closed systems (Restricted autonomous operation of machines, etc.)
■In 5G service areas
progress in Manufacturing DX, improvement in the efficiency of the recycling industry by collection IoT data

The current industry with Beyond 5G

■Progress of DX(even in quarries, oceans, forests)
Remote equipment operation, cloud integration, optimization of the entire value chain
■No restrictions on installation
Increase the number of data collection targets
Expansion of recycling industry

4G/5G
Communication area centered on ground base stations
Massive connectivity

Beyond 5G
Universal coverage (satellite communication / HAPS / underwater communication)
Ultra-massive connectivity, low power consumption terminals / contactless power supply

Evolution of Capability

4.7 Automotive (1)

The aging society restricts people's mobility in rural areas, and population concentration in urban areas causes traffic congestion. A future society is envisioned in which all people can be ensured with unconstrained and efficient mobility irrespective of their living areas.

Current Situation and Challenges

- Lack of drivers negatively affects the sustainability of public transportation in rural areas, while population concentration in urban areas causes traffic jam. Both adversely affect the quality of people's lives.
- Increased awareness of societal crisis on energy and environmental issues, and problems of traffic-accident caused by the aging society.

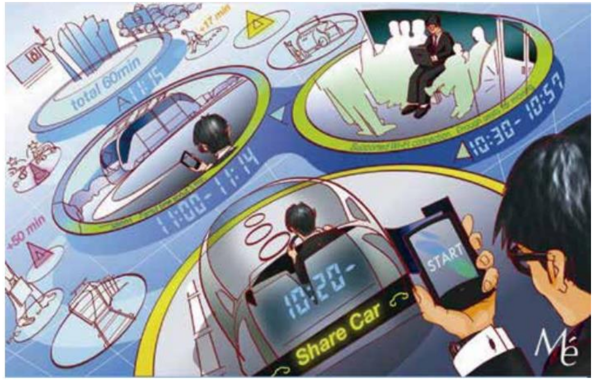
- Realize a mobility-inclusive society that provides unconstrained and efficient mobility for all people
- Build a robust infrastructure for automated driving and safety driving assistance, and a low carbon-emission society

Future Vision

1. A society all people can move freely and efficiently

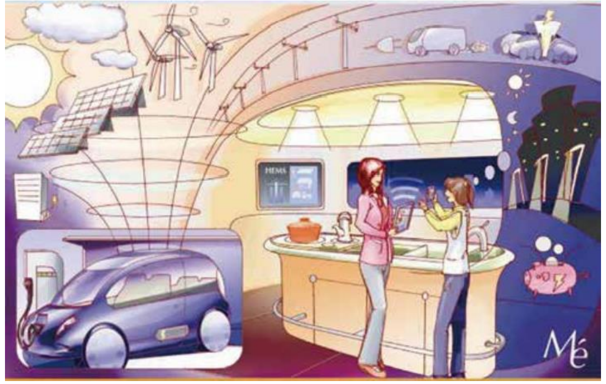
Source: ITS Japan

2. MaaS Platform allowing the Multi-modal mobility of people



Source: ITS Japan

3. Collaboration between vehicles with Smart Cities



Source: ITS Japan

4. Enabling digital society to realize Mobility-inclusive

Source: The Government of Japan, ITS Roadmap

4.7 Automotive (2)

UPDATE on Version 1.5

Towards Automotive Society in 2030 Era, Beyond 5G shall require the integration of highly accurate sensing and communication, distributed AI learning & inference, and ultra reliability

What is required for Beyond 5G

Safety Driving Assistance

Beyond 5G sensing and enhanced connectivity are required so as to support Safety Driving under extreme conditions, e.g., driving at intersections without a signal, under bad weather or in the event of a disaster.

Evolution of Applications	4G/5G	Beyond 5G
Future	The future industry with 4G/5G ● **Look-ahead information via cloud-based coordination** ●**See-through, AR/VR Navigation**	The future industry with Beyond 5G ●**Complement V2I cooperation by sensing (Sensing Fusion, Sensing capability)** ●**Enhanced connectivity and availability (ultra low latency, ultra high reliability, VLEO/HAPS)**
Now	The current industry with 4G/5G ●**Data Volume: 50MB/Car monthly** ●**Probe data retrieval with V2N**	The current industry with Beyond 5G ●**88% of new car sales are connected cars** ●**Active utilization of V2V communication (Sidelink)**

Evolution of Capability

Automated Driving

Integrated sensing and communication, distributed AI learning & inference, and quantum-cryptography-based security are required to accelerate the implementation of automated driving

Evolution of Applications	4G/5G	Beyond 5G
Future	The future industry with 4G/5G ●**Dynamic Map, SW downloading with OTA** ●**Improved Connectivity utilizing V2I, V2V and V2P communications**	The future industry with Beyond 5G ● **Sensing and distributed AI learning & inference** (**sensing accuracy at cm level**) ●**Remote monitoring and remote driving** (data speed at **50 Gbps**, **E2E latency at 1 ms**, **reliability at 10-6 or higher**)
Now	The current industry with 4G/5G ●**Autonomous Level-3** ●**Expressway** ●**L3 Cars Sales: 70K/Year**	The current industry with Beyond 5G ●**Cooperative automated driving Level-5** ●**Data Volume: 5GB/Car monthly** ●**L3-5 Sales: 8Mil./Year (30% of new car)**

Evolution of Capability

4.8 Machines (1)

Machines are the foundation of all aspects such as daily life, production / distribution, social infrastructure, and energy use. Improving performance, efficiency, and reliability through various improvements, sensor evolution and system optimization by utilizing ICT are progressing.

Current Situation and Challenges

- Decline in the working population (SDG 8,9)
  - Automation/Labor saving, Collaborative work with humans
- Global environment protection (SDG 13)
  - Reducing the environmental burden at every stage
- Production / energy efficiency (SDG 7,12)
  - Optimization of design / manufacturing / logistics / operation
  - Utilization of ICT
- Resolving inequality (SDG 10)
  - Gender / Disability / Age
  - Country / Region / Race

Future Vision

Item	Expected progress
Design	● Improved design efficiency through remote collaboration and digital twins ● Design employing contactless power supply and wireless communication ● Optimal design of fuel efficiency, mechanical efficiency, and control efficiency by AI / HPC
Manufacturing	● Digital twin and optimized production by connected cyber factories ● Efficient logistics, distributed production and local production for local consumption
Autonomous control	● AI-based maneuvering, labor saving, unmanned and autonomous operation of machines ● Autonomous driving with accurate and dense sensing, positioning, and optimal control
Expanding the coverage area	● Coverage expanding to sky, stratosphere, space, pelagic, underwater, underground
Machine intelligence and cooperation with human	● AI-based autonomous robot with improved accuracy and speed ● Enhanced human with expanded organs, perception, multi-sensory and remote operation capability of plural machines ● Robots serving as communication partners and alternatives to home appliances
Monitoring and maintenance	● Acquisition of operating data with enhanced types, sampling density and number of objects in operation ● Analysis and feedback through computing resources distributed optimally among devices/edges/clouds

4.8 Machines (2)

What is required for Beyond 5G

Expected Use Cases

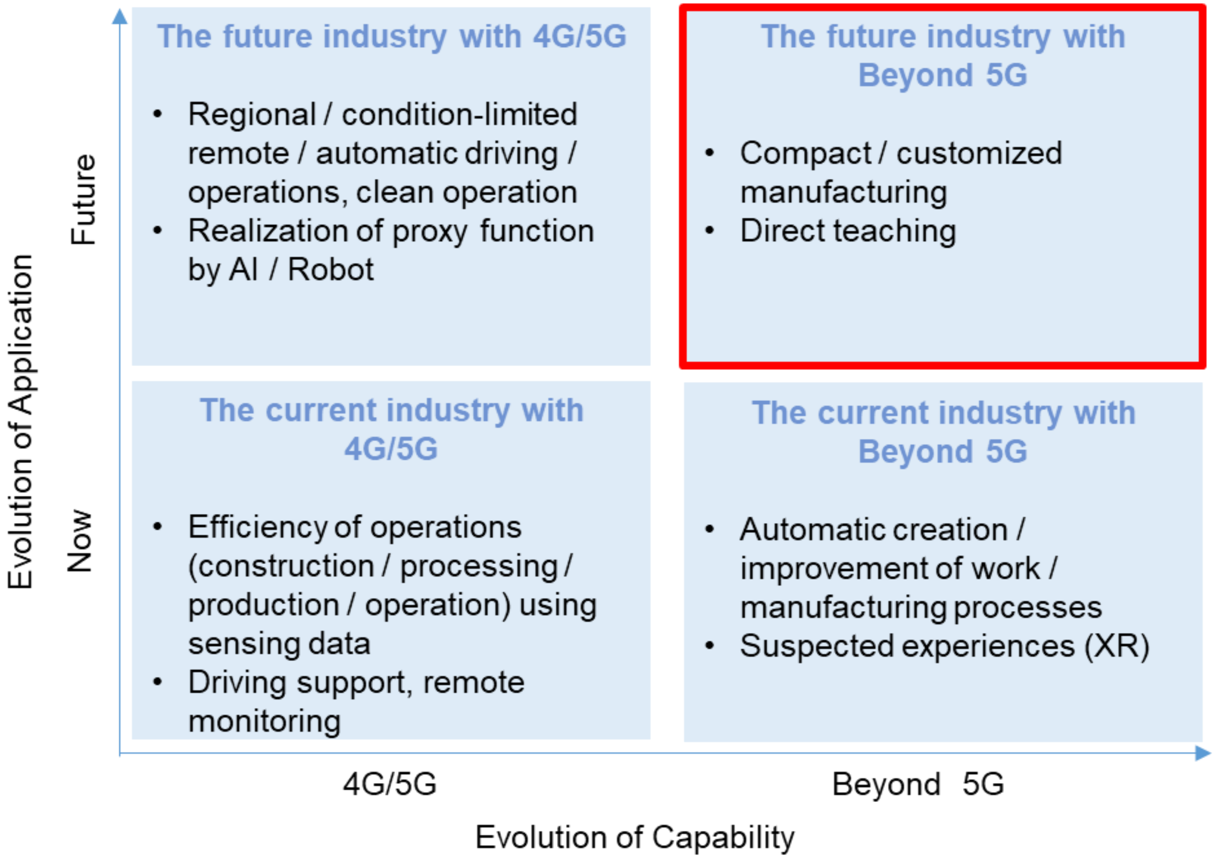
1 Intelligent / automated work / manufacturing process
Automatic process generation / improvement, ultra-low latency motion control*, direct teaching, real-time CPS

2 Remote operation / control / diagnosis
Application of robot technology to construction machinery and agricultural machinery, application of autonomous driving technology to aircraft and ships, intuitive HMI, product / breeding management

3 Flexible construction / processing / production / operation management
Smart maintenance by AI and/or robot / equipment sharing / reflection of production / working environment conditions

4 High-speed mobility / energy saving / comfort
High-precision positioning and control of wide-area, high-speed moving objects, navigation plan management by utilizing data, automation and sophistication of security inspections, traceability , seamless transportation

5 New mobility service
Flying taxi, simulated experience



Example : Agricultural machinery industry in Beyond 5G era

*: 100 micro second in E2E local area communication

4.9.1 Electronics and Precision electronics industry

Widely adopted Beyond 5G connected equipment into daily work and life.
Required to transform platform industries for support social essential infrastructure.

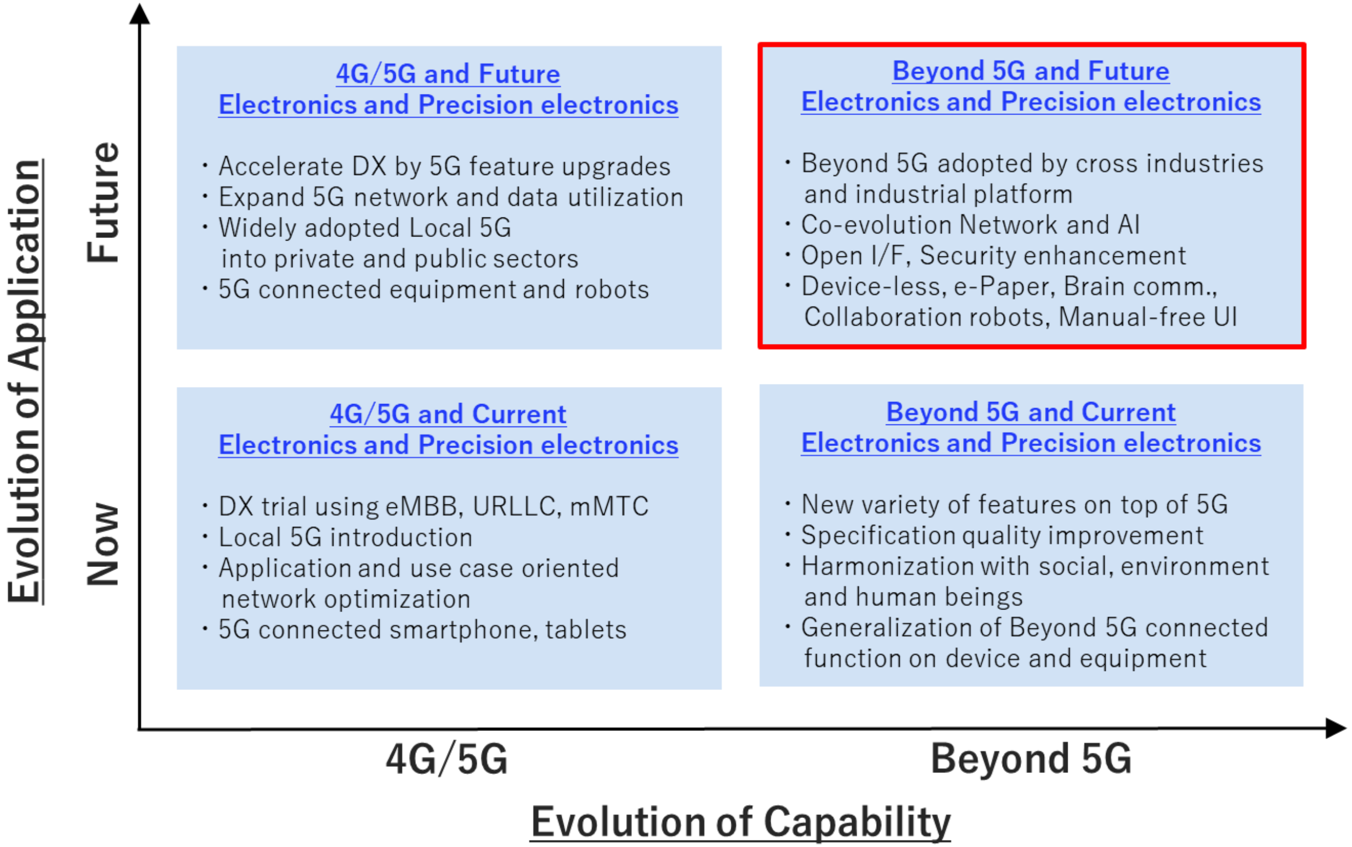
Current Situation

- Electronics and precision electronics equipment to be important parts of social platform with accelerating DX and 5G deployments.
- AI active use leads to Co-evolution between Network and AI

Challenges

- Socially total optimization of equipment / system sharing, energy efficiency & consumption
- Cross industries collaboration
- Shift to future-oriented and user-centric design

What is Required for Beyond 5G



4.9.2 Semiconductor

Current Situation and Challenges

- Semiconductor understock
- Anti-stress reinforcement to a disaster
- Soaring of semiconductor equipment
- Reduction in power consumption
- Lack of understanding supply chain

Future Vision

- Shortage lead time
- Manpower saving of factory, unmanned
- Reduction in equipment price
- Power consumption is reduced in Next-Semiconductor
- Improvement of the supply chain management power

What is required for Beyond 5G

Evolution of Applications (Now → Future) / Evolution of Capability (4G/5G → Beyond 5G)

The future industry with 4G/5G

- **Reducing human resource by introducing AI, IoT and robots into factories**
- **Introduction of 3D methods in semiconductor processes and packaging technologies**
- **Increase in market share of next-generation semiconductors**
- **Re-recognition of supply chain value**

The future industry with Beyond 5G

- **Reducing lead times to a few days**
- **Disaster resilient plants**
- **Price reduction of Semiconductor manufacturing equipment**
- **Development of new semiconductors**
- **Improved supply chain management using AI**

The current industry with 4G/5G

- **Lead times of several months**
- **Factories requiring a lot of human resource**
- **Expensive equipment due to increasing miniaturization**
- **Mainly silicon, some next-generation semiconductors**
- **Lack of supply chain awareness**

The current industry with Beyond 5G

- **Optimization of TAT by visualization**
- **Remote repair of semiconductor manufacturing equipment (Delay time 1ms)**
- **Breakaway from Moor's law**
- **Reinforcement of power consumption standards**
- **Extensive supply chain management**

4G/5G | Beyond 5G

Evolution of Capability

4.10.1 Agriculture and Fisheries

UPDATE on Version 2.0

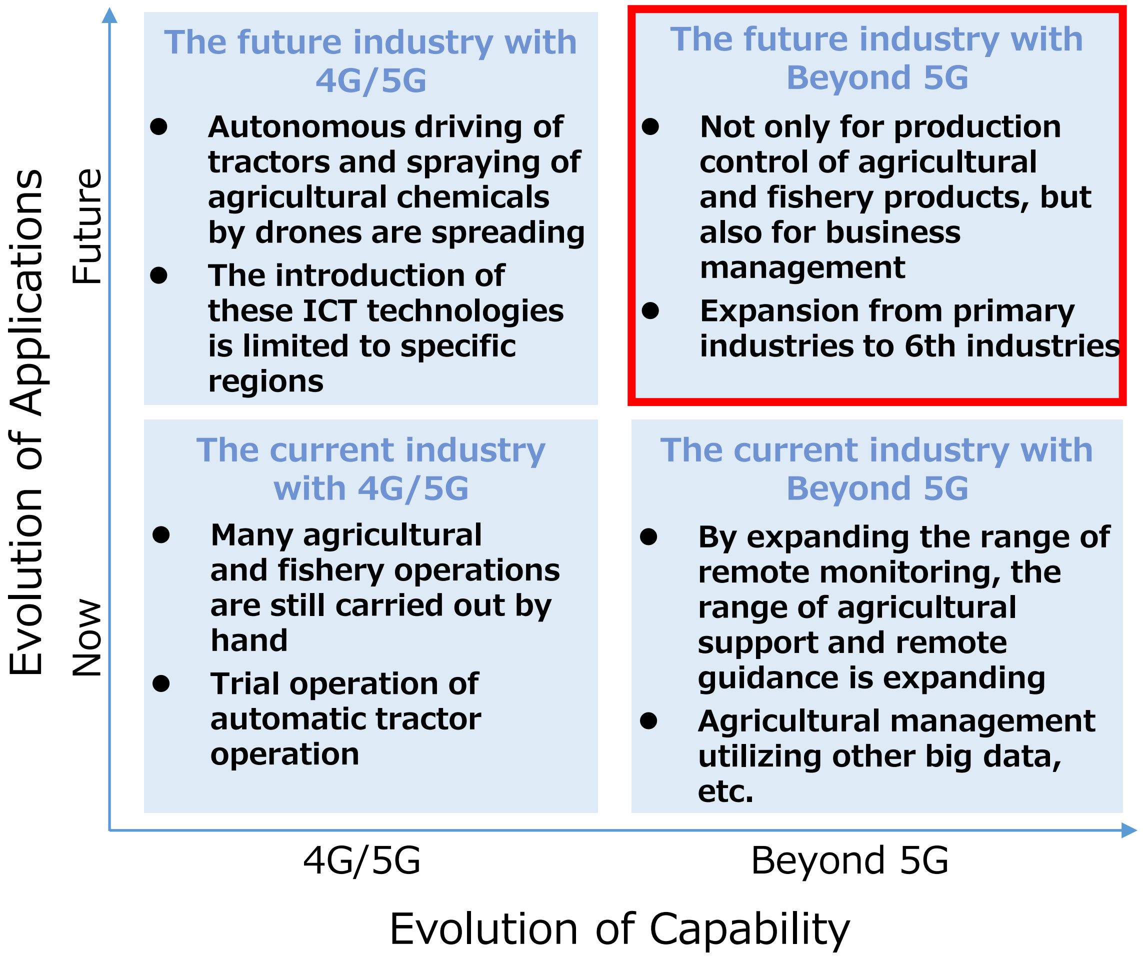
Current Situation and Challenges

- The labor shortage caused by the aging society with fewer children and the declining population is a serious problem.
- Reducing the burden of farm work and fishing, as well as labor saving in farm work and fishing, have also become issues.
- To strengthen the production base regardless of the size of the operation and the conditions of the farming and fishing village areas.

Future Vision

- By combining state-of-the-art technologies such as robots, AI, and IoT with Beyond 5G, "smart agriculture / fishery" will be advanced, including remote monitoring, automation of agricultural work / fishery, and improvement of productivity of crops.
- Remote control and automatic operation of tractor, tiller, rice-planting machine, etc. from cyberspace.
- Pesticide spraying using drones, animal damage monitoring using IoT technology, and agricultural support and remote guidance using XR technology.
- Production, fishing and management of agricultural and marine products.

What is required for Beyond 5G



4.10.2 Food Industry (Food Processing Industry)

Current Situation and Challenges

- The shortage of working population due to the aging society with fewer children and the declining population is a serious problem.
- In the field of food production, automation and stable operation of production lines and quality assurance of products are important issues.
- Stable supply of materials to food processing plants, inventory control of products and logistics management are also issues.

Future Vision

- Advancement of "smart factories" through automation of factories, stable operation, and quality assurance of products using robots, AI, IoT, etc.
- The introduction of Beyond 5G wireless technology in factories will contribute to the stable operation and improved productivity of production lines such as video monitoring.
- Reduce food loss by using big data to understand the inventory status of food products at stores.

What is required for Beyond 5G

Evolution of Applications (Now → Future) / Evolution of Capability (4G/5G → Beyond 5G)

Evolution of Applications	4G/5G	Beyond 5G
Future	**The future industry with 4G/5G** ● FA and PA are expected to be introduced more and more in the future ● Introduction of these ICT technologies is limited to factories	**The future industry with Beyond 5G** ● Automation of production lines, stable operation and quality assurance ● Product supply chain management, Business management including inventory and transportation management
Now	**The current industry with 4G/5G** ● Limited automation and stable operation of production lines ● Factory visualization through introduction of IoT technology	**The current industry with Beyond 5G** ● Expansion of the range of automation of production lines by expanding the range and accuracy of remote monitoring ● Plant management utilizing other big data is possible
	Evolution of Capability	

4.10.3 Living and Cultural Goods (Manufacturing)

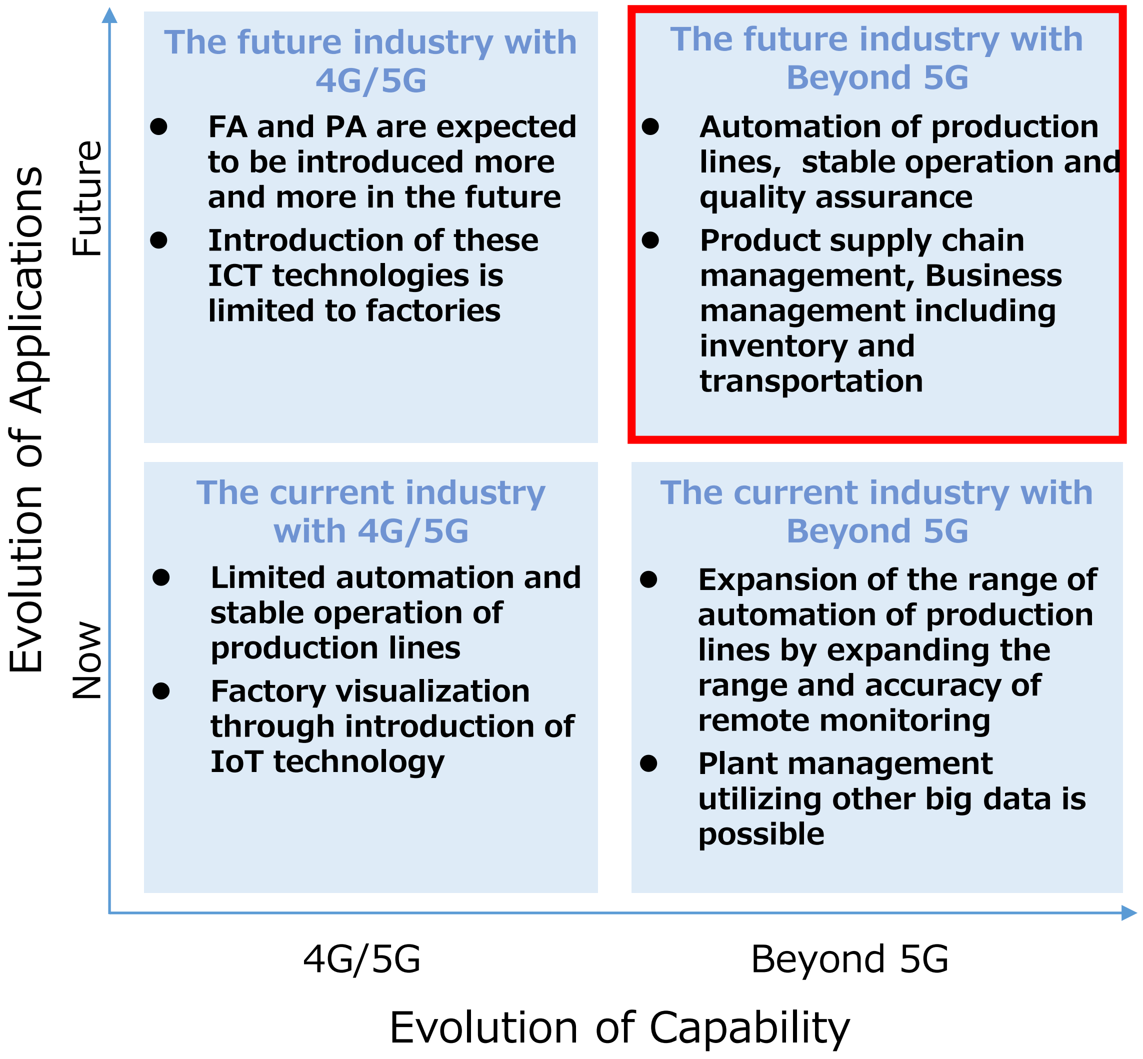
Current Situation and Challenges

- The shortage of working population due to the aging society with fewer children and the declining population is a serious problem.
- In the field of food production, automation and stable operation of production lines and quality assurance of products are important issues.
- Stable supply of materials to food processing plants, inventory control of products and logistics management are also issues.

Future Vision

- Advancement of "smart factories" through automation of factories, stable operation, and quality assurance of products using robots, AI, IoT, etc.
- The introduction of Beyond 5G wireless technology in factories will contribute to the stable operation and improved productivity of production lines such as video monitoring.
- Big data is used to identify the raw materials of products and the inventory status at retail stores, which is also used for business management.

What is required for Beyond 5G



4.11 Retail and wholesale distribution business

Current Situation and Challenges

- The shrinking domestic market due to a shrinking population, difficulties in securing human resources such as producers, ESG initiatives, sustainable supply in times of disaster, and many other issues are coexisting.
- Labor shortage and aging of drivers in the logistics industry.
- There are both positive and negative effects of changes in purchasing behavior due to the COVID-19.

Future Vision

- Creation of innovation in industries using advanced technologies such as robotics, AI artificial intelligence, and IoT.
- Comprehensive and integrated promotion of agriculture, forestry, fisheries (primary), manufacturing (secondary), retail (tertiary), and other industries to create new added value through sixth-tier industrialization.
- Promote the Logistics DX “Outline of Comprehensive Logistics Policies".

What is required for Beyond 5G

Evolution of Applications (Now → Future) / Evolution of Capability (4G/5G → Beyond 5G)

Evolution of Applications	4G/5G	Beyond 5G
Future	**The future industry with 4G/5G** ● **Evolution of IoT by analyzing more sensing and image data with AI** ● **Real-time processing through high-speed communications**	**The future industry with Beyond 5G** ● **Realization of sixth industrialization through supply chain evolution** ● **Further efforts to realize the SDGs**
Now	**The current industry with 4G/5G** ● **Verify solutions to issues through IoT demonstrations** ● **Consider solutions to future challenges through digital technologies**	**The current industry with Beyond 5G** ● **Establishing supply chain infrastructure through Data Collaboration Platform** ● **Innovation through CPS and Web 3.0**

Evolution of Capability

4.12.1 Healthcare (1)

Current Situation and Challenges

- Coexistence of various people in super-aging society
  - achieving harmony with a super-aging society, and to fulfill the role of presenting the world with solutions
- New solutions to unknown diseases
  - putting systems and measures in place to respond and resolve them promptly when they occur.
- Further development of medicine and medical device
  - achieving the world's highest medical technology standards and take the lead in the industry

Future Vision

1. Support and reproduction of physical functions and abilities

Source: Ministry of Health, Labor and Welfare (Home page)

2. Immediate response to unknown infectious diseases

Source: Cabinet Secretariat (COVID-19 Information and Resources)

3. Development of medical technologies

Source: Japan Agency for Medical Research and Development (Achievements)

4. Support for super-aging society

Source: Ministry of Health, Labor and Welfare (Home page)

5. Extension of healthy lifespan

Source: Ministry of Health, Labor and Welfare

4.12.1 Healthcare (2)

What is required for Beyond 5G

Use cases with Beyond 5G

1-1 Assisting perceptual abilities
Augmented human, Brain machine

2-1 Minimum contact, monitoring infections
Positioning, Centralized management of health status

3-1 DB of genome analysis
Personalized medicine, AI-based drug discovery

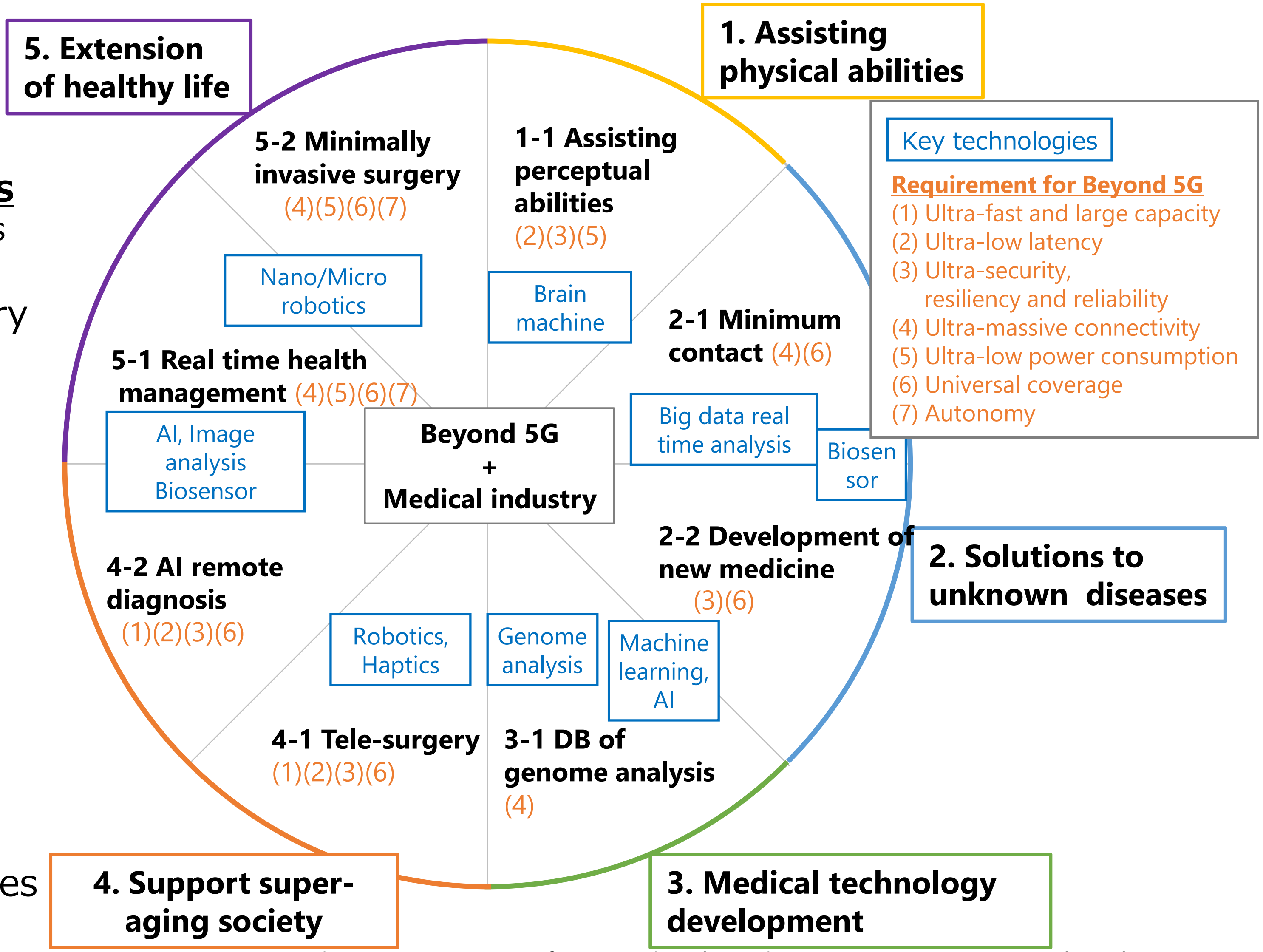
4-1 Tele-surgery
Robotics, AI based surgery

5-2 Minimally invasive surgery
Nano/Micro robotics, Energy harvesting

Beyond 5G requirements

Tele-surgery
- Tens of Gbps throughput
- 10^{-7} reliability

Minimally invasive surgery
- up to tens of millions/km² connectivity
- Autonomous communication control of devices



Future visions and requirements for medical and communication technologies

4.12.2 Government

UPDATE on Version 2.0

Current Situation and Challenges

- Government administrative systems established individually for each jurisdiction or use (system collaboration is difficult)
- Regulations and practices that impede digitization (seals, etc.)
- Complicated and cumbersome procedures (application for each system and processing at administrative counters)

Future Vision

- Collaboration and integration between systems
  - ✓ One-stop processing of operations across jurisdictions in response to events (Birth, marriage, moving, etc.)
- User-friendly UX
  - ✓ Administrative services open to anyone at anytime and anywhere (eliminating the digital divide)
- Service collaboration between public institutions and private sectors
- Utilization of open data from government

What is required for Beyond 5G

Evolution of Application (Now → Future) / Evolution of Capability (4G/5G → Beyond 5G)

Future – The future industry with 4G/5G
- **One-stop application processing**
- **Service collaboration between public and private sectors**
- **Utilization of open data**

Future – The future industry with Beyond 5G
- **UX improvements (Use of multiple devices, holograms, etc.)**
- **Open access to large amounts of real-time data (Ultra-massive connectivity)**

Now – The current industry with 4G/5G
- **Individual administrative systems by jurisdiction and use**
- **Complicated and cumbersome procedures (User support, system-specific application)**

Now – The current industry with Beyond 5G
- **Stable quality during heavy communication traffic, such as during disasters and emergencies**
- **Administrative services available anytime, anywhere (Wide coverage, private network)**

4G/5G | Beyond 5G

Evolution of Capability

4.13 Restaurant Industry

Current Situation and Challenges

- Business operating with reduced hours and voluntary suspension of business had been forced by the repeated declaration of an emergency.
- Due to the recent business operating with reduced hours cancellation, the number of stores that reopen due to the presentation of certificates of vaccination, etc., has increased.
- The biggest challenge now seems to be to regain lost customer traffic due to the pandemic.

Future Vision

- Revival of a restaurant where a large number of people can enjoy dining together without presenting a vaccination certificate or a negative certificate.
- Provision of a mechanism that enables smooth presentation electronically when the need for presentation of these certificates continues
- Reduced service hours and labor costs through the introduction of cooking / serving robots, ordering terminals, and cashless payments
- Respond to a variety of takeout needs and reduce food losses in conjunction with home meal delivering service

What is required for Beyond 5G

Evolution of Application	4G/5G	Beyond 5G
Future	**The future industry with 4G/5G** ● **Go-to-Eat Campaign and Others bring back some traffic** ● **Limited ability to capture nesting consumption such as telework**	**The future industry with Beyond 5G** ● **An "unmanned restaurant" that automates everything from receiving orders to serving meals and payment.** ● **Home meal delivering service and reducing food loss by using drones.**
Now	**The current industry with 4G/5G** ● **After the business operating with reduced hours was lifted, limited operations were resumed by presenting certificates of vaccination, etc.** ● **Expansion of business by providing take-out menus**	**The current industry with Beyond 5G** ● **Sophistication of cooking robots and introduction of serving robots using autonomous driving technology** ● **Sophistication of home meal delivering service**

Evolution of Capability

4.14 Entertainment and Leisure (1)

Current Situation and Challenges

- Opportunities to enjoy entertainment in virtual space have increased due to the effects of COVID-19
- Diversification of entertainment is accelerating due to integration with social media, mainly in the younger demographic
- Challenges to support massive traffic and low latency communication for interaction

Future Vision

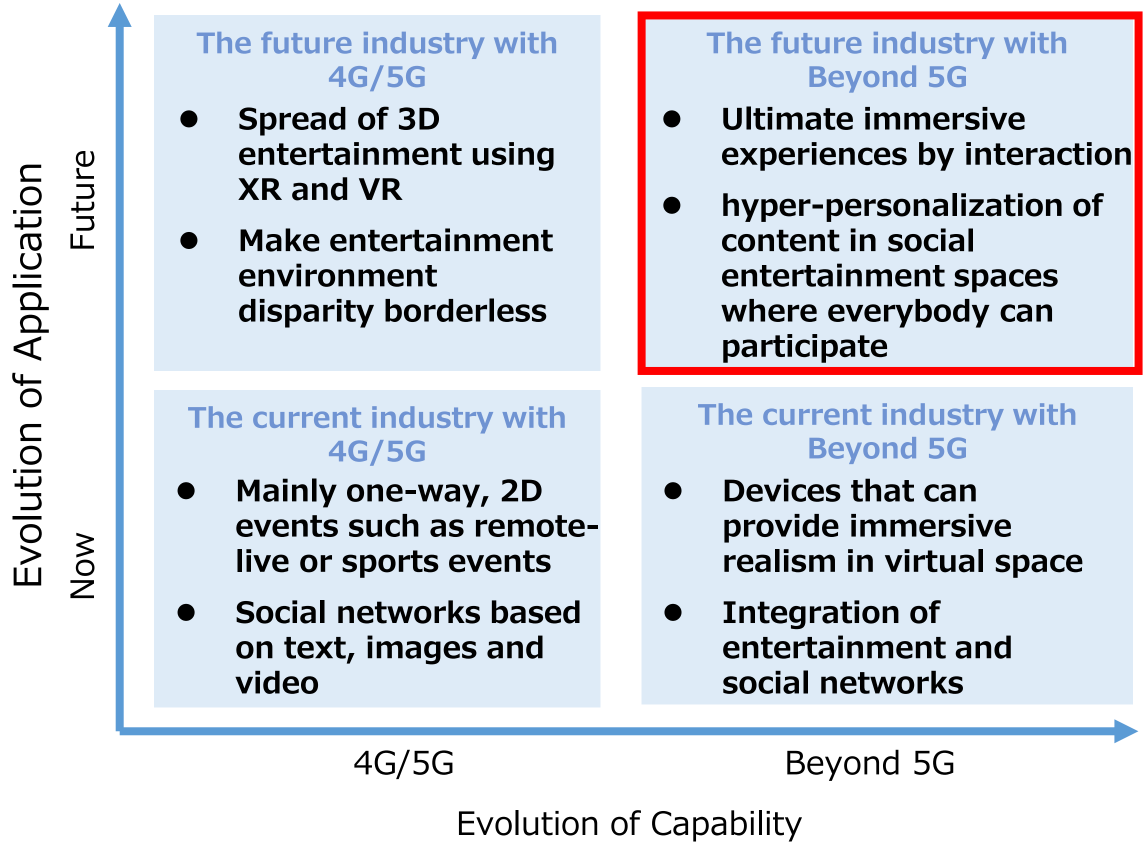
- Provide the ultimate immersive experience that fully stimulates the five senses
- Integrate virtual and real for entertainment
- Integrate entertainment and social
- High-grade content creator support and hyper-personalization of content
- Borderless entertainment services

What to expect in Beyond 5G

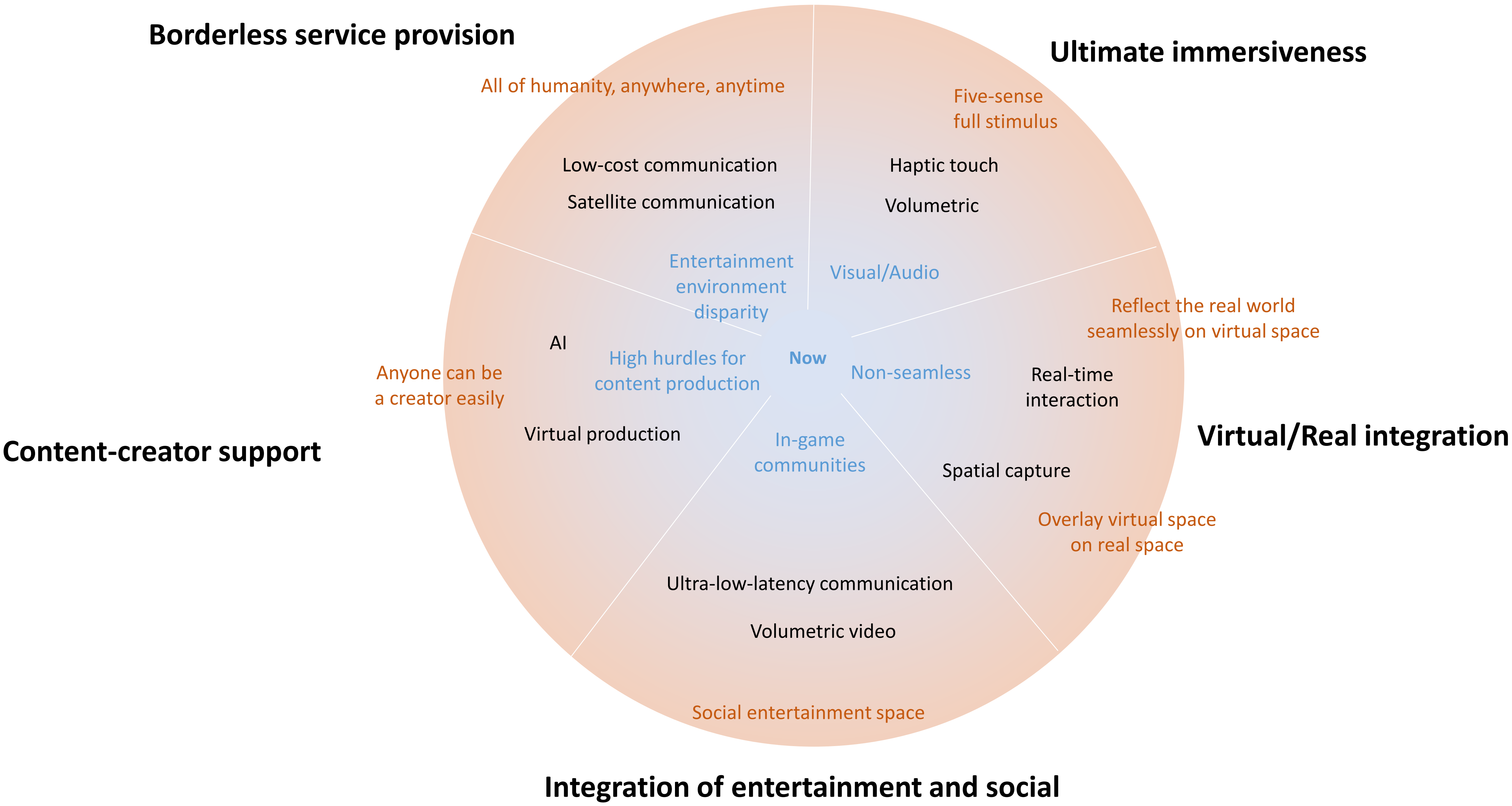
Example : Interactive Live Music Use Case

- High data rate : **48-200Gbps** (Raw data)
- Low latency : MTP*1 **10ms**, TTP*2 **70ms**

*1MTP: Motion To Photon
*2TTP: Time To Present



4.14 Entertainment and Leisure (2)



4.15.1 Space (1)

To protect the people's lives on earth, it is required to contribute to solving social issues by space utilization. By developing of space utilization technology, efforts to expand the living area and activity area to space are required.

Current Situation

- Space utilization is mainly preceded by national government, specific industries, R&D and satellite broadcasting
- New efforts are required by utilizing space and space development technology to solve social issues.

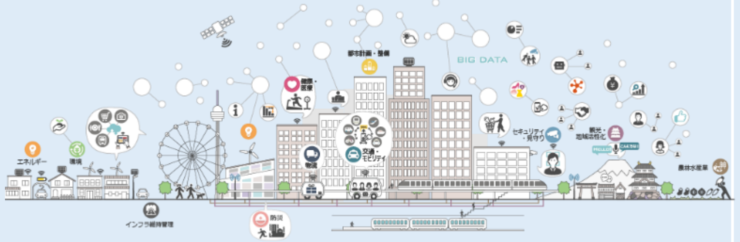
Challenges

- Japan's aging society and population decline
- Global warming, intensification of natural disasters
- Shift to clean energy, energy competition
- Increased pandemic risk and realization of "New normal"
- Realization of a society that affirms diverse ways of life

Future Vision

1. Communication to protect life

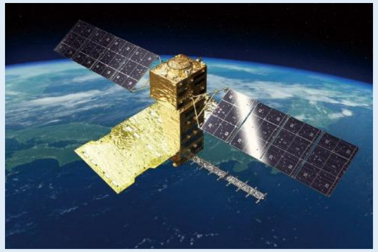
Smart communication infrastructure using space



Source: Smart City Public-Private Partnership Platform HP

2. Protect life by space data

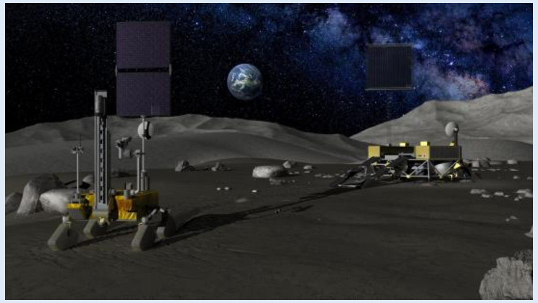
Space-generated data from a secure and resilient environment



Source: JAXA observation satellite HP

3. Utilization of space environment

Expanding the area of human activity to space



Source: JAXA

4. Adapt space to lifestyle

Realizing each diverse lifestyle using space

Source:JAXA/Adobe.stock.com

4.15.1 Space (2)

Ultra-fast and large capacity, universal coverage, ultra-security, resiliency and reliability, autonomy and ultra-low latency are required as requirements for 5G and beyond toward expected future image to protect the people's lives on earth.

What is required for Beyond 5G

Coverage extension to the sky, sea and space

Ultra-fast and large capacity(approximately <u>several dozens of Gbps</u> by low/medium earth orbit satellite), universal coverage, ultra-security, resiliency and reliability and autonomy as Beyond 5G's performance are required for smart cities and autonomous driving support.

Evolution of Application: Future / Now; Evolution of Capability: 4G/5G / Beyond 5G

4G/5G's Future
- ✓ **For specific industries such as aircraft**

Beyond 5G's Future
- ✓ **Universal coverage extension**
- ✓ **For all industries and integrates with terrestrial networks, or independent of terrestrial networks** (Ultra-fast and large capacity, Universal coverage, Ultra-security, resiliency and reliability, Autonomy)

4G/5G's Current
- ✓ **For mobile backhaul, for sea and air**

Beyond 5G's Current
- ✓ **For specific apps such as wide area robotics in spot areas**

Utilization platform for space data

Universal coverage, ultra-security, resiliency and reliability, autonomy and ultra-low latency as Beyond 5G's performance are required for utilization platform for data observed and generated in space.

Evolution of Application: Future / Now; Evolution of Capability: 4G/5G / Beyond 5G

4G/5G's Future
- ✓ **Past data processed from the terrestrial cloud using AES for individuals**

Beyond 5G's Future
- ✓ **Enhanced security with quantum cryptography technology** (Ultra-security, resiliency and reliability)
- ✓ **Beyond space real-time data by AI processing on the space data utilization platform for personal use** (Universal coverage, Ultra-security, resiliency and reliability, Autonomy, Ultra-low latency)

4G/5G's Current
- ✓ **Past data processed on the ground for enterprises**

Beyond 5G's Current
- ✓ **Beyond space slightly delayed enterprise data processed in a terrestrial cloud with stronger security than AES for corporate use**

AES(Advanced Encryption Standard)

4.15.1 Space (3)

Ultra-fast and large capacity, ultra-security, resiliency and reliability, ultra-low latency, universal coverage and ultra-low power consumption are required as requirements for 5G and beyond toward expanding the area of human activity to space and realizing each various lifestyle using space.

What is required for Beyond 5G

Utilizing space as a sustainable activity area

Ultra-fast and large capacity, ultra-security, resiliency and reliability as Beyond 5G's performance are required for utilization space as a human activity area (moon and/or planets) sustainably. In addition, since the installed resources are limited, it is vital to realize ultra-low power consumption.

Evolution of Application	4G/5G	Beyond 5G
Future	**4G/5G's Future** ✓ **Generalization of space travel** ✓ **Exploration and Utilization of space resource**	**Beyond 5G's Future** ✓ **Workcation at space, Emergency evacuation to space** ✓ **Autonomic operation of Space infrastructure, construction of space factory** (Ultra-fast and large capacity, Ultra-security and resiliency, Ultra-low power consumption)
Now	**4G/5G's Current** ✓ **R&D at ISS(*)** ✓ **Observation and reduction of space debris**	**Beyond 5G's Current** ✓ **Control space objects** ✓ **Detection of space debris and Collision avoidance by spacecraft**

Evolution of Capability

***ISS(International Space Station)**

Incorporating space/cyber into our lifestyle

Ultra-fast and large capacity, ultra-low latency, universal coverage as Beyond 5G's performance are required for cross-cultural communication by using space/cyber which has no border.

Evolution of Application	4G/5G	Beyond 5G
Future	**4G/5G's Future** ✓ **Constant internet access at spaceship** ✓ **Lunar trip by using avatar**	**Beyond 5G's Future** ✓ **Diverse lifestyle without affects of real world** ✓ **Simulated experience of life on the moon using VR Haptics** (Ultra-fast and large capacity, Ultra-low latency, Universal coverage)
Now	**4G/5G's Future** ✓ **Live broadcast from ISS** ✓ **Space trip by VR**	**Beyond 5G's Current** ✓ **Cross-cultural community formation without affects of place and/or time** ✓ **School trip to cyber "space"**

Evolution of Capability

Sustainable and Ultra-wide Coverage is required to address social issues raised in the SDGs

Current Situation and Challenges

- Several companies are already experimenting with stratospheric communications using various HAPS platforms. In order for HAPS to be widely adopted, following regulatory issues need to be addressed.
  - ✓ Aviation: International rules for the stratospheric flight, common compliance test procedures for HAPS aircraft.
  - ✓ Spectrum: Additional identification for HAPS in WRC-23(*), international scheme for frequency coordination with neighboring countries

* Candidate bands: 694-960MHz, 1710-1885MHz, 2500-2690MHz

Future Vision

①Efficient coverage for rural area

At an altitude of around 20 km, HAPS can provide ultra-wide coverage and connect directly to existing user terminals.

②Resilient NW to natural disasters

HAPS is invulnerable to weather and can move anywhere, providing a resilient NW in the event of natural disasters, such as Typhoon and Tsunami.

③Carbon neutral NW

HAPS can provide a zero-emission operation using solar, hydrogen or other energy sources.

Source: SoftBank Corp.

The unique capabilities for Beyond 5G are required to provide Sustainable and Ultra-wide Coverage

What is required for Beyond 5G

Applications

- **Connecting the unconnected**
  Efficient coverage extension to the unconnected or difficult-to-connect areas
- **Disaster recovery**
  Resilient NW that can continue to operate (or be quickly restored) in the event of natural disasters
- **Urban air mobility**
  3D coverage for urban air mobility such as flying cars and drones
- **IoT**
  Ultra-wide coverage for IoT such as sensors, home appliances, machines, and cars

Capabilities

- **Maximum Horizontal Coverage**
  Maximum radius of the area covered by a single base station (in km/BS).
  (Covering up to tens to hundreds of kilometers in radius.)
- **Maximum Vertical Coverage**
  Maximum altitude of the area covered by a single base station (in km/BS).
  (Covering around ten kilometers above ground.)
- **Carbon Neutrality**
  Capability to provide coverage area with zero carbon emissions during operation.

※It is assumed that the same devices used in terrestrial IMT systems can also be used, and the required latency are equivalent to those of eMBB usage scenario of IMT-2020.

4.15.3 Society （1）

Social infrastructure to review the social system according to population composition and to protect human lives and property from natural disasters

Current Situation

- The population continues to decline
- The ratio of people aged 65 and over to the total population is the highest in the world
- Natural disasters caused by climate change (e.g. typhoons, floods) and geographical factors(e.g. earthquakes, volcanoes)

Challenges

- How to solve for the labor shortage
- How to spend a long life meaningfully
- How to protect human lives and property from natural disasters

Future Vision

Labor force

Advances in capacity enhancement technologies and remote work will increase the number of workers and improve productivity

Transportation

Enhanced personal mobility and infrastructure system that allows individuals to go where they want to go

Disaster avoidance

Distribution all at once of personalized emergency bulletins according to personality, location and situation

Disaster assistance

Communication system capable of exchanging information without worrying about securing power supply or outside of service area even in case of disaster

4.15.3 Society （2）

Beyond 5G requires Ultra-fast and large capacity, Ultra-low latency, Ultra-security, resiliency and reliability, Autonomy and Coverage for its expected future realization, to solve social issues

What is required for Beyond 5G

Solving social issues / Creating a sense of purpose for life

Ultra-fast and large capacity, Ultra-low latency, Ultra-security, resiliency and reliability and Autonomy are required to ensure augmented reality technology, robotics and safety of personal mobility

Evolution of Application	4G/5G	Beyond 5G
Future	**The future industry with 4G/5G** • **Use of assist suits and robotics** • **Self-driving bus**	**The future industry with Beyond 5G** • **Wide range of ultra-immersive services** (Ultra-fast and large capacity, Ultra-low latency, Ultra-security, resiliency and reliability) • **Personal mobility & infrastructure** (Ultra-fast and large capacity, Ultra-low latency, Autonomy)
Now	**The current industry with 4G/5G** • **IoT Watch** • **Health management app**	**The current industry with Beyond 5G** • **Evolution of remote working with XR and immersive education** • **Secure and fair communications infrastructure**

Evolution of Capability

Measures for aging and declining population in Beyond 5G era

Reducing damage / Protecting lives and properties

Autonomy, Coverage, Ultra-fast and large capacity, and Ultra-security, resiliency and reliability are required for simultaneous distribution of full-personalized emergency bulletins and information sharing in disasters, and guaranteeing more than 10Mbps at anytime and anywhere should be required.

Evolution of Application	4G/5G	Beyond 5G
Future	**The future industry with 4G/5G** • **Improvement of prediction accuracy with evolution of prediction/sensing technologies** • **Utilization of SNS**	**The future industry with Beyond 5G** • **Personalized emergency bulletins** (Universal coverage) • **Resilient communication system for safe evacuation** (Ultra-security, resiliency and reliability, Autonomy, Universal coverage, Ultra-fast and large capacity)
Now	**The current industry with 4G/5G** • **IoT infrastructure monitoring** • **Portable base station**	**The current industry with Beyond 5G** • **Communication satellite and HAPS base station** • **Distributed network topology**

Evolution of Capability

Measures for natural disasters in Beyond 5G era

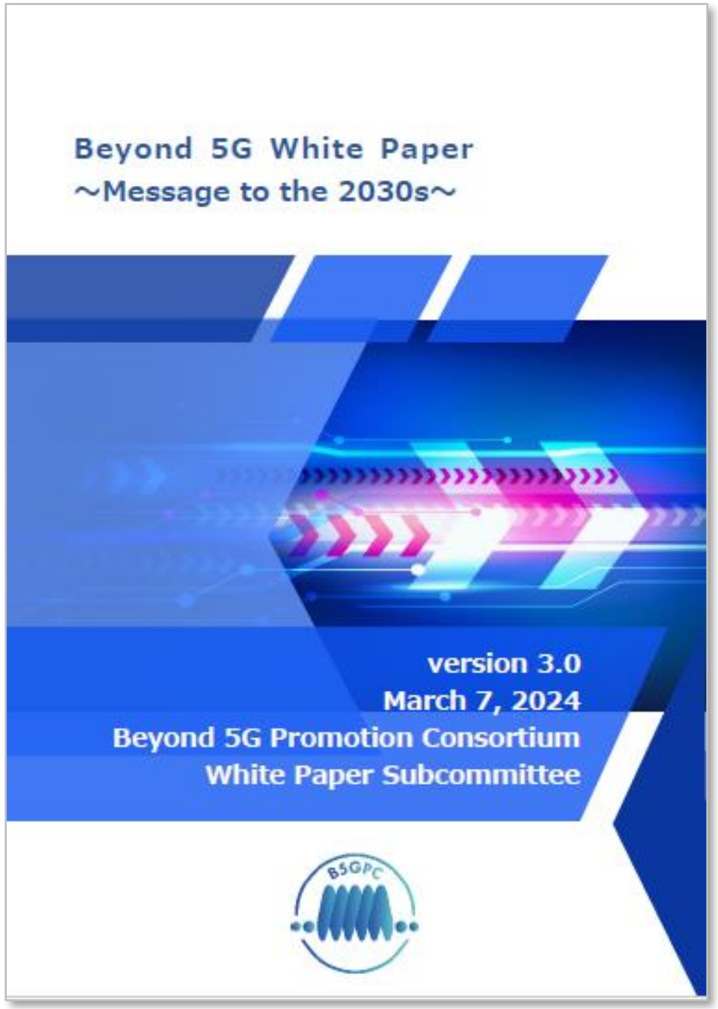
Beyond 5G White Paper (ver.3.0)
～Message to the 2030s～
【Beyond 5G technologies】

Technology Working Group, Spectrum Working Group
White Paper Subcommittee, B5GPC

Mar. 7, 2024

Table of Contents (Target KPIs and Technology trends)

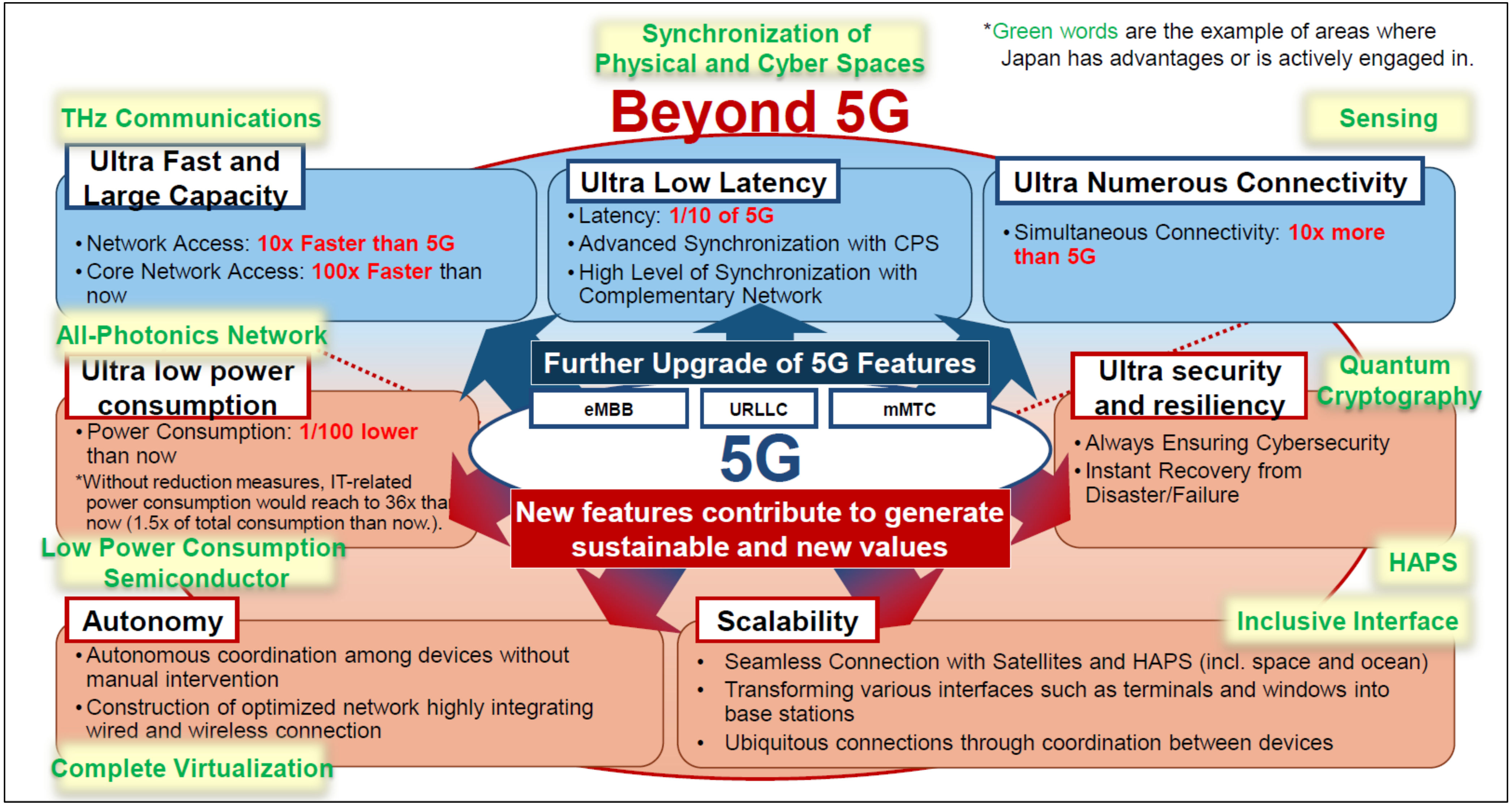
UPDATE on Version 3.0



https://b5g.jp/en/output/

UPDATE on Version 2.0

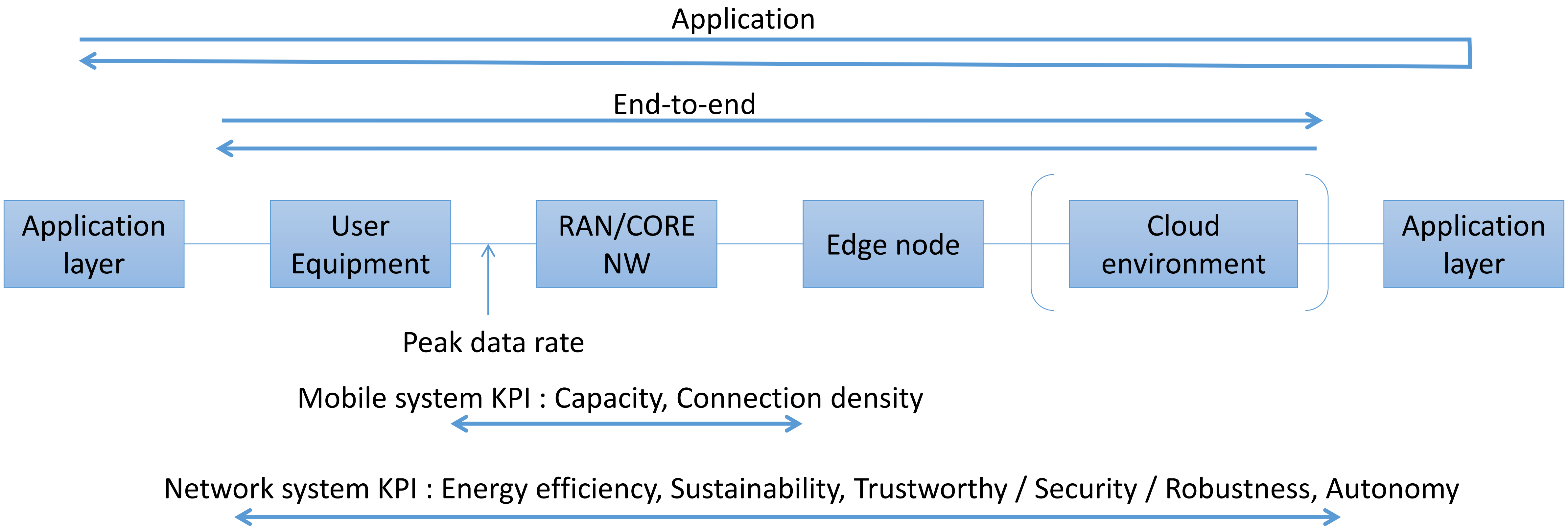
5.3.1 Key Features for Beyond 5G



"Beyond 5G Promotion Strategy Roundtable Recommendations", Beyond 5G Promotion Strategy Roundtable (June 2020).

5.3.2 Consideration of Target Key Performance Indicators for Beyond 5G

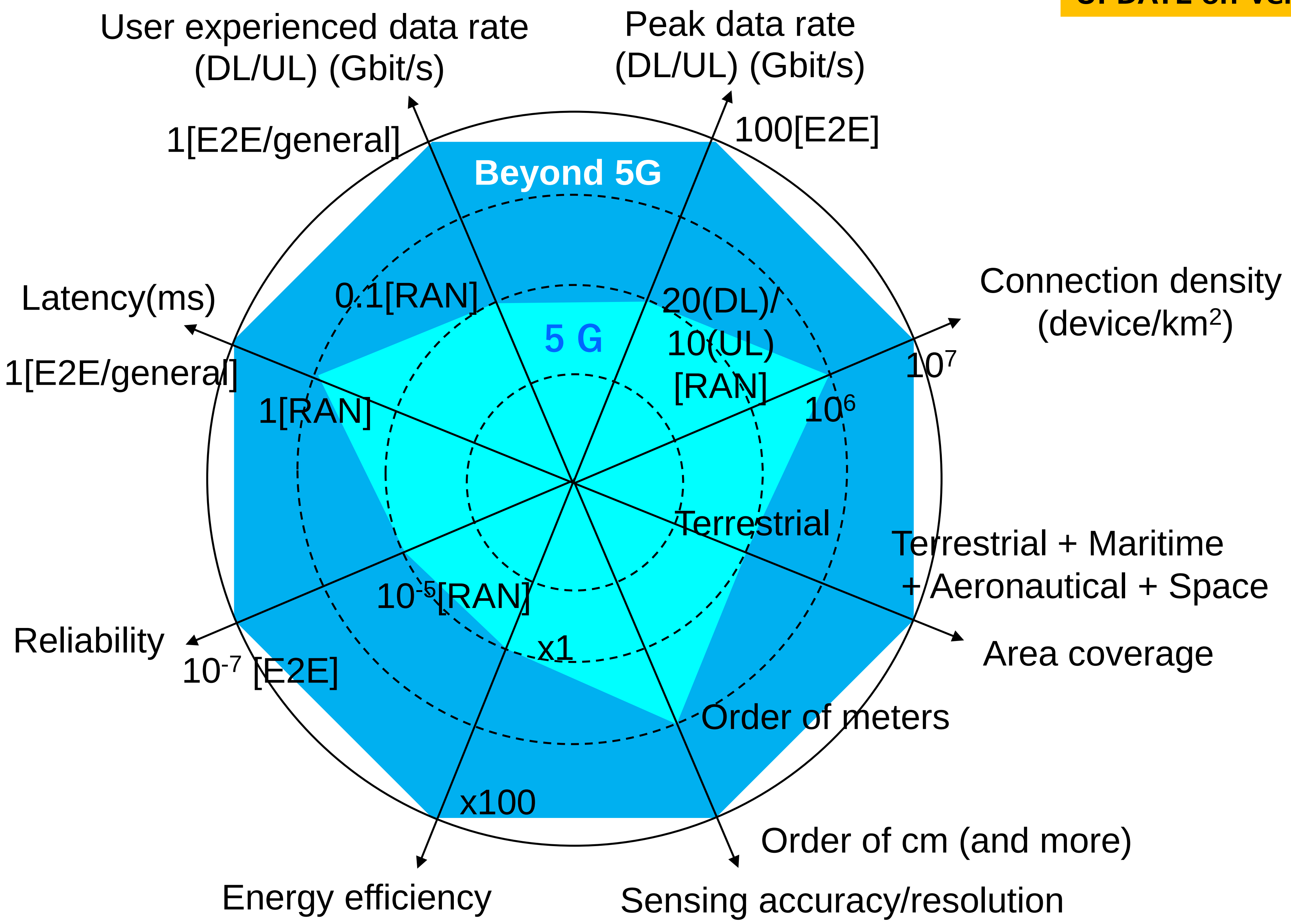
User experienced KPI (end-to-end): Data rate, Latency/Jitter, Reliability, Coverage, Mobility, Position accuracy



Applicable parts of the target KPIs

5.3.2 Target KPIs for Beyond 5G (Quantitative indicators)

UPDATE on Version 2.0



5.3.2 Target KPIs for Beyond 5G (Qualitative indicators)

UPDATE on Version 1.5

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

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 speed in all workflows, from construction to operation

Scalability

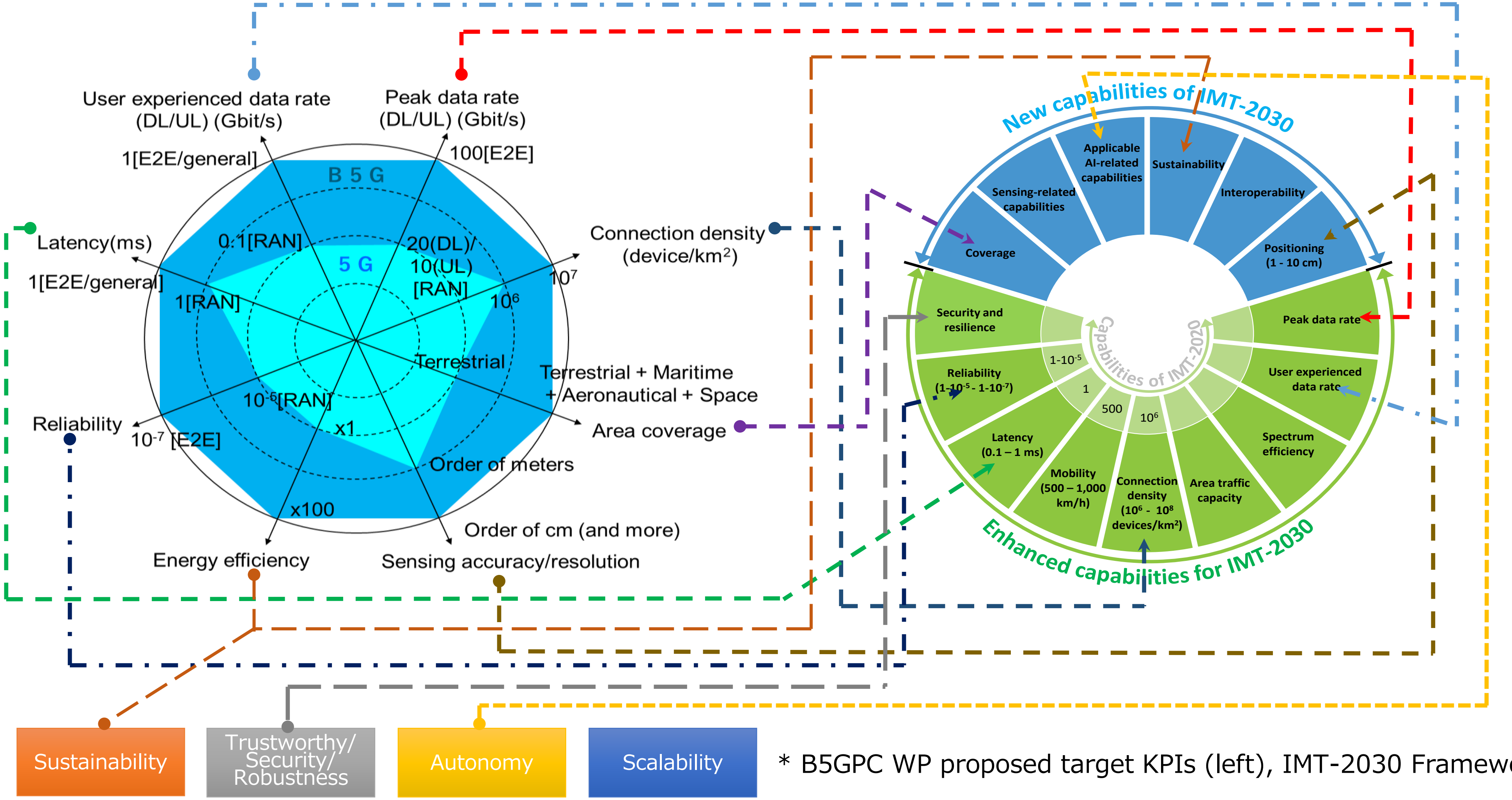
- Seamless connections with satellites and HAPS
- Communications within buildings (Via Terminals, windows, etc. as base stations)
- Open interfaces (Network API, application API)
- Network sensing/Wireless sensing

5.3.3 Comparison with ITU-R Recommendation

UPDATE on Version 3.0

All items except for "scalability" in proposed target KPIs are reflected in the IMT-2030 Framework. The major differences are following.

- **B5GPC WP: scope is "End-to-End" vs. IMT-2030 Framework: scope is "air interface"**
- **B5GPC WP: "one" target value vs. IMT-2030 Framework: "wide range" value (e.g., 50～200 Gbps)**



* B5GPC WP proposed target KPIs (left), IMT-2030 Framework capabilities (right)

5.3.3 Comparison between B5GPC WP and IMT-2030 (quantitative)

UPDATE on Version 3.0

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. 300Mbps, 500Mbps possible example
Latency (msec, E2E/general)	1ms (E2E/general)	Latency (air interface)	0.1 – 1 ms
Reliability (E2E)	10^{-7} (E2E)	Reliability (air interface)	from $1\text{-}10^{-5}$ to $1\text{-}10^{-7}$
Sensing accuracy/resolution	Order of cm (and more)	Positioning	1 – 10 cm
Connection density (device/km^2)	10^7 devices/km^2	Connection Density	10^6 – 10^8 devices/km^2
Area coverage	Terrestrial + Maritime + Aeronautical + Space	Coverage	(no specific value)
Energy efficiency	x100	Energy efficiency (quantifiable metric of sustainability) (bit/Joule)	(no specific value)
(not listed)	-	Spectrum efficiency	Greater than IMT-2020. e.g. x1.5 and x3
(not listed)	-	Area traffic capacity	Greater than IMT-2020. e.g. 30 Mbit/s/m^2 and 50 Mbit/s/m^2
(not listed)	-	Mobility	500 – 1 000 km/h
(not listed)	-	Sensing-related capabilities	(no specific value)

5.3.3 Comparison between B5GPC WP and IMT-2030 (qualitative)

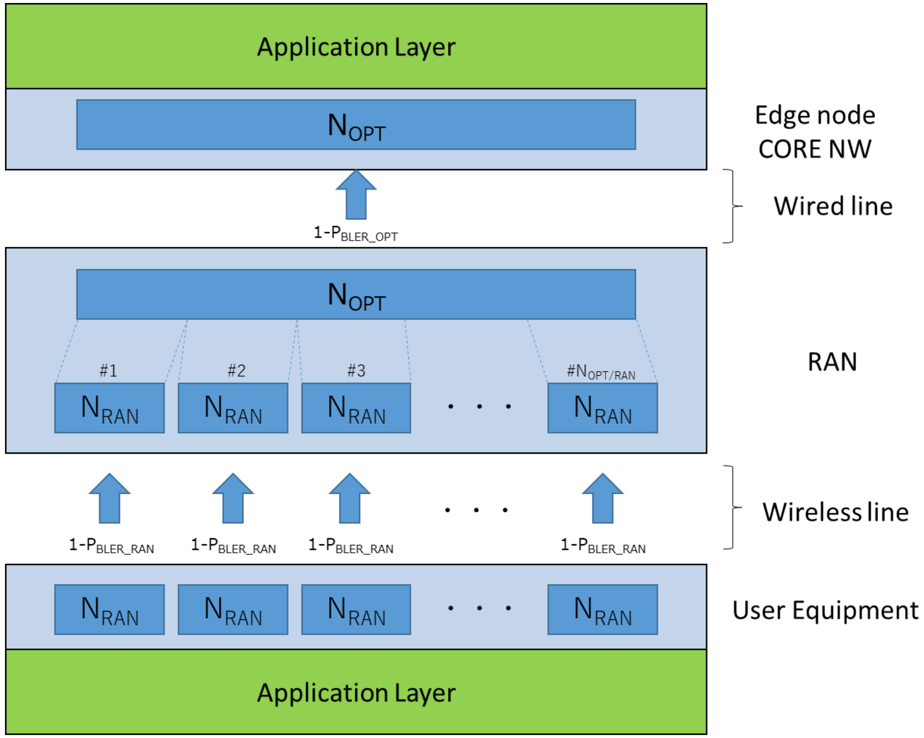
UPDATE on Version 3.0

B5GPC White paper		IMT-2030 Framework	
Sustainability	• Reduce the environmental impact of equipment • Equipment longevity • Carbon neutrality	Sustainability (environmental sustainability)	the ability of both the network and devices to minimize greenhouse gas emissions and other environmental impacts throughout their life cycle
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: - preservation of confidentiality, integrity, availability of information - protection of networks, devices and systems against cyberattacks. Resilience: - continue operating correctly during and after a natural or man-made disturbance.
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 • Open interfaces • Network sensing /wireless sensing	(not listed)	-
(not listed)	-	Interoperability	the radio interface being based on member-inclusivity and transparency, so as to enable functionality(ies) between different entities of the system

Appendix Example of decomposition analysis of "Reliability" into RAN and CN

UPDATE on Version 2.0

An examination of the transmission quality required for the wireless and the wired transmission sections to achieve the required end-to- end transmission quality of 10^{-7} in the constituting transmission system.



Example of End-to-End Packet Transmission Quality and Wired and Wireless Transmission Quality analysis

N_{RAN}	P_{BLER_RAN}	$1\text{-}P_{BLER\_RAN}$	$N_{OPT/RAN}$	P_{BER_OPT}	P_{BLER_OPT}	$1\text{-}P_{BLER}$
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%

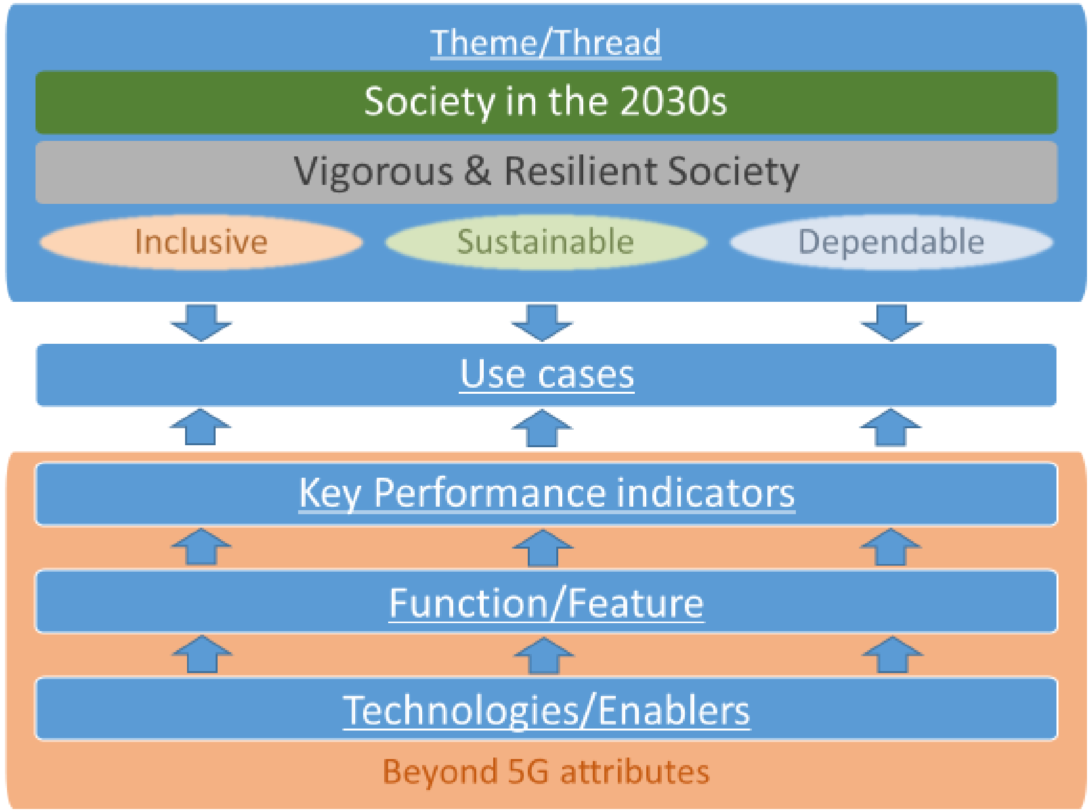
6. Technology trends

6.1 Observations of technology trends towards Beyond 5G

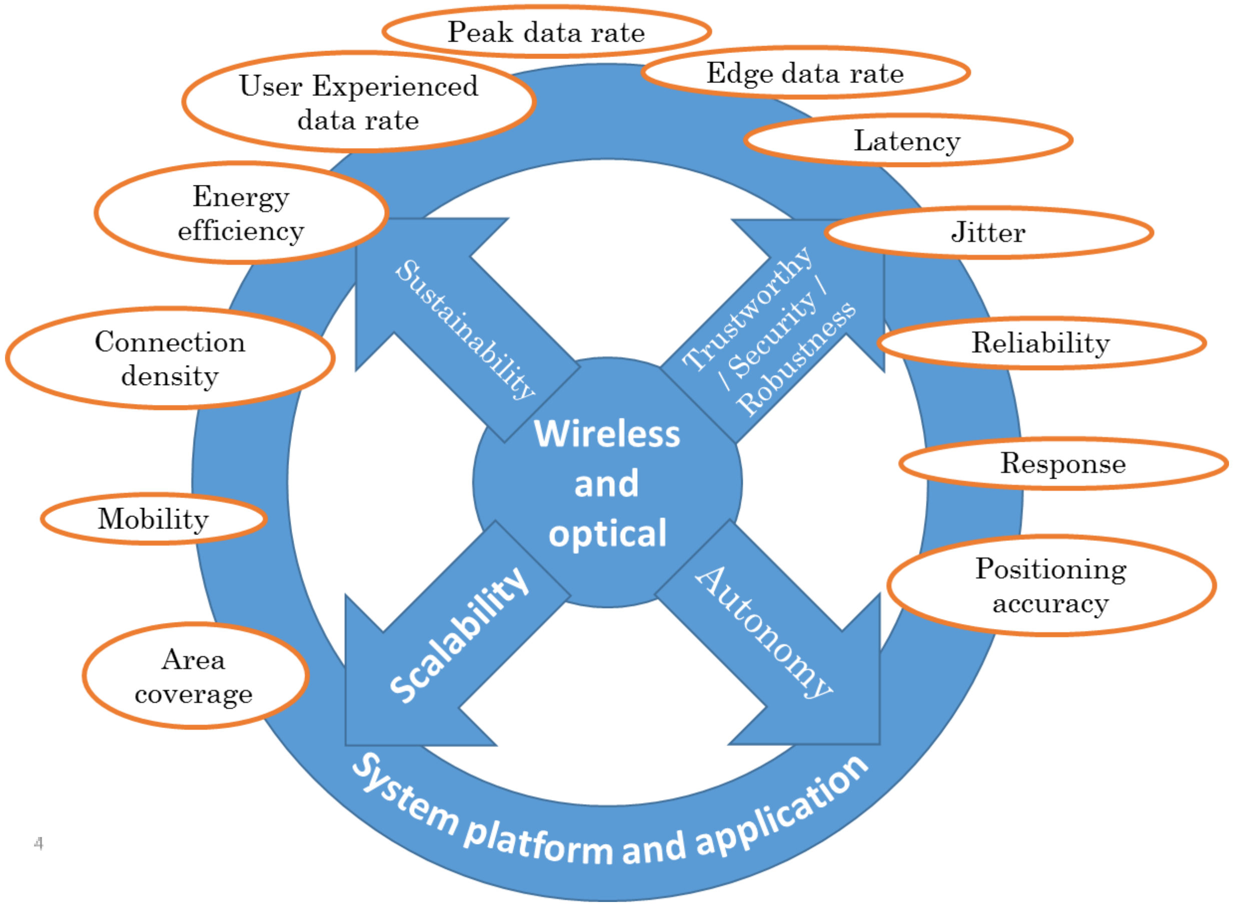
As mentioned in the previous chapters, various efforts are being made to develop technologies for Beyond 5G in order to meet the market demands and expectations for the 2030s and to contribute to the achievement of the target KPIs described in Chapter 5.2. Before going into the role of these technologies and their implications in Chapter 6.2-6.8, we describe an overview of market demand and deployment below, and also touch upon the perspective of Global Commons.

6. Technology trends

6.1.1 Market demands



Technologies and enablers supporting societies in the 2030s



Technologies supporting the Target Key Performance Indicators

6. Technology trends (6.2 to 6.8)

UPDATE on Version 3.0

6. Technology trends

6.1 Technology trends towards Beyond 5G

6.2 Beyond 5G Architecture

6.3 Technical aspect of radio spectrum

6.4 System Platform and Application

6.5 Trust-enabling technologies (security, privacy, reliability, resilience)

6.6 Network energy efficiency enhancement

6.7 Network coverage extension via non-terrestrial networks (NTN)

6.8 Wireless and optical

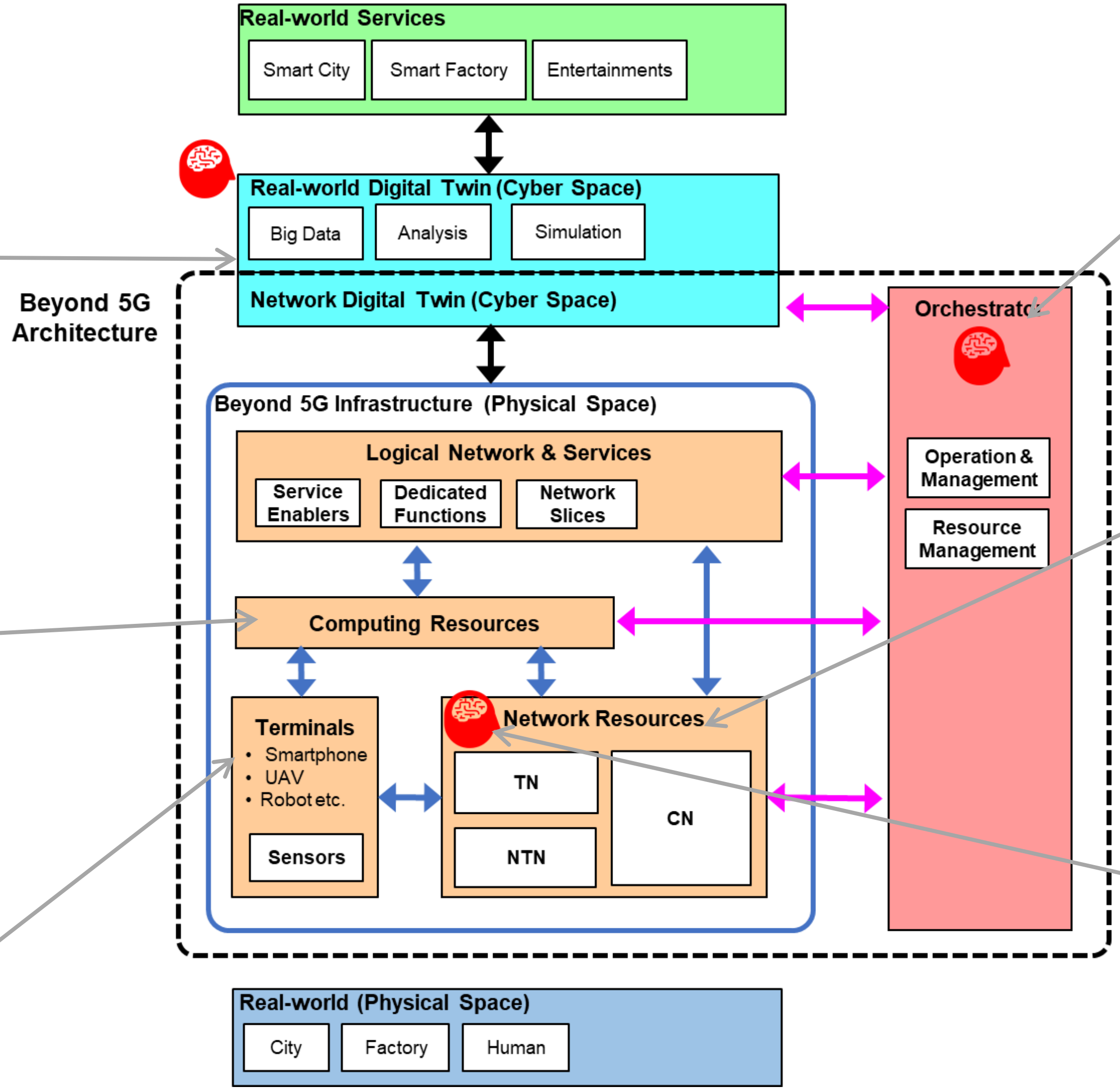
6.2 Beyond 5G Architecture

Beyond 5G Architecture enables efficient provision of communication and services using Beyond 5G Infrastructure.

(1) Providing Network Resources and Computing Resources functions through the collaboration of Real-world Digital Twin for society and Network Digital Twin for infrastructure.

(2) Providing not only network functions, but also Computing Resources that are distributed throughout the entire infrastructure on-demand.

(3) “Users” who use terminals are included not only human but also realization of things and services.



(4) Providing autonomous management, optimization and fault tolerance for the entire infrastructure.

(5) Providing user-centric communication, where necessary communication functions are secured from the Beyond 5G infrastructure based on User intent.

(6) AI applies wide range, including not only controls of operation & management and resource management, but also optimization of entire infrastructure and inside of communication systems such as radio links.

TN: Terrestrial Network, NTN: Non-Terrestrial Network, CN: Core Network

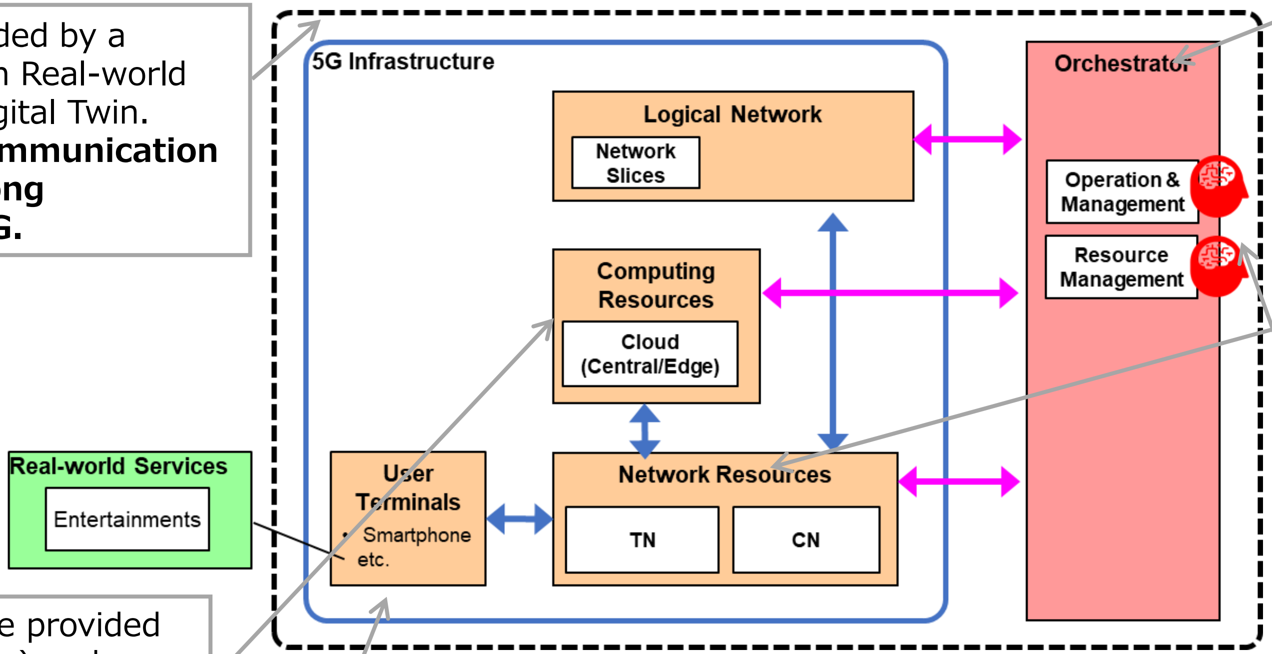
6.2.1 Beyond 5G Architecture: Differences from 5G

UPDATE on Version 3.0

Main differences between 5G and Beyond 5G

	5G	Beyond 5G	Relation
Digital Twin	Communications only	Strong collaboration	(1)
Infrastructure control	Each element	Entire infrastructure optimization	(2)(4)(6)
User	Mainly human	Human, things, and services	(3)
Center of control	Network	User	(5)

(1) Digital Twin is not provided by a strong collaboration between Real-world Digital Twin and Network Digital Twin.
⇒ **5G is only used as a communication links, and it is not the strong collaboration in Beyond 5G.**



(2) Computing Resources are provided only by Cloud (Central / Edge) and are used only for providing network functions.
⇒ **Integration of network and computing resources in Beyond 5G is not implemented.**

(3) Main services in 5G is for humans such as smart phones, and IoT devices are handled as user terminals.
⇒ **Terminals will be integrated into various users (humans, things, and processes) in Beyond 5G.**

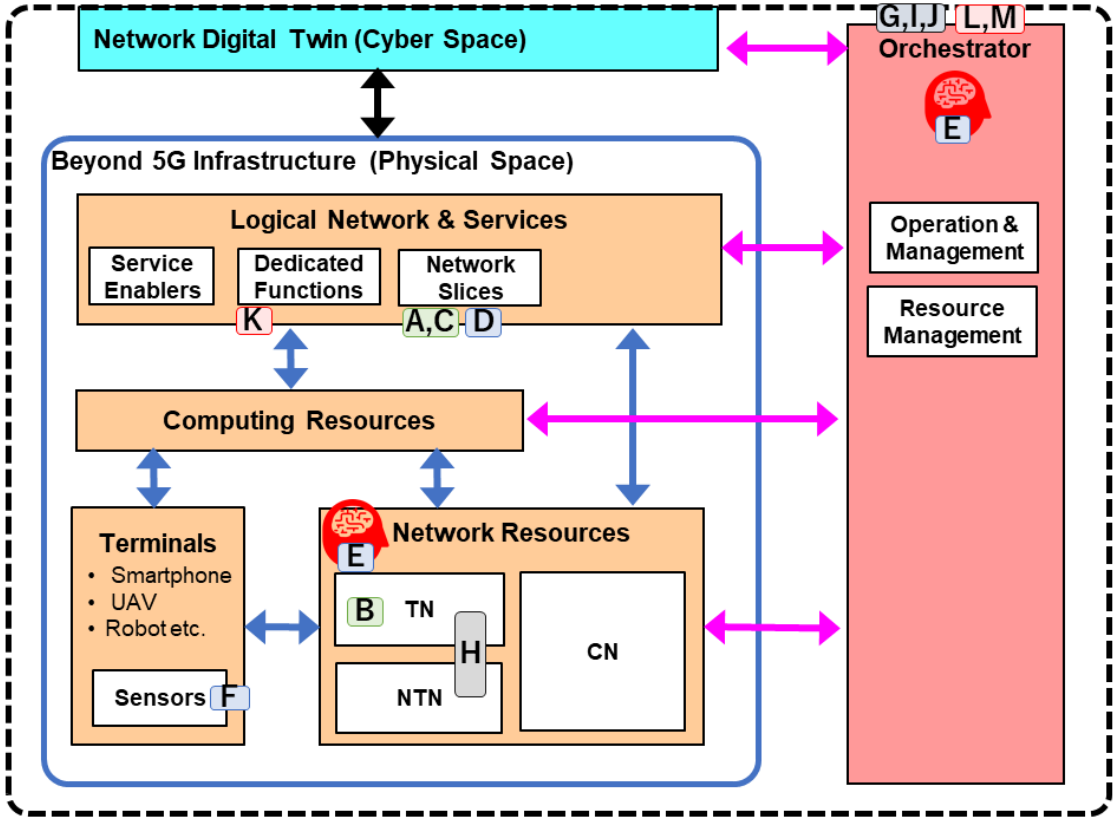
(4) Orchestrator controls Operation & Management and Resource Management individually. Optimization of the entire infrastructure is not provided.
⇒ **In Beyond 5G, Orchestrator will optimize through the entire infrastructure to collaborate with Digital Twin.**

(5) Networks are mainly provided by TN and CN. Controls are performed based on network convenience and it is not user-centric.
⇒ **In Beyond 5G, communications will be realized based on both user-centric and application optimization.**

(6) AI is used for individual controls and does not optimize the entire communication system. Its utilization in the infrastructure is limited.
⇒ **In Beyond 5G, AI will be utilized for controlling the entire communication system and in various places such as within the communication system.**

6.2.1 Beyond 5G Architecture: Usage Scenarios and Overarching Aspects

- The contents of use case in this white paper are reflected as a use case scenario of IMT-2030 in ITU-R framework recommendation (Rec. M.2160-0) (see: 5.2.2). We can know feasibilities by mapping functions in Beyond 5G architecture to IMT-2030 use case scenario.
- The main functions of Beyond 5G architecture can be mapped to the usage scenarios and overarching aspects of IMT-2030 (A to J in this figure), making it possible to realize all items.
- The original feature of Beyond 5G architecture is as follows:
  - User/Network functions (K)
    Providing high real-time/wideband applications and AI inference to Terminals with various capabilities on demand through dedicated functions.
  - User Intent (L)
    Providing communication functions for humans, things, and services by a user-centric network based on a specific intent of user.
  - Autonomy (M)
    Realization of advanced infrastructure with minimal effort by automation and AI utilization.



Implementation of IMT-2030

[6 Usage scenarios]
Extension for IMT-2020
A) Immersive Communication
B) Massive Communication
C) HRLLC (Hyper Reliable & Low-latency Communication)
New
D) Ubiquitous Connectivity
E) AI and Communication
F) Integrated Sensing and Communication

[4 Overarching Aspects]
G) Sustainability
H) Connecting the unconnected
I) Ubiquitous Intelligence
J) Security/Resilience

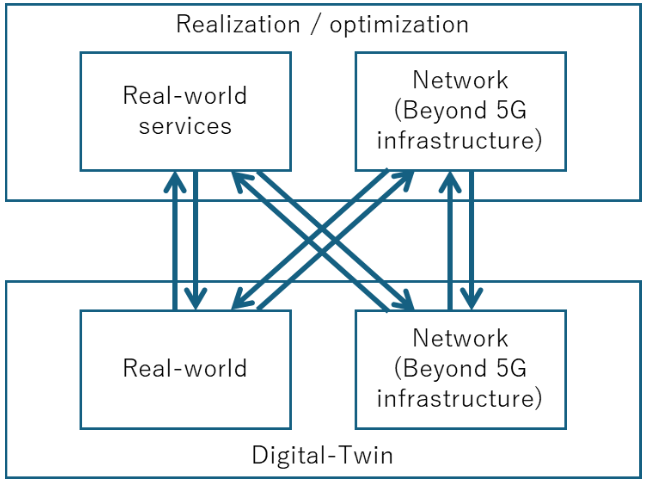
Additional of IMT-2030
(Original of this architecture)
K) User/Network function
L) User Intent
M) Autonomy

6.2.2 Beyond 5G Architecture: Enabling Technologies

UPDATE on Version 3.0

(1) Management of Digital Twins

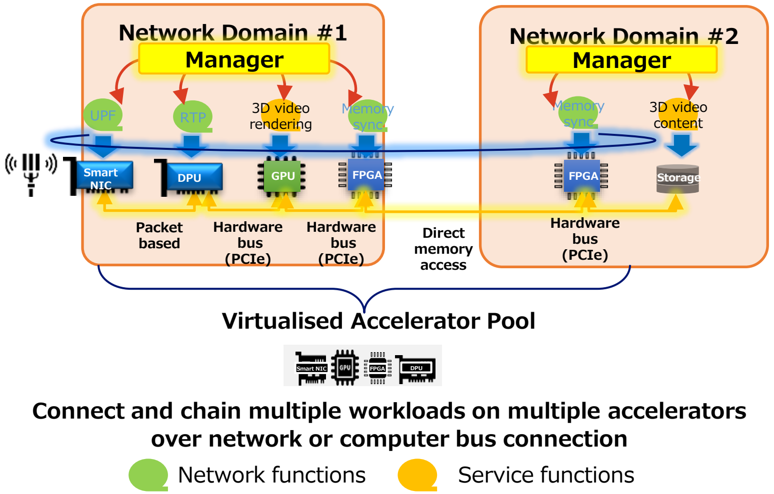
- Network technology and real-world services co-evolve through integrated use of network and real world digital twins
- Cross-domain orchestration drive the evolution of large-scale, wide-area, cross-industry services.



Digital Twin of Real Space and Beyond 5G Infrastructure

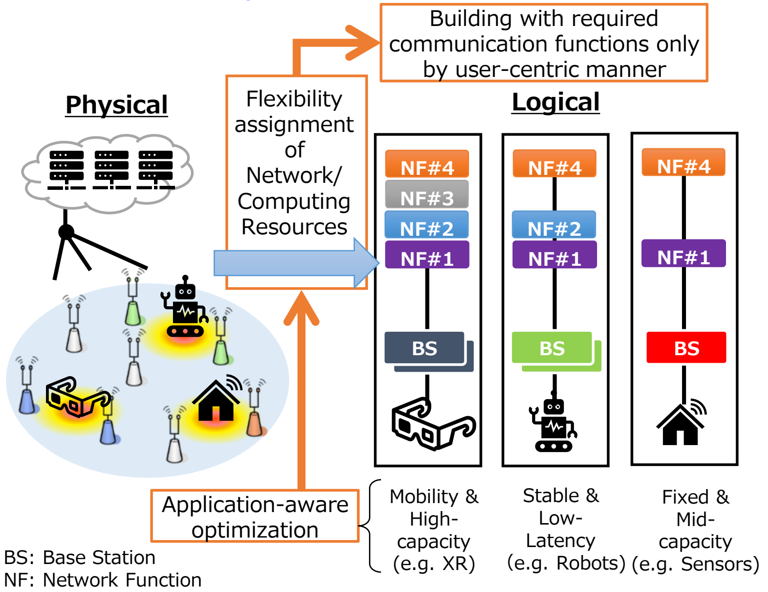
(2) Integration of network functions and computing resources

- This network architecture can provide the virtual computing resource as a network endpoint.
- The technology of network transport is employed APN (All Photonic Network).
- Computing resources have deployed in different network domain as virtualized one computing resource via presence.



(3) User-centric and application aware network technologies

- The technologies can provide communications required by both users (humans/things/services) and applications.
- Those are realized through User-centric network and Application-aware network optimization.



See paper of Volume and Supplementary Volume on "E2E Architecture" in detail

https://b5g.jp/w/wp-content/uploads/2024/03/Beyond-5G-White-Paper-Supplementary-Volume-E2E-Architecture.pdf

6.2.2 Beyond 5G Architecture: Enabling Technologies

UPDATE on Version 3.0

(4) Orchestrator

- Beyond 5G Orchestrator is responsible for the control of the entire Beyond 5G architecture.
- It quickly provides the optimal infrastructure functions for each service and optimize whole Beyond 5G.
- Furthermore, it enables the system and end-to-end fault tolerance which does not halt social systems in the event of a failure.

(5) Network AI Architecture

The architectural concept of Network for AI (NET4AI) integrates communication, computing, and sensing functions.

AI as a Service (AIaaS) can be easily provided from this AI native Architecture.

Three key enablers are shown as;
(a) Requirements for NW AI Archi.
・Towards Network AI from Cloud AI
・Coordinated ICDT infrastructure
・Organized secure Network
・Development of flexible AI
(b) Task-oriented architecture
(c) OP &Management of AI services

(6) System Architecture and Migration towards Beyond 5G

- Architectural tenets for Beyond 5G system design and migration are analyzed.

  a) Lessons learnt from 5G standardization and deployment
  b) Enablers for system architecture design and network migration
  c) Interworking with legacy systems
  d) RAN – CN separation and interface
  e) Logical RAN architecture

See paper of Volume and Supplementary Volume on "E2E Architecture" in detail
https://b5g.jp/w/wp-content/uploads/2024/03/Beyond-5G-White-Paper-Supplementary-Volume-E2E-Architecture.pdf

6.2.3～5 Beyond 5G Architecture: Applications

UPDATE on Version 3.0

- **6.2.3 User-centric and application aware network technologies**
  - In various communication environments, technologies that can flexibly provide networks according to each demand of “Users" (including people, things, and processes) and “Applications" is necessary to ensure reliable provision.
  - User-centric networks and Application-aware network optimization are those enabler.

- **6.2.4 Autonomous Network**
  Network operation for Beyond 5G will achieve full automation (automation level 5) that simultaneously satisfies labor savings, flexibility, and speed in all workflows from construction to operation.

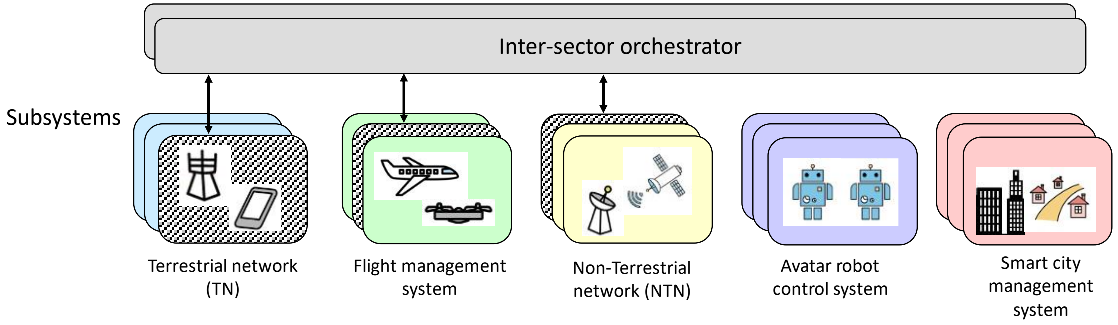
  Network Autonomous Operation Values:

  (1) Rapid provision of network functions based on business requirements.

  (2) One-stop end-to-end network provision across applications/IT/network.

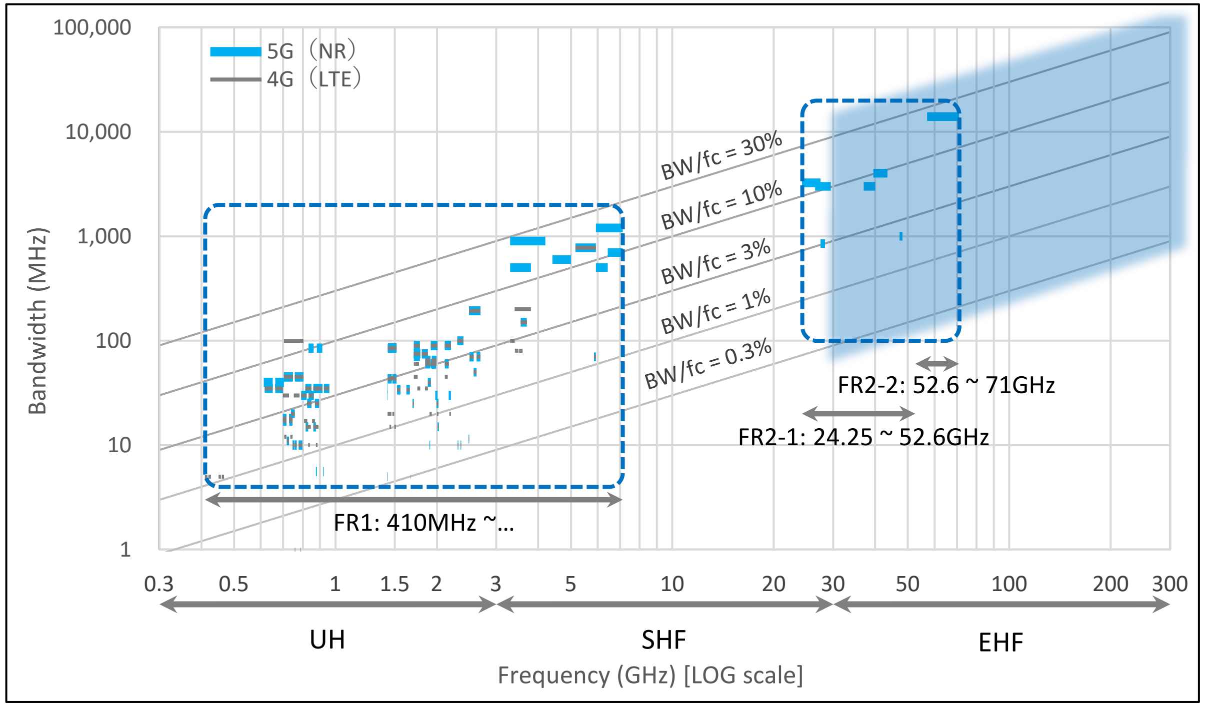
  (3) Autonomous decision making that does not require detailed instructions by humans

- **6.2.5 Resilience**
  To ensure fault tolerance not only for network resilience but also for various systems, orchestration of subsystems across sector boundaries is necessary.

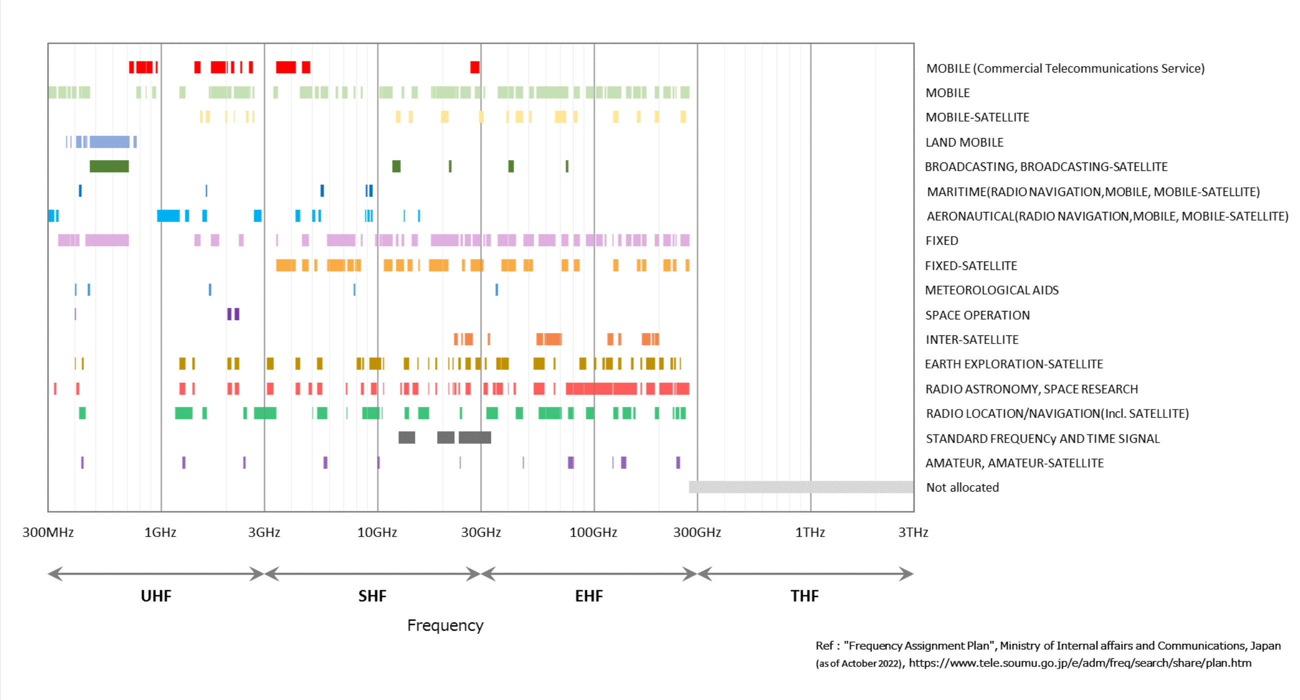


6.3.1 Trends in radio frequency resource utilization

UPDATE on Version 3.0



Frequency bands defined for 4G and 5G in the 3GPP specifications [1] [2] [3]



Frequency assignments in Japan [4]

[1] 3GPP TS 36.101, (V18.0.0), “E-UTRA; User Equipment (UE) radio transmission and reception”, 2022-12.
[2] 3GPP TS 38.101-1, (V18.0.0), "NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone", 2022-12.
[3] 3GPP TS 38.101-2, (V18.0.0), "NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone", 2022-12.
[4] Ministry of Internal affairs and Communications, "Frequency Assignment Plan", (as of Aug. 2022).

6.3.1 Trends in radio frequency resource utilization

UPDATE on Version 3.0

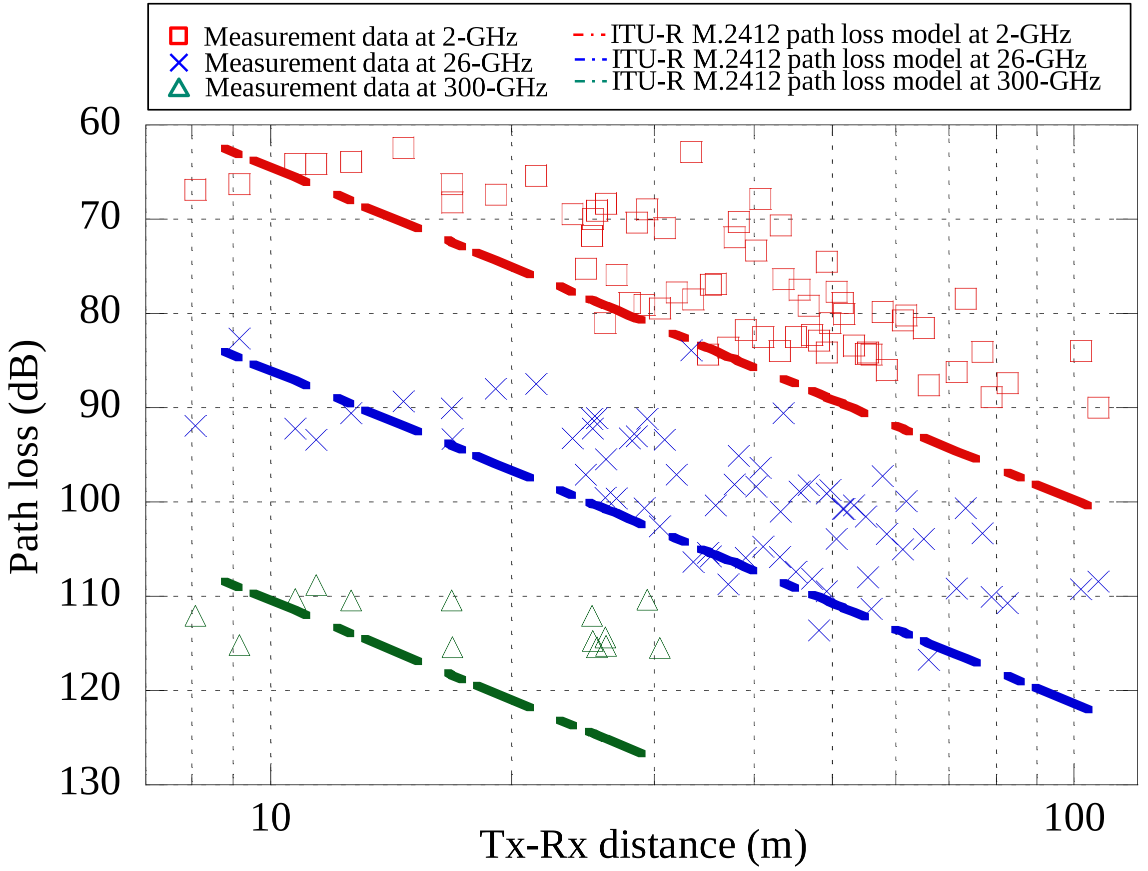
- The use of Beyond 5G frequency bands has been studied in ITU-R, APT and the fora in other countries.
    - New frequency resources beyond 6 GHz band, mmWave, and Terahertz, which enable further broadband, and
    - It is also important to use the existing frequency bands below 6GHz and the new bands together.

- Results of WRC-23 (World Radiocommunication Conference 2023)
    - 6425 – 7125 MHz（WRC-23 Agenda Item 1.2）
    - 7125 – 8400 MHz、14.8 - 15.35 GHz（WRC-27 Agenda Item 1.7）

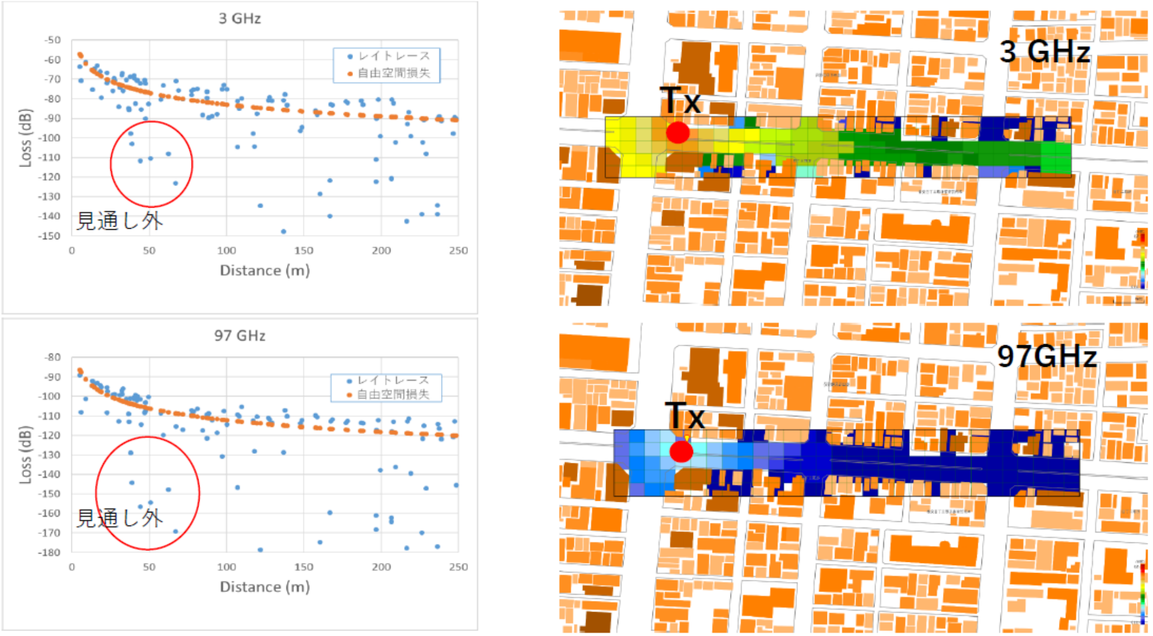
- Investigation on domestic use of 7125 – 8400 MHz and 14.8 - 15.35 GHz
    - Existing radio systems, the number of radio stations of them, and so on
    - It is important to study compatibility with the existing radio systems.

6.3.2 Studies related to Radio Propagation [1/3]

UPDATE on Version 3.0



Measurement of path loss characteristics [1][2]



Ray-tracing and free-space propagation model comparison (Outdoor street canyon) propagation[4]

[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).

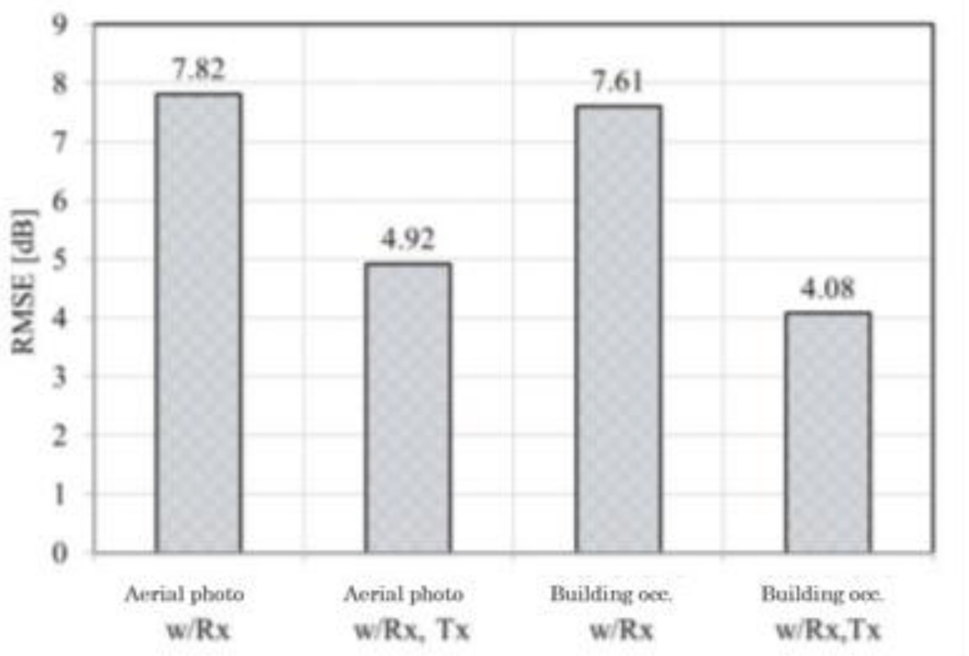
[2] M. Inomata et.al, "Path Loss Characteristics from 2 to 100 GHz Bands in Urban Microcell Environment for 6G," IEICE Technical Report, A·P2021-51 (2021-08).

[3] ITU-R M.2412, "Guidelines for evaluation of radio interface technologies for IMT-2020," Sep. 2017.

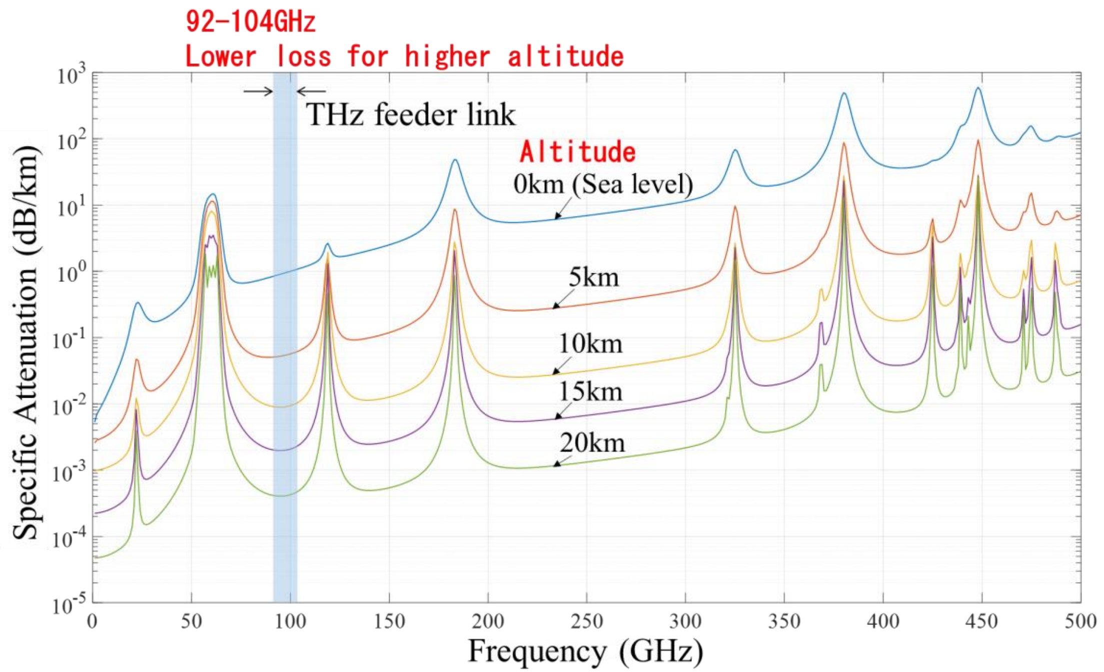
[4] Y. Oda, "Technical study on radio wave propagation characteristics of Terahertz wave", Planning and Strategy Committee of Beyond 5G Consortium, (in Japanese, Feb. 2021).

6.3.2 Studies related to Radio Propagation [2/3]

UPDATE on Version 3.0



Root mean square error (RMSE) from the measurement results[1][2][3]



Propagation losses due to atmospheric gases and related effects[4][5]

[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," 202014th 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.

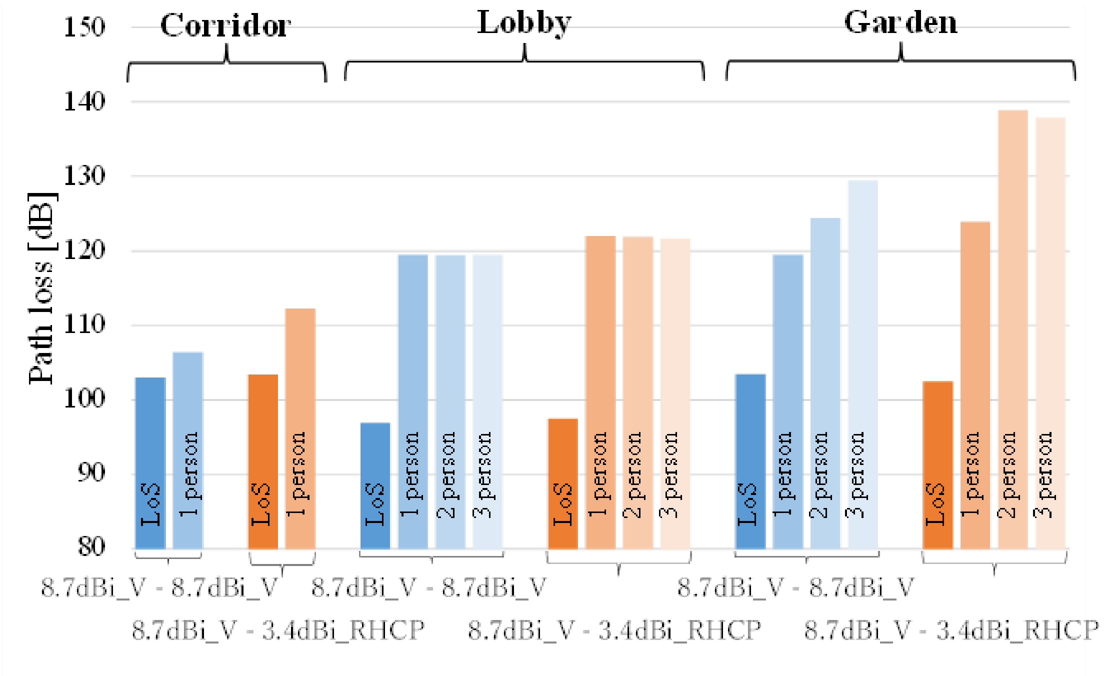
[3] T. Nagao and T. Hayashi, "Geographical Clustering of Path Loss Modeling for Wireless Emulation in Various Environments," [Manuscript submitted for publication] 2022 15th European Conference on Antennas and Propagation (EuCAP), 2022.

[4] Kawanishi et.al, "THz communications for non-terrestrial-networks," Proc. IEICE Gen. Conf. 2022, CI-7-2, Mar. 2022.

[5] Recommendation ITU-R P.676-12(2019), Attenuation by atmospheric gases and related effects.

6.3.2 Studies related to Radio Propagation [3/3]

UPDATE on Version 3.0



Indoor propagation characteristics in the 300 GHz band [1][2]
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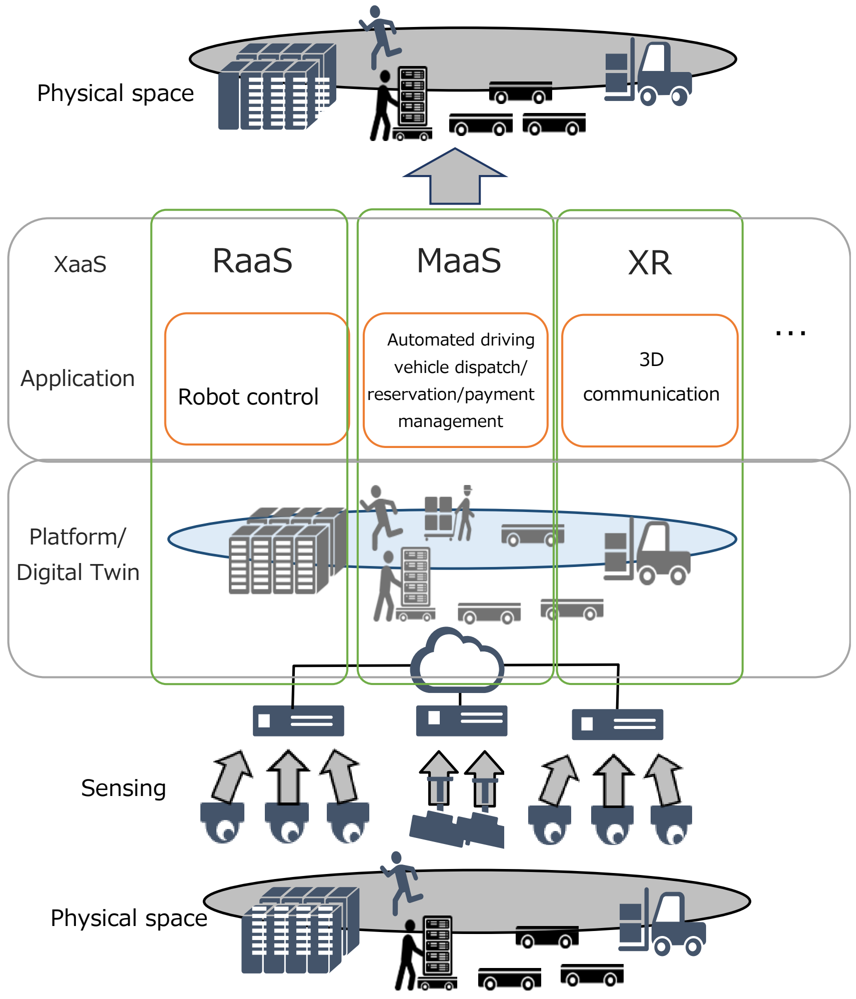
[1] S. Nishi, et. al., "A 280 GHz Circular Polarized 4x4 Elements Antenna Array", 2022 the 9th International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications, Aug. 2022.

[2] K. Tamesue, et. al., "300GHz Indoor Propagation Measurement, Simulation and Characterization", 2022 the 9th International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications, Aug. 2022.

6.4 System Platform and Application

UPDATE on Version 3.0



Service (XaaS) and Platform/Application technologies in CPS

＊ A part of figures is provided by NEC.

Promotion of Society 5.0

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).

- ■ Considerations of communication infrastructure technology and associated platform and application technology.

Examples of fundamental technologies for XaaS in CPS

- Estimation of object location and posture with the digital twin
- Object recognition/identification with the digital twin
- Real-world prediction using the digital twin
- Robot control for safety, acceptability, and efficiency
- Physical space reconstruction and augmentation
- Multimodal interaction

6.5 Trustworthiness (Security, Privacy, and Resilience)

UPDATE on Version 3.0

- **Network trust-enabling technologies (ultra-secure and reliable network technologies) (6.3.1)**
  - **Technologies related to the design of Beyond 5G networks to enable trust**
  - **Technologies related to the operation of Beyond 5G networks to enable trust**
  - **Technologies related to 5G network security management to enable trust**

- **Trust-enabling technologies related to other Beyond 5G features (6.3.2)**
  - **Ultra-fast and large capacity**
  - **Ultra-low latency**
  - **Ultra-massive connectivity**
  - **Ultra-low power consumption**
  - **Autonomy**
  - **Scalability**

Security considerations for seven Beyond 5G features (Revision of [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

[1] Yutaka Miyake, "International Coordination in the R&D (4) Security," Beyond 5G International Conference. Nov. 10, 2021.

6.6 Network energy efficiency enhancement

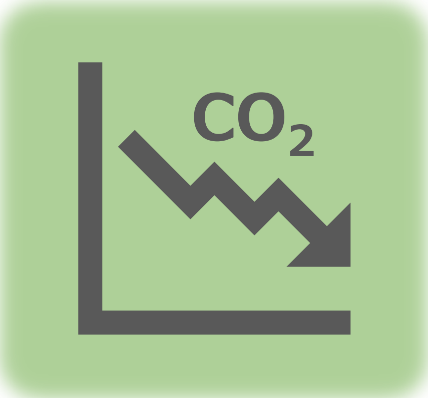
UPDATE on Version 3.0

Goal of energy efficiency for Beyond 5G

- By introducing the green design concept and native AI capability, the overall energy efficiency across the Beyond 5G network (defined in bits per Joule) will be improved, e.g., 100-fold.
- Keeping the total energy consumption (in unit of Joules) lower than that of 5G, while also ensuring optimal service performance and experience.

Technologies and research directions

- Framework for designing and evaluating the energy efficiency of networks
- Hardware aspect (especially power amplifier efficiency)
- Network aspect (service provision in accordance with traffic dynamics in time and space)
- Renewable energy, passive transmission
- Distributed network to solve the centralized AI training and inference power problem



6.7 Network coverage extension via non-terrestrial networks (NTN)

UPDATE on Version 3.0

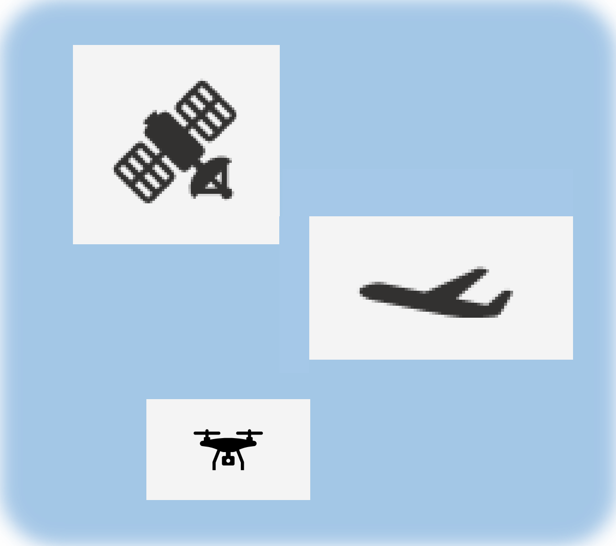
Non-terrestrial networks (NTN) enhance the coverage of future IMT from ground through the air toward space, which enables ubiquity of communications, and is expected to enable new use cases, such as effective connection with unmanned systems, monitoring (video and data), mobile eMBB, IoT, logistics systems, and backhaul (especially for emergencies), and smartphone integration.

■ Research and development initiatives for 2030s:

High throughput and capacity, Low latency, Massive connection for IoT, Optical laser communications, Optimal route selection and multi-connectivity technology, Quantum cryptography communications, Autonomous operations, Edge computing technology

■ Non-terrestrial networks (NTN) :

- High Altitude Platform Station (HAPS)
- Satellite communications
- UAV(Unmanned Aerial Vehicle)-assisted Wireless Communications



6.8 Wireless and optical (1/2)

Clause	Title	Features, strengths	Value	Role	Technical overview
6.7.1	New Radio Network Topology	Radio network topology utilizing advanced NW elements	High stability, low power consumption, high flexibility	high-capacity communications regardless of users' locations	distributed antennas, repeaters/relays, Reconfigurable Intelligent Surface (RIS)
6.7.2	Technology for wider bandwidth and advancement of frequency utilization	Wider bandwidth utilizing millimeter and terahertz waves, ultra-massive MIMO system	Wider bandwidth enables optimized use of spectrum, covering new use cases, improving user experience	Processing massive amounts of data from any location instantly and accurately.	Radio propagation models and simulation, advanced device technology, spectrum sharing etc.
6.7.3	Further advancement of RAT/air interface	Radio access technology (RAT) and air interface specialized in Beyond 5G	Ultra-high capacity and data rate	Bridging the digital divide, providing better environmental awareness	New waveform, modulation, coding, multiple access, full duplex schemes, and advanced MIMO/massive MIMO
6.7.4	Technology to support extreme ultra-reliable and low latency communications	Extremely low latency communication at end-to-end by high-precision space-time synchronization	Supporting mission-critical industries etc.	Reduction of energy and frequency resources through the efficient data transfer	Extremely low latency of about 1 ms or less on the end-to-end basis
6.7.5	Technology to enhance energy efficiency and low power consumption	A long history of improving spectral efficiency and power consumption	Providing sustainable and carbon-neutral communication systems	Contributing to carbon neutrality by eliminating unnecessary energy consumption	Energy harvesting technologies, advanced resource management of the network resources
6.7.6	Integrated sensing & communications and high-accuracy localization	High-resolution sensing by high-frequency radio wave feature, pico-second level synchronization accuracy with wireless space-time synchronization	Building an intelligent digital world using High-resolution and high-accuracy sensing, localization (including positioning)	Mutual functioning of sensing and communication functions for digital twin	Integration of sensing and communication functions at different levels of the communication systems

6.8 Wireless and optical (2/2)

Clause	Title	Features, strengths	Value	Role	Technical overview
6.7.7	Management of radio access/core network and other wireless systems	Providing large capacity and low latency communications via radio resource management etc.	Flexible services, effective use of finite radio resources	Providing required communication services using available radio resources	Integration of various wireless technologies, Core network management
6.7.8	Technology for native AI-based communication	Improving the overall system performance by deeply integrating AI	More efficient in terms of power consumption and spectrum utilization	To revolutionize wireless network architecture and air interface design.	AI-enabled intelligent PHY and MAC controller, AI-enabled intelligent protocol and signaling
6.7.9	Optical communication technology	A decades-long history of optical technology development, a high-speed nationwide optical network	Providing efficient, large-capacity, comfortable and stress-free communication services	To support a sustainable society as part of the advanced communication infrastructure	Multi-core fiber, photonics-electronics convergence technology
6.7.10	Radio over Fiber(RoF)	Large-capacity mobile fronthaul transmission, power and space saving of base stations	Large-capacity mobile fronthaul transmission, power and space saving of base stations	Large-capacity mobile fronthaul transmission, power and space saving of base stations	Intermediate Frequency over Fiber（IFoF) technologies
6.7.11	Optical wireless and acoustic communications	Complementary solution to the radio communication systems, providing positioning or sensing services	Unlicensed spectrum, low cost, low-power-consumption communication, security, communication service underwater	Complementary solution to the radio communication systems, providing positioning or sensing services	Integrated Sensing and Communication with Optical Wireless（ISAC-OW）technologies

Beyond 5G White Paper(ver.3.0)
～Message to the 2030s～
【Technology Supplementary Volumes】

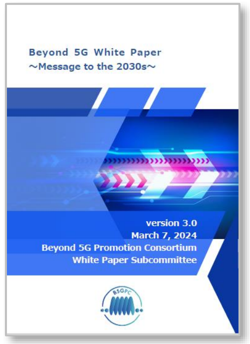
Technology Working Group
White Paper Subcommittee, B5GPC

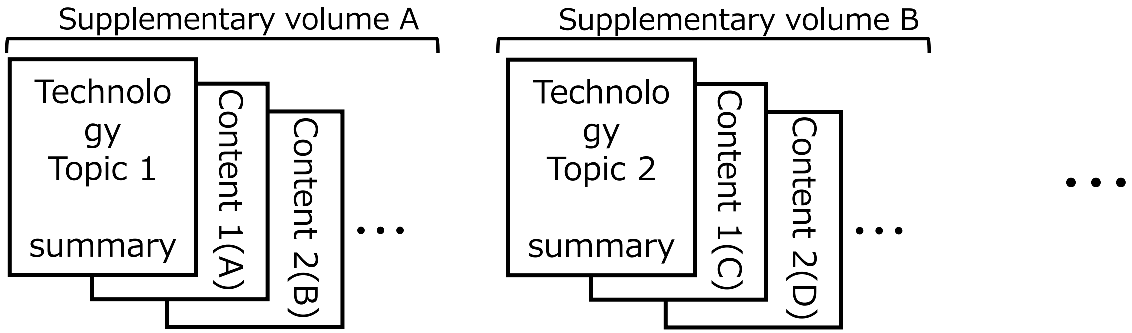
Mar. 7, 2024

Publish Technology Supplementary Volumes (TSV)

UPDATE on Version 3.0

B5GPC published new eight TSVs of the Beyond 5G Whitepaper which realize Beyond 5G/6G. They are utilized for sending messages domestically and internationally with the Beyond 5G Whitepaper V3.0.





TSV Title	Contributing Organizations
• E2E Architecture:	NICT, Osaka University, NTT, KDDI, NEC, Huawei Technologies Japan, NOKIA
• Cell-Free/Distributed MIMO:	KDDI, NTT, NTT DOCOMO, NEC, Fujitsu, Tohoku University, Tokyo University of Science, The University of Electro-Communications
• Radio Technologies for higher frequency:	NTT DOCOMO, NTT, Chiba Institute of Technology, Waseda University, Fujitsu, KDDI, Nagoya Institute of Technology, Huawei Technologies Japan
• Relay and Reflector Technologies:	NTT DOCOMO, NTT, KDDI, Yamaguchi University, Hokkaido University, Tohoku University, PSNRD, Fujitsu
• AI/ML Technologies:	NEC, KDDI, NOKIA, Tokyo Denki University, NTT DOCOMO, Huawei Technologies Japan
• Sensing Technologies:	NTT DOCOMO, NTT, Kyushu University, Osaka University, Sophia University, Huawei Technologies Japan, NICT
• Sustainability/Energy efficiency:	NOKIA、Fujitsu, NICT, Rakuten Mobile
• NTN Technologies:	SoftBank, NTT DOCOMO, Huawei Technologies Japan, NTT

【TSV】E2E Architecture

This supplementary white paper details Japan's extensive R&D efforts and outcomes in end-to-end Beyond 5G architecture technologies realizing the 2030 vision and catering to the varied needs of users* through Beyond 5G infrastructure functions.

- Aims to deliver the best infrastructure functions that meet application performance needs and user experience, seamlessly integrating Beyond 5G's infrastructure and technologies without user awareness of underlying complexities, including congestion management and security.
- Integration of Real and Virtual Spaces, Cyber-Physical Systems (CPS) is the key to support Society 5.0 services, optimizing network functions and providing computing resources for AI utilization.

* In Beyond 5G, it is assumed that "users" include not only people who use smartphones, but also devices that realize things, such as robots, drones, sensors, and other broadly defined IoT devices.

(Editor: Kentaro Ishizu, Mitsuhiro Azuma, NICT)

Contributor (representative)	Contents Title
Hideyuki Shimonishi, Osaka University	Digital-Twin for and by Beyond 5G
Minoru Matsumoto, NTT	Optimum collaboration of network functions and computing resources
Hiroyuki Shinbo, KDDI	User-centric Network
Takayuki Kuroda, NEC	Intent-based operational plan generation for business utilization of autonomous networks
Koshimizu Takashi, Huawei Technologies Japan	Task-Oriented 6G Native-AI Network Architecture
Hideaki Takahashi, Nokia	Envisioning Architectural Transformation towards 6G

【TSV】Cell-Free/Distributed MIMO

This supplementary white paper details Japan's extensive R&D efforts and outcomes in Cell-Free/Distributed MIMO technologies that aims to enhance system capacity and to improve communication quality.

- Cell-Free MIMO, or distributed MIMO, is highlighted as a key technology to enhance mobile systems by reducing interference among cells and maintaining stable connections under tough radio propagation environments through distributed antennas.
- Technical challenges include simplifying signal processing for scalability, increasing fronthaul capacity with manageable costs and energy use, providing wide coverage in higher frequency bands with efficient cooperative beamforming, and ensuring operational flexibility for diverse user needs.

(Editor: Issei Kanno, KDDI)

Contributor (representative)	Contents Title
Issei Kanno, KDDI	Research activities towards wide area deployment of Cell-Free massive MIMO
Daisei Uchida, NTT	High-frequency Band Distributed Antenna System
Kiichi Tateishi, Satoshi Suyama, NTT DOCOMO	Real-Time Simulator for 6th Generation Mobile Communication System Using Distributed MIMO
Kazushi Muraoka, NEC	Distributed MIMO Technologies for High Frequency Bands
Takashi Dateki, Fujitsu	Distributed Antenna Technology (High-density Distributed Antenna System, and Transmission Point Sharing Control
Fumiyuki Adachi, Tohoku University	User Cluster-centric Approach for Cell-free Massive MIMO Systems
Kenichi Higuchi, Tokyo University of Science	Low-Complexity User-Centric TRP Clustering Method in Downlink Cell-Free MIMO with Regularized ZF-Based Beamforming
Koji Ishibashi, The University of Electro-Communications	Toward Practical Cell-Free MIMO Network

【TSV】Radio Technologies for higher frequency

UPDATE on Version 3.0

This supplementary white paper details Japan's extensive R&D efforts and outcomes in radio technologies for higher frequency, from millimeter to THz waves.

- Challenges include THz waves' limited propagation distance, necessitating research into their propagation characteristics, development of new propagation models, device and antenna technology advancements.
- The technologies to utilize higher frequency spectrum, such as ultra-massive MIMO, RIS and Sensing technologies, are discussed in detail in our other white papers.

(Editor: Kazunori Sakumoto, Fujitsu)

Contributor (representative)	Contents Title
Nobuaki Kuno, Satoshi Suyama, NTT DOCOMO	Spatial Characteristics of Sub-THz Band Radio Propagation in Indoor Environments for Beyond 5G
Minoru Inomata, Wataru Yamada, NTT	Path Loss Characteristics from Microwave to Sub-THz Bands in Urban Environment for Beyond 5G
Akihiko Hirata, Chiba Institute of Technology	Evaluation Technique for Propagation Characteristics of 300-GHz-band Radio wave near the Human Body
Keita Kuriyama, NTT	AI Calibration Technique for RF Impairments with Sub-THz transmission
Satoshi Suyama, NTT DOCOMO	Sub-THz-Band Massive MIMO Technology for Beyond 5G/6G
Doohwan Lee, NTT	High Capacity Wireless Transmission Technology using Orbital Angular Momentum Multiplexing in the Sub-THz Frequency Bands
Shuhei SAITO, Fumiaki Maehara, Waseda University Doohwan Lee, NTT	Performance Analysis of OAM Multiplexing Using Parabolic Antenna
Shiro Ozaki, Fujitsu	Antenna Array Module for Sub-THz Communications
Satoshi Ito, KDDI	Virtualized terminal technologies for high-capacity communications in Beyond 5G era
Kunio Sakakibara, Yoshiki Sugimoto, Nagoya Institute of Technology	Sub-THz multi-beam antennas for virtualized terminal technologies
Yasunori Suzuki, NTT DOCOMO	Sub-THz band device technologies
Koshiro Kitao, Satoshi Suyama, NTT DOCOMO	6G Simulator using Real Environment Model based on Point Cloud Data
Koshimizu Takashi, Huawei Technologies Japan	THz Sensing and Communication Towards Future Intelligence Connected Networks
Tetsuya Kawanishi, Waseda University	300GHz point-to-point fixed wireless transmission systems

【TSV】Relay and Reflector Technologies

UPDATE on Version 3.0

This supplementary white paper details Japan's extensive R&D efforts and outcomes in relay and reflector technologies to realize New Radio Network Topology (NRNT) as one of key Beyond 5G technologies.

- Adopting a spatially distributed network topology for increasing the number of communication paths to reduce radio propagation loss and increase redundancy and reliability
- The technologies improve coverage, increase system capacity, and reduce power consumption
- Approaches to realize NRNT are,
  - Utilization of existing urban infrastructure (e.g. streetlamps), and relay and reflector technologies to virtually increase the number of base station and mobile station antennas
  - Wireless transport technologies that enable a distributed network topology are exploited

(Editor: Satoshi Suyama, NTT DOCOMO)

Contributor (representative)	Contents Title
Kenta Goto, Satoshi Suyama, NTT DOCOMO	Analysis of Using Transmissive Metasurfaces toward Beyond 5G
Takahiro Tomie, Satoshi Suyama, NTT DOCOMO	High-Performance Radio Propagation Simulation Method for Path Loss Estimation
Daisuke Murayama, Tomoki Murakami, NTT	Relay-Related Technologies in New Radio Network Topology (NRNT)
Takuya Ohto, KDDI	Development of Meta-surface Reflectors for Millimeter-wave Mobile Communication Systems
Hidekazu Murata, Yamaguchi University	Terminal-Collaborated MIMO Reception
Toshihiko Nishimura, Hokkaido University	Beamforming-Based IRS Control for Sub-Terahertz-Band Communications in Indoor Office Environments
Yuichi Kawamoto, Tohoku University	Beam Squint-aware Frequency Resource Allocation for IRS-aided Communication
Hiroyuki Uno, Panasonic System Networks R&D Lab.	Prototype and Evaluation of Intelligent Reflecting Surface for 60 GHz Band
Hiroaki Asano, Panasonic System Networks R&D Lab.	Wireless transport technology for xhaul
Kazuyuki Ozaki, Fujitsu	A Study on High-Capacity UL communication in Relay systems with UAV

【TSV】AI/ML Technologies

This technical supplement introduces leading-edge R&D efforts on AI/ML for Beyond 5G in Japan, with the aim of accelerating R&D to advance future communications and services.

- Roles of AI/ML in Beyond 5G:
  - Automation: streamlining network operations and management
  - Analytics: understanding the characteristics of communications at each layer
  - Optimization: optimizing computing and networking resources
  - Adaptation: meeting the individual needs of diverse services/applications
- Requirements for AI/ML R&D:
  - Shift from traditional technology to learning-based technology
  - Appropriate combination of AI/ML and conventional physical/mathematical models

(Editor: Eiji Takahashi, NEC)

Contributor (representative)	Contents Title
Takuya Miyasaka, KDDI	AIOps for Autonomous Networks
Takayuki Kuroda, NEC	Logic-Oriented Generative AI Technology for Autonomous Networks
Hideaki Takahashi, Nokia	Scalable AI/ML for Radio Cellular Access
Tetsuro Imai, Tokyo Denki University	AI/ML-based Radio Propagation Prediction Technology
Koshimizu Takashi, Huawei Technologies Japan	6G Network AI Architecture for Everyone-Centric Customized Services
Eiji Takahashi, NEC	AI-based Application-aware RAN Optimization

【TSV】Sensing Technologies

This supplementary white paper details Japan's extensive R&D efforts and outcomes in sensing technologies, which have been discussed on Integrated Sensing and Communication (ISAC) in 3GPP, for utilizing radio waves for sensing.

- Radio waves used only for communication can also be used for sensing to meet new use cases, such as detecting intrusions by humans or animals in indoor or outdoor environments. It also contributes to localization services with highly accurate location information
- The use of base stations and terminals for communication eliminates the need for additional devices for sensing, and rapid advances in AI/ML further expand the application range
- Challenges of sensing technologies:
    - Clarification of sensing performance using channel state information (CSI) and reception level
    - Elucidation of relationship between sensing physical space and CSI in CSI measurement
    - System design and optimization to satisfy both communication and sensing KPIs
    - Space-time synchronization to achieve pico-second level synchronization for high-precision sensing

(Editor: Satoshi Suyama, NTT DOCOMO)

Contributor (representative)	Contents Title
Tomoki Murakami, Shinya Otsuki, NTT	CSI-based device-free sensing using deep learning with 5G NR 28 GHz band
Osamu Muta, Kyushu University	Indoor Experimental Evaluation of Device-free Localization Schemes Using Channel State Information in Distributed Antenna Systems
Shunsuke Saruwatari, Osaka University	CSI2Image: CSI-to-Image Conversion using a Generative Model
Masakatsu Ogawa, Sophia University	Use Cases for CSI Sensing with an Example of Pedestrian Movement Direction Identification
Koshimizu Takashi, Huawei Technologies Japan	Integrated Sensing and Communication (ISAC)
Tetsuya Ido, NICT	Space-Time Synchronization

【TSV】Sustainability and Energy efficiency

UPDATE on Version 3.0

This supplementary white paper details Japan's extensive R&D efforts and outcomes in Sustainability and Energy efficiency technologies to make the planet and society sustainable.

- Exploration of Key Value (KV) and Key Value Indicator (KVI) concepts for evaluating mobile telecommunication systems for sustainability.
- Technical Enablers for Energy Efficiency:
  - Covers a wide range of technical solutions across the system (CN, RAN, Air-IF, NTN coordination).
  - Demonstrates quantified energy savings, such as 37% power consumption reduction in RAN through optimal vRAN resource deployment.
  - Highlights up to 40% power saving through pedestrian flow analysis and NTN utilization.

(Editor: Hideaki Takahashi, Nokia)

Contributor (representative)	Contents Title
Hideaki Takahashi, Nokia	Sustainability, design goals and technical enablers for Energy Efficiency
Yasunari Izawa, Fujitsu	Optimal deployment planning technology for vRAN resources, exemplified by energy saving
Takaya Miyazawa, NICT	Coordination with Non-Terrestrial Network (Power Management for Base Stations Utilizing Pedestrian Flow Analytics and Non-Terrestrial Networks)
Kenichiro Aoyagi, Rakuten Mobile	Global Standards for Mobile Communication Networks

【TSV】NTN Technologies

This supplementary white paper details Japan's extensive R&D efforts and outcomes in NTN (Non-terrestrial network) technologies to enhance connectivity across terrestrial, aerial, and space domains.

- Addressing NTN communication challenges, including high throughput with weather-sensitive frequencies, and reducing latency through LEO satellites and HAPS.
- Enhancing IoT connectivity with efficient network configurations using various satellite types and improving reliability and coverage via multi-routing and multi-connectivity technologies.
- Edge computing technologies is key area to manage large IoT data volumes and achieve low-latency communications in NTN environment.

(Editor: Kazunori Sakumoto, Fujitsu)

Contributor (representative)	Contents Title
Yusuke Segawa, Masaki Nishimura, SoftBank	HAPS Technology: HAPS Flight and Communication Test Results Show Path to Unlock Stratospheric Communications
Yuki Hokazono, NTT DOCOMO	Extreme Coverage Extension in Beyond 5G and 6G: Cooperative HAPS Architecture Integrating Terrestrial Networks
Koshimizu Takashi, Huawei Technologies Japan	Very Low Earth Orbit Satellite Networks 6G
Munehiro Matsui, NTT	Multi-layer non-terrestrial network and its routing management for Beyond 5G /6G

Thank you