Beyond 5G / 6G Vision Whitepaper

\Orchestrating a brighter world NEC

Executive Summary

This Whitepaper summarizes the current discussion regarding how telecommunications and associated technologies will evolve in relation to the society we will have in 2030 and what role NEC will take in this development.

As of 2023, 245 operators in 95 countries had launched or soft-launched at least one 3GPP-compliant 5G service, according to the GSA (February 2023). 5G's expanding use in society is widely anticipated to bring significant changes in various sectors, including communications, entertainment, transportation, healthcare, and many others. Against this backdrop, NEC declares its mission to create value to realize a sustainable society where everyone can reach their full potential. For example, by creating an environment in which we can move seamlessly between real and virtual worlds, we can create new communication experiences which provide a more immersive and engaging experience for participants, especially for remote teams. By freeing ourselves from physical constraints, we can transcend beyond human, beyond space, and beyond time as if we had seemingly superpowers, and bring about the advent of a society where people can create the lives they want according to their own diverse values.

To realize new types of communications supporting such a future, new data from previously untapped sources, including various phenomena and life activities in the real world as well as any significant contextual and emotional states, need to be collected — all the while ensuring each individual's privacy. And while protecting people's safety, we will also develop frameworks to circulate and use such data organically. Beyond simply increasing the performance of communications, this will require real-time analysis, archiving, and utilization of the huge amounts of data generated by the real world.

Therefore, we see Beyond 5G / 6G as more than a dramatic evolution in the performance of 5G wireless technology. Beyond 5G / 6G is an image of society created by social systems integrating communications infrastructure with a set of technologies and products that use real-time processing of enormous amounts of diverse data. From that perspective, we outline the technical areas that need to be a focus in the future to realize such a society in the Beyond 5G / 6G era.

With 5G and 6G at the core, NEC will further accelerate open collaboration through co-creation with customers and partners in the industry, government, and academia. To achieve this, NEC will also leverage world-class technologies such as facial recognition; a wide range of equipment and software to support various aspects of business, from networks to IT solutions for industry; system construction and operation, and know-how related to these areas; and services such as NEC Smart Connectivity, which connects data generated by people and things across industry boundaries through networks.

Through these initiatives, we aim to create the social values of safety, security, fairness, and efficiency in our redesigned image of society centered on Beyond 5G / 6G. By continuing to strive for next-generation social systems, we will contribute to creating a sustainable society that will realize sustainable development goals (SDGs).

We will also continue this discussion and consider the image of society in 2030 described in this Whitepaper more deeply as we advance toward a bright future for everyone.

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Chapter 1

Future society in 2030 and beyond

1-1 Introduction

Digital transformation is accelerating and revolutionizing societies, economies, and industries by using rapidly developing digital technologies such as AI and IoT. Communication technologies such as 5th-generation mobile communications systems (5G) play an important role in the business processes and business models being changed by digital transformation. The search and evaluation of services and use cases that utilize both 5G features such as ultra-high speed, high capacity, ultra-low latency, high reliability, and massive connectivity, as well as Private 5G features such as safety, stability, and flexibility, has begun A wide range of solutions is being developed and studied to solve issues that both companies and communities face.

NEC is using 5G and Private 5G with telecommunication providers and partners in many fields to promote co-creation in many directions. With a focus on the NEC Smart Connectivity service, which connects data generated by people and things across industry boundaries through networks, NEC is promoting the creation of new business models with customers that go beyond digital transformation. NEC also aims to realize next-generation city management infrastructure to support supercities that will revolutionize the way cities are run. So, in the future, what sort of society will we live in?

In this Whitepaper, we outline our vision for developments in the 5G era and for the Beyond 5G / 6G era in 2030 and beyond. It also describes our current vision of the society we want to achieve. As we approach 2030, what will be the state of issues such as population decline, which Japan is facing already, and which other nations may face in the near future? What about SDGs and other global issues that many nations are currently working together to address? How should NEC, with network business at its core, address these issues as they evolve from the current situation?

5G

5G (5th Generation) refers to wireless communications systems that are successors to 1G, 2G, 3G, and 4G systems that satisfy the IMT-2020 standard set by the International Telecommunication Union (ITU). The ITU Radiocommunication Sector (ITU-R) has defined 5G's three key features as high speed and capacity, low latency, and massive connectivity.

Private5G

Wireless communication systems that are built within a local network by a company or local government, separate from 5G services provided by a mobile communications operator. Local 5G systems have the features of safety, stability, and flexibility, and they can handle communications outdoors or in a large factory where Wi-Fi cannot be used and are not as susceptible to communication difficulties.

Beyond5G/6G

The generation after 5G, which is not yet clearly defined and has been called Beyond 5G, Post 5G, and 6G, among other things. In this Whitepaper, we refer to all of these as Beyond 5G / 6G for convenience.

To find solutions for these issues, NEC is building deeper open, collaborative relationships with all stakeholders, including our customers, industry-academia partners aiming to produce new social value, and local as well as national governments. We are working to bring them together to design new social systems. What path should we be taking toward a sustainable society in which everyone can reach their full potential by creating the social values of safety, security, fairness, and efficiency that NEC upholds? Here we introduce the technical infrastructure and development elements that NEC considers important for the Beyond 5G / 6G era.

1-2 Toward a sustainable society where everyone has a chance to reach their full potential

In a world infused with digital technology, barriers due to issues of gender, age, race, and disability disappear. People are able to connect with anyone, overcome separation in space and time, live in ways that best suit them and reflect their individual values, and pursue various styles of work. An "inclusive society" is coming where we can attain self-expression through one's work; rich communication that transcends time, space, language, and generations; and the sharing of knowledge, as well as fostering empathy. In such a society, for example, a child or elderly person confined to a hospital for a long time could converse with family as though they were there in person and recover without social isolation. More people could feel emotionally enriched in their daily lives.

Furthermore, global observation data obtained from satellites and space stations, as well as large amounts of social activity data collected on a global scale, will provide continuous input for policies as well as the business activities of corporations. AI will provide awareness of global-scale phenomena such as global warming, abnormal weather, forest destruction, ocean contamination, and tectonic changes. It will also provide early warning of disasters such as earthquakes, tsunamis, floods, landslides, or wildfires and provide support for a broader transportation system that three-dimensionally covers land, sea, and sky with vehicles such as flying cars, in order to avoid such disasters. In an area where disaster is anticipated, it could show areas expected to flood in real space using 3D artificial and virtual reality (AR/VR) technology. A distributed, cloud-based remote medical system could provide support, autonomously focusing resources in specific areas. Citizens will be supported by social infrastructure thanks to the communications and peripheral technologies of Beyond 5G / 6G. In a more resilient and sustainable society realized in this way, energy and resource consumption can be minimized while enabling both individual lifestyles and overall optimization. We hope to achieve net-zero greenhouse gas emissions before the 2050 deadline is declared by governments. By gaining a broad, real-time understanding of all phenomena from micro to macro and from local to global, a sustainable framework will evolve that better harmonizes the earth with the actions of human society, and the living environments and diverse values will also evolve. Cities and infrastructure will be redesigned for a way of life that reflects those values. In this way, we, as part of our ecosystem, can build a sustainable relationship with the earth and a symbiotic world that preserves biodiversity. What kind of communications and related technologies will support such an inclusive society”? The next chapter describes three technologies that will take us “beyond.”

1-3 Tele-X society: Beyond Human, Time and Space

We believe that in creating sustainable societies where everyone has the chance to reach their full potential, communication has great power to change society for the better. In the past, the telephone and television have overcome space constraints and had powerful effects, as indicated by the prefix “tele-” (meaning “distant”). In the future, what would look like superpowers, such as teleportation, telekinesis, or telepathy could be attained through many new forms of communication. These “tele-” capabilities can be regarded as a type of human augmentation because they take us beyond our limitations — not only beyond our spatial constraints but also beyond our sensory/motor constraints, such as our abilities to understand, empathize, or be emotionally moved as well as our abilities to move objects physically. We can also overcome time limitations by predicting the future or retrospectively analyzing and making judgments about the past.

When we consider the future society in 2030 and beyond, it will be a society in which people can overcome constraints of their natural abilities through the "teleX" services implemented by Beyond 5G / 6G technologies. For example, telework will be more than simply performing office work from a remote location using online interactions. It will co-work through deeper, non-verbal, and other types of communication, giving a feeling of being in the same space, even from a remote location. "Tele-X" capabilities will enable us to share more that involves our other senses, such as touch and smell, enabling more people to do more types of work remotely. These types of services will thereby also expand to more life scenarios, such as tele-housework, tele-leisure, and tele-adventure. Such abilities will not only be available to people. Robots, automobiles, and AI characters that do not exist in the real world will have such abilities and co-exist with us.

In this way, we conceive a future that will take us beyond human, space, and time (Fig. 1-1), and our goal for Beyond 5G / 6G is to implement new forms of communication that can be used to realize such a society.

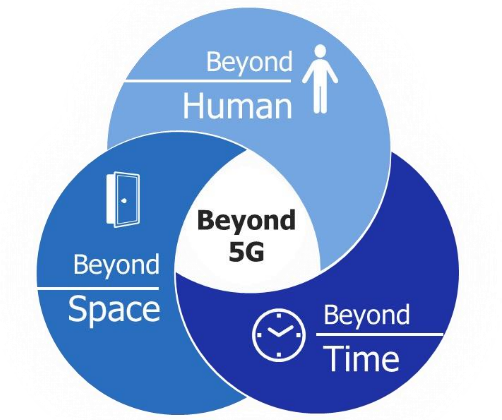

Fig. 1-1 A world beyond human, beyond space, and beyond time

Beyond human:
Open society relieving limitations and unleashing human potential

In the future brought about by Beyond 5G / 6G, a society where human potential is unleashed, and limitations are removed, what sort of lifestyles will we experience?

For example, when we want to make friends or read books from around the world, there has always been a language barrier to overcome. This barrier has been removed to some extent even now. Still, perhaps we can realize a highly diverse society in which we have mind-to-mind communication in real time, integrating both conceptual and cultural translation without being limited by factors such as our senses, language, and cultural background. In such a society, knowledge, including implicit in-group knowledge, can be shared, and a deeper, mutual understanding and empathy can be attained. This can apply more broadly than just to people, achieving seamless communication with pets, animals, robots, and cars. Having an exciting life that follows the diverse values that people demand will surely play a role in realizing a human-centric society suited to each individual's needs.

Mind-to-mind communication
Using sensors to convey a person's actions—including their bodily abilities, perceptions, and cognition—through cyberspace to someone at another location so that their thoughts are conveyed without using words or gestures like telepathy.

Telexistence
A technology by which a robot at a remote location acts as a person's avatar, enabling them to see, feel, and act as though they are at that location.

The implementation of 3D technologies (AR and VR) and cyber-physical systems for on-site activities such as sightseeing or watching sports or concerts; the social implementation of cyber-physical systems together with the appearance of the Internet of Senses reproducing our senses such as touching or feeling textures, tasting, and smelling; and communication infrastructure with even-more advanced 5G features (high capacity, low latency, and massive connectivity) all contribute to gaining teleportation capabilities that overcome the limitations of space and enable instant transport to other locations. For example, staff for a luxury brand could instantly move to a remote island resort and meet with customers in their rooms as if they were in the store. Customers could enjoy shopping for skin-care products, shirts, jewelry, and other products while experiencing the texture and feel of the products. Then at the same time, with telepresence, an avatar robot could be used to participate in a violin concert being held elsewhere, providing the individual with a healing sensation from the performance by experiencing changes in metabolism, heart rate, and body temperature. This could allow people to enjoy a more luxurious and relaxing holiday.

Beyond space:
Beyond real and virtual in space and at sea

In the Beyond 5G / 6G era, frontier areas where services have not yet been reached will draw public attention. Services will expand to cover every corner of the earth, including space and at sea. In space, this will include space stations, bases on the moon, and perhaps even on Mars. Even beyond that world, Telexistence for cities or even the Earth itself could be established so that people living in a base on Mars can spend time in Tokyo, New York, or Sydney through cyber-physical systems. This would represent even greater integration and unification of real and virtual space than ever, and various new services would be created on such social systems.

In such a world, we expect the far-away person (or non-existent character created by AI) to seem real and to be able to empathize with them. If that is the case, people will be liberated from physical limitations through new forms of communication and cognition; they will be able to work, study, and enjoy themselves with a feeling of being there, even if they are not. Having the life experience of going to a workplace or school while not leaving your home, going to the South Pole, or looking at the Earth from Mars will enable dramatically more efficient activity, not just in terms of space but also in terms of time and energy. There will be less need to physically travel, which will also reduce CO_2 emissions and could help prevent sea levels from rising and the related loss of habitable land.

By also creating various virtual worlds that do not actually exist and acting within them just like in the real world, people will be able to challenge themselves to reach new potentials. As we advance toward the future, we look forward to the beginning of an era where we can reach unlimited frontiers.

Beyond time:
A world where we can know the future and return to the past

With the advance of global-scale networks collecting huge amounts of data in real time and related technologies such as artificial intelligence (AI) and extended reality (XR), we can expect to predict future events more accurately and find solutions to more complex problems than ever before. If we could put on glasses that could predict and show us what will happen 20 or 30 seconds in the future, we might be able to dramatically reduce unexpected accidents. As our use of weather and ocean current data advances, we will more accurately predict harvests of agricultural and fishery products six months or a year in the future and any excesses or shortages by region. Then, we will adjust orders to food companies and producers accordingly. Such warnings from the future could reveal clues to how we could solve the problems of food supply and hunger.

Looking back into the vast amounts of past data, analyzing past experiences that include people's emotions, and applying the results to future scenarios could have major effects on policies as well as corporate decision-making.

For example, the scenery, culture, and daily practices of medieval Europe could be reproduced. Then we could take a walk and have a conversation in that place and time and be able to interact with things as if we were actually there in that era. Any actions would lead to a new future which could then be experienced in the virtual world.

By sharing experiences through mind-to-mind communication with others and including the senses and emotions, barriers between generations would be swept away. Knowledge could be passed from elders to the younger generations, and techniques and know-how could be passed on without loss; the younger generation could also seamlessly share with their elders. They could learn from each other, and people could be connected beyond generations. This ability to foster deeper empathy is another benefit to be gained.

We have described NEC’s image of society in 2030 and beyond from three perspectives. In that not-too-distant future, we expect Beyond 5G / 6G and related technologies to enable us to go beyond human, space, and time. That world will be one step closer to a society in which everyone can reach their potential.

In the following chapters, we discuss the scope of Beyond 5G /6G in detail and important technologies that are anticipated.

Chapter 2

Beyond 5G / 6G vision

2-1 Evolution of telecommunication and communications technology

New types of telecommunications will need to be implemented to achieve the 2030 future society described in Chapter 1. We will discuss advances in telecommunication and supporting technologies with reference to Fig. 2-1.

The 4G/LTE era focused on telecommunication by people using smartphones and other devices for high-speed data communications. The scope of human communication expanded from one-to-one conversations using a telephone to simultaneous video communication among multiple people and sharing the events of the day with people worldwide through SNS, enabling people to foster empathy and communicate with others.

4G and Long term evolution(LTE)
4th Generation mobile communications systems. LTE is often included in 4G as one of the standards for increasing the speed of 3G. We use "4G/LTE" to represent both of them together.

In the 5G era, communication is expanding from just people, as has been the case earlier, to also include things (IoT devices). The digital transformation will expand and improve lives and businesses, and create new value supported by communication infrastructure with ultra-high speed and capacity, very low latency, and massive connectivity.

Beyond 5G / 6G will implement new types of telecommunications as described in Chapter 1. To go beyond human, time, and space, AI will analyze and understand everything about people — inside and outside, objects nearby and in the whole world — and instantly convert this information to digital data. This, along with past data, real-time data, and future prediction data, will be freely available for use. Compared to IoT in the 5G era, more digital data will be produced. We can expect society to change dramatically — similar to how the evolution of creatures leaped forward by having eyesight in the Cambrian explosion. Here, Beyond 5G / 6G takes the role of essential infrastructure for realizing lifestyles and society richer than ever before.

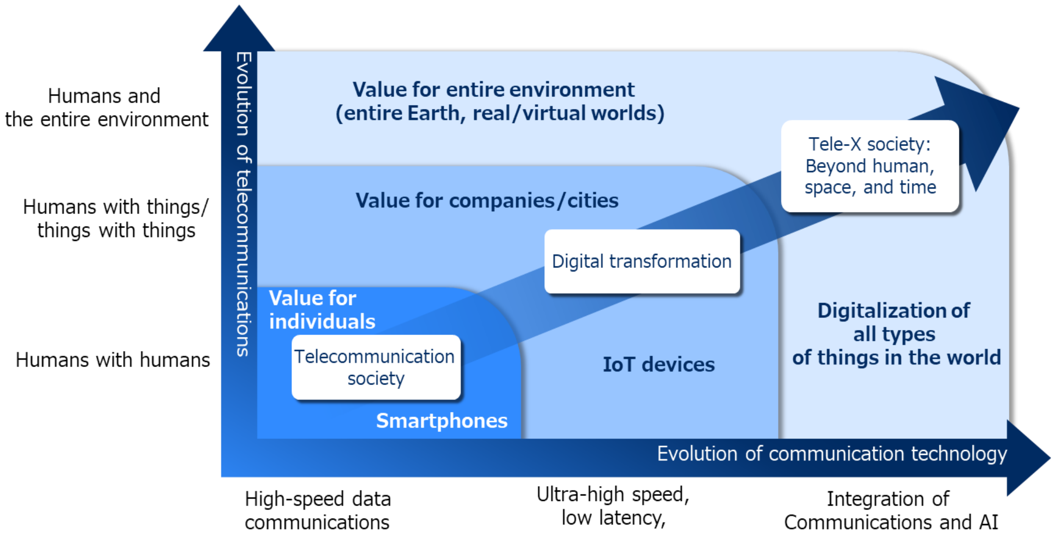

Fig. 2-1: Evolution of telecommunication and communication technologies

2-2 Scope of Beyond 5G / 6G

Beyond 5G / 6G is being presented in various forms by many organizations, corporations, and universities: Whitepapers, lectures at conferences, and in other ways. As an example, the Ministry of Internal Affairs and Communications in Japan published a Beyond 5G / 6G promotion strategy that described seven Beyond 5G / 6G features:

- Ultra-high speed and capacity 10 to 100 times that of 5G
- Ultra-low latency 1/10 that of 5G
- Massive connectivity 10 times that of 5G
- Ultra-low power consumption, 1/100 of current values
- Ultra-safe and reliable (security and fault tolerance)
- Autonomy (Zero-touch operation, optimization)
- Scalability (ultra-coverage through satellite, high-altitude platform stations (HAPS), etc.)

These “ultra” performance improvements as an extension of 5G are essential for realizing the future society we have discussed here. We are not just referring to only mobile networks in isolation but to the total

Zero-touch operation
Complete automation, from detecting faults and quality degradation to completing countermeasures.

network infrastructure, including wired networks, the cloud, the internet, broadcasting, and private networks. As such, a social infrastructure perspective on how these various networks will be managed and how to satisfy increasingly complex communication requirements is needed.

However, to produce this huge amount of digital data AI analysis and an understanding of the enormous and constant flow of raw sensor data that is produced seamlessly requires large bandwidth and power. Another problem is the need for real-time processing and the geographic distribution of the data sources and the users of the results of the data processing. If the sensor data is collected at a data center for processing, a large amount of energy is required for the data transfer, and communications latency makes real-time processing difficult. A reasonable approach to address communication latency and energy consumption issues is to use distributed processing, in which the data is processed where it is needed. The dynamic optimization of the entire network connects these elements.

Based on these points, this Whitepaper considers the scope of Beyond 5G / 6G as greater than just quantitatively expanding on 5G. It also integrates aspects such as distributed data processing. We define Beyond 5G / 6G as a communications system that integrates networks with distributed data processing, organically utilizes communication and computation resources distributed throughout the world, utilizes digitalization, and implements real-time interaction with the real world.

2-3 New forms of telecommunication through Beyond 5G / 6G

Beyond 5G / 6G, as defined in the previous section, will realize the following new types of communication.

1. Person-to-person and person-to-thing hyper-reality communication, transcending time and space

Person-to-person and person-to-thing hyper-reality communication will be possible by converting any information in any world to digital data in real-time and sharing it instantly through networks in the Beyond 5G / 6G era. Here, we mean more than the high-accuracy sharing of data from conventional media such as voice and video. Communication that surpasses realism will be created by also sharing data such as the following

- Experiences using the five human senses, including vision, hearing, and touch
- One's own and others' intentions and context
- Spatial information, including 3D images, structures, and placement in the real world
- Conveying motives of people, controlling machines, etc.

Context
In IT, this generally refers to user intentions and circumstances, judgement materials and conditions, etc.

Digital twin
A near-real-time reproduction of real-world physical data within a virtual world, using technology such as IoT

2. Expansion of digital twins and cyber-physical systems

With IoT in the 5G era, digital twins can be implemented using IoT terminals to extract data from the real world and reflect it in a virtual world. These digital twins are confined to the object of interest, such as a manufacturing process in a factory or an athlete in a stadium.

In the Beyond 5G / 6G era, on the other hand, with diversified sensing and advanced technology for analysis and learning, all kinds of data not available earlier, such as 3D spatial data, including buildings and scenery, and the internal state and thoughts of people, will be captured and used. Thus, everything in the real world and data that has not manifested in the real world will be reflected in the virtual world as a digital twin (Fig. 2-2).

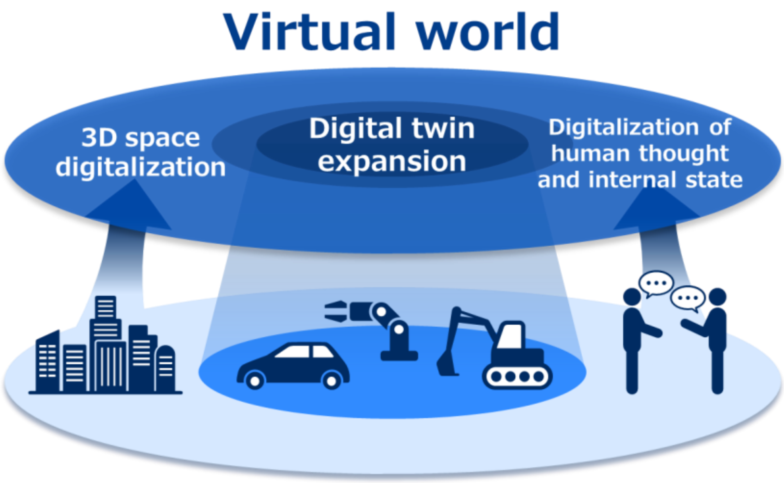

Fig. 2-2: Digital twin expansion and building virtual worlds

With Beyond 5G / 6G, such extended digital twins will be reflected in virtual worlds, shared worldwide, and used to optimize both real and virtual worlds. Then the results will be reflected in the real world, creating a loop called a cyber-physical system (Fig. 2-3). In virtual space, it is possible to fly freely in the sky or space and go anywhere in the world. Newly created worlds will open up as spaces or facilities reflecting the ideas and imaginations of people around the world, such as a shopping mall floating in the air to provide a new shopping experience or a venue where you can enjoy music or video together with people around the world. People will be able to interact with avatars in a virtual city created by AI. A world that is vastly different from the one we see today is bound to emerge.

Cyber-physical systems (CPS)
A concept in which IoT is used to gather various data and transmit it to cyberspace, perhaps through the cloud, where the CPS analyzes and generates feedback to the real world.

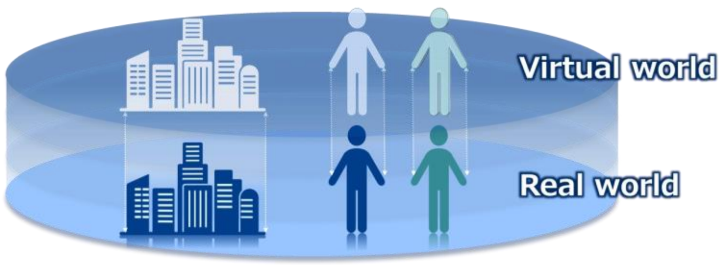

Fig 2-3 Cyber physical systems utilizing a virtual world

3. Seamless coverage connecting all locations on earth

Telecommunication will be available seamlessly in every possible space where humans and robots are active (Fig. 2-4). To achieve this, in addition to resolving dead zones in cities by using millimeter waves and terahertz waves, other means such as low Earth orbit (LEO) satellites and high-altitude platform stations (HAPS) will be used to provide communication in environments such as remote areas and at sea. A range of methods will be used to provide coverage, such as customized coverage combining carrier communication with local communication. If the cost of LEO or HAPS falls significantly in the future, they could also be used as an effective alternative to mobile communications in countries or outlying areas where the population density is low.

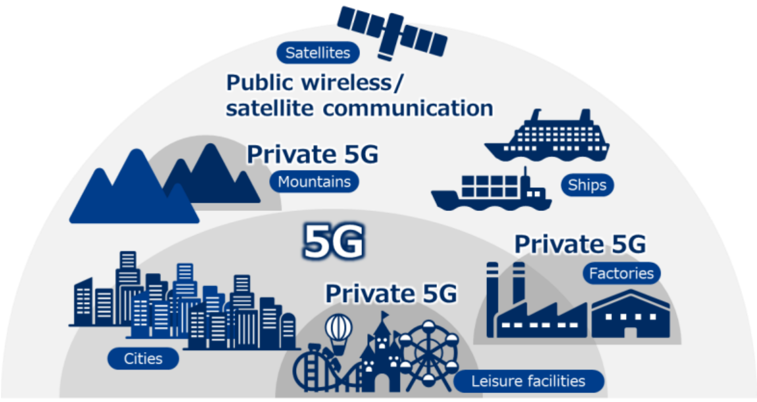

Fig 2-4 Securing seamless coverage connecting all

Coverage
The range for transmitting and receiving radio waves and the extent that they reach.

Millimeterwaves & terahertzwaves
Millimeter waves have frequencies from 30 to 300 GHz and wavelengths from 1 to 10mm, whereas terahertz waves range from 300 GHz to 3 THz and 100 μm to 1mm. These are promising for applications in ultra-high-speed radio communications.

Low Earthorbit satellites (LEO)
Satellites that can provide communication services at lower cost, higher speed, and lower latency than conventional communications satellites with stationary orbits.

HAPS (high altitude platform stations)
Unmanned aircraft that fly continuously in the stratosphere and are used as base stations. They can be used to cover mountainous areas and remote islands not reachable with terrestrial base stations and situations when terrestrial base stations are damaged by disaster or other causes.

Chapter 3

Key technology areas

3-1 Two facets of Beyond 5G / 6G

As mentioned in Chapter 2, this Whitepaper discusses two facets of Beyond 5G / 6G: quantitative expansion of 5G and distributed data processing. This is represented as system architecture in Fig. 3-1.

Quantitative expansion of 5G involves further enhancement for the ultra-high speed and capacity, ultra-low latency, and massive connectivity of the elements in the 5G network (user equipment (UE), radio units (RU), central unit (CU), distributed units (DU), etc.) is required to reproduce ultra-realism and extended digital twins. Ultra-high reliability and security are also important to ensure the security and safety of the expanded cyber-physical. Ultra-wide-area coverage over the entire Earth space and ultra-low power consumption are also needed.

Requirements for a distributed data processing infrastructure are a network in which bandwidth and latency can be controlled freely to be combined with more diverse sensing methods, and a computing environment that can process sensing data in real time. To capture all kinds of information from the environment as digital data, real-time distributed AI processing and distributed digital twin data processing by using multi-access edge computing (MEC) will be important. Other important means used in capturing digital data from the real world include spatial sensing and object positioning using millimeter-wave, terahertz-wave, and optical fiber communications.

For the control plane and orchestration, integration of distributed processing with the network, as well as advanced optimization and automation, will be needed so that network performance and structure can be adjusted according to the needs of users.

System architecture
The design, from an optimal overall perspective, for the functions and reciprocal data updates required to perform what the system needs to do efficiently.

User equipment (UE)
Terminals and equipment such as smartphones and Wi-Fi routers that are used by users.

Radio units (RU), central unit (CU), and distributed units (DU)
Devices comprising the 5G network that perform processing for radio components. The number and types of these are combined according to how the network is deployed and used.

Multi-access edge computing(MEC)
A standardized technology that provides access to various communication standards for edge computing, which handles some of the processing formerly done in the cloud with very low-latency.

Sensing
Measurement of data using sensors and conversion to numeric values.

Control plane
The communication path between the controller and network devices.

Orchestration
Automation of configuration and operations management for systems, applications, and services.

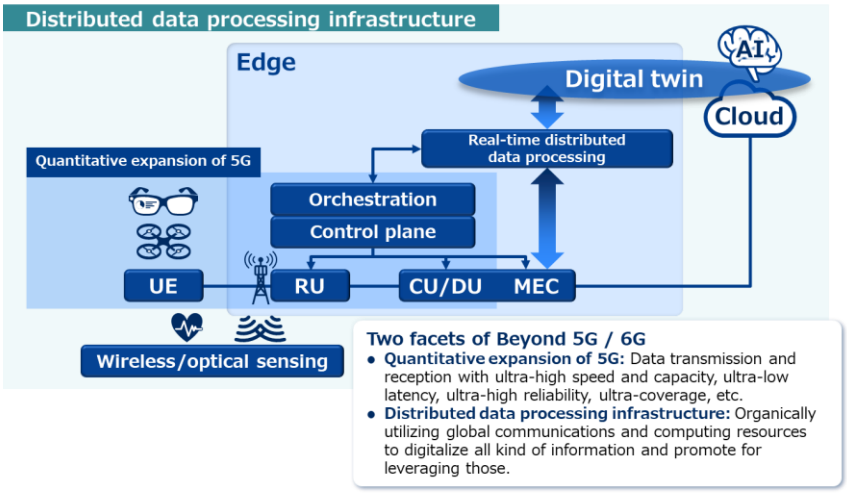

Fig. 3-1 Two facets of Beyond 5G / 6G

3-2 Directions for technology advancement

As technology trends, the two facets described in the previous section will not advance entirely independently but will complement each other in a so-called co-evolutionary relationship. As shown in Fig. 3-2, service and application platform technology for digitalizing the real world requires a communication performance with high speed, high capacity, and low latency, and then promote advances in wireless communication technology and optimize its own algorithms to compensate for wireless networks' limitations. Similarly, as wireless communication technology advances to meet requirements for higher speeds and capacity, those advances will also enable new digital technologies and service applications. At NEC, we refer to the former as “AI for NW” (AI for networks) and the latter as “NW for AI” (networks for AI), and we promote R&D utilizing the strengths of both. This section gives a simple introduction to the technical content of each of them.

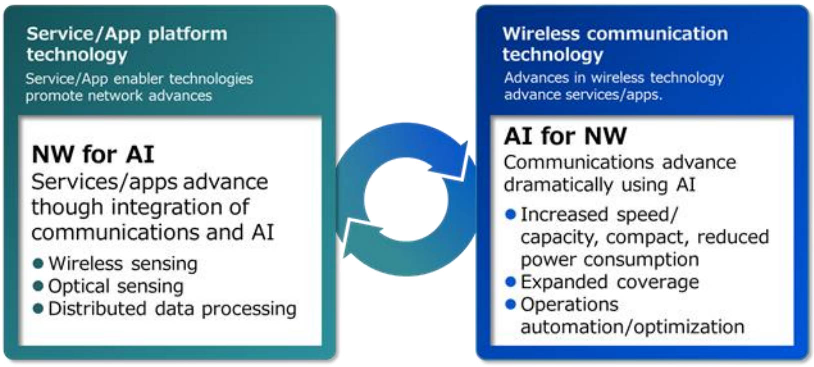

Fig. 3-2: Co-evolution of technologies

The technology evolution toward Beyond 5G / 6G, as conceived in this whitepaper is shown in Fig. 3-3. The horizontal axis shows progress in telecommunications, similar to the horizontal axis in Fig. 2-1. The vertical axis shows lateral expansion from wireless communications into distributed data processing. This section introduces these concepts.

Technical details are given in the appendices.

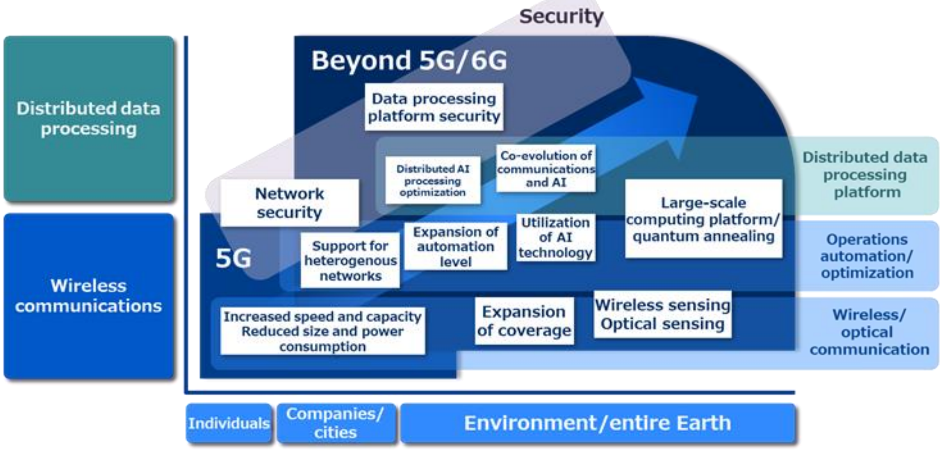

Fig. 3-3: Beyond 5G / 6G key technology areas

1.) Wireless/optical communications

- High-speed and Large-capacity/Compact-size and low-power consumption: To meet the continuing demand for higher performance, we are advancing technologies on higher frequency technologies such as antennas amplifiers on the communication devices to utilize millimeter and terahertz waves, digital signal processing technologies on wide-band signal processing, and AI application technologies to be adopted to those technologies.

- Expanded coverage: To expand coverage to every corner of the earth will require combining various methods, including expansion of efficient coverage using millimeter and terahertz waves, introducing new wireless communication methods such as LEO satellites and HAPS, and customized coverage combining carrier and local communications.
- Wireless/optical sensing: In addition to conventional sensors such as cameras, sensors using communication radio waves and optical fiber are promising for digitalizing entire spaces. Beamforming for adjusting the directionality of radio waves and precise positioning technology for tracking objects indoors and outdoors are also needed.

2.) Operations automation/optimization

- Support for heterogeneous networks: Beyond 5G / 6G involves more than the advancement of mobile network systems and will create networks that are highly composite and complex, including fixed systems, ad-hoc networks, and satellite and HAPS systems, so advanced operations and management will be needed. Integrated operations and management will be needed to operation and manage distributed data processing, as described below.
- Enhanced operations and management automation: For these highly composite and complex networks, the level of automation must be enhanced steadily. The ultimate goal is full automation that does not require human intervention.
- Advancement and utilization of AI technology: To achieve the optimization and automation described, it will be essential to develop a range of AI. To achieve full automation able to handle unforeseen circumstances, AI that can evolve and adapt to changes in the environment will also be necessary for the future.

3.) Distributed processing platform

- Distributed AI processing optimization: Distributed AI processing requires large-scale data transport and processing, which requires constant performance optimization involving real-time, dynamic optimization of distributed processing and allocation of computing and

Heterogeneous networks
Networks that support connection by devices using multiple different access technologies.

Quantum annealing
A next-generation computing technology suited to combinatorial optimization problems based on quantum computing, which is said to overcome the performance limitations of conventional computers.

communication resources.

- Co-evolution of communications and AI algorithms: With advances such as those described earlier, in addition to optimizing processing and resources for AI and communications, the processing algorithms used for each of them will also evolve each others.
- Large-scale computing platform: Large-scale, distributed processing will require the introduction of processors specialized for edge AI. Furthermore, the development of new computing paradigms is expected, such as addressing large-scale optimization issue by using quantum annealing.

4.) Security

- Communications infrastructure security: The reliability of communications infrastructure will need to be strictly maintained as systems become more open, interconnected, and heterogeneous and the effects of geopolitical factors expand.
- Data processing infrastructure security: To deal with various concerns accompanying digital transformation, platforms will need to ensure authenticity, visualize risks, and automatically deal with risks associated with digital-twin data.

4

Chapter 4

Summary

4-1 Beyond 5G / 6G evolutionary model

In the society of the coming era, the structure of the industry will change as user needs diversify, advances in information and communications accelerate, the players change, and the roles of each player evolve. All types of industries will be required to adapt to the new normal, including how they conduct their business, duties, and work in general. .

Beyond 5G / 6G will become the leading information and communications technology penetrating and supporting all scenarios in our lives and society. It will play a critical role in supporting both people and society as the platform for digital transformation and contribute to seamless interaction among people, things, and events in real and virtual worlds. More than ever, people will use communication technologies to realize comfortable lifestyles and working styles. In doing so, network installation, operation, and service provision will expand to a much greater range of choices and flexibility than is available now. And networks will expand to areas where services are needed, beyond cities and busy areas to include rural communities and less populous areas.

Through the popularization of private and closed networks that companies and other organizations install, operate and use, and through the efficient use of distributed data processing infrastructure that is unevenly distributed with these networks, we hope that the future society described in Chapter 1 will be realized. With the provision of integrated solutions for individual requirements and applications like Private 5G, as well as multiple uses by community users to solve regional problems, information and communications will develop and evolve through new scenarios toward the new era.

4-2 NEC contributions

Technical performance and requirements must be secured to provide such increasingly complex services and solutions. The overall systems integrating networks, applications, and services must be developed and evolved while also optimizing itself. As such, NEC will not only enhance and expand on 5G performance and focus on innovation by integrating distributed data processing platform. We aim to implement communications infrastructure satisfying the enormous communication and computing performance required to digitalize all kinds of conditions and states in the real world and optimally maneuver all kinds of objects in the real world from virtual worlds. This will realize a sustainable society in which everyone can reach their potential.

Rather than conventional initiatives by individual organizations such as companies or universities, a key component in supporting a sustainable new society will be for multiple stakeholders to cooperate closely and to allocate roles appropriately, exceeding the bounds of their previous standpoints and business types.

NEC is one of the very few companies in the world with a good balance of top-class technologies in a wide range of fields, from networking and IT to data and services. Beyond the conventional information and communications technology framework, we have a unified and integrated approach to extending 5G performance capabilities and distributed data processing from the R&D stages, which is essential for Beyond 5G / 6G.

In addition to NEC's technology assets, we are also maximizing the use of our system building and operations know-how, as well as promoting open initiatives in R&D and business development with all our customers and partners.
We are working with everyone toward implementing what will lead to the creation of an amazing society beyond expectations. NEC will continue the challenge of implementing leading-edge technologies in society and creating value that is accessible to everyone.

Appendix

Key technology area details

A. Wireless and optical communication technologies

Increasing speed and capacity & reducing size and power consumption

To handle the communications demand as it rises, speed and capacity will need to continue increasing, even after 5G. According to the Beyond 5G / 6G promotion strategy of the Japanese Ministry of Internal Affairs and Communications, a speed and capacity 10 to 100 times greater than that of 5G, and a power consumption 1/100 that of 5G, will be required. Additionally, 5GPPP came up with similar numbers in its "The 6G Architecture Landscape" Whitepaper, claiming that a throughput of 100 Gbit/s or even significantly higher might be required for 6G.

The first requirements to achieve this will be to use new antenna technologies, power amplifier technologies, and beam-forming technologies and to also build propagation models using millimeter-wave and terahertz high-frequency bands. In addition to higher speed and capacity, low power consumption will also be a major requirement for device technologies.

Another major requirement for increasing capacity will be to boost the speed and bandwidth of digital signal processing technology that supports compensation for non-linear distortion, equalizer optimization, distributed MIMO (multiple-input, multiple-output), and other aspects. In addition to conventional ways of increasing speed using circuit design, completely new technologies such as optimization and signal processing technologies using AI will be needed. Furthermore, as the speed of wireless communications increases and MIMO is applied in optical communications, wireless and optical technologies are nearing convergence. Digital signal processing technology is increasingly anticipated for use as a common core technology for both.

Beamforming
A technology that extends the transmission distance or improves sensitivity by increasing the directionality of radio waves from an antenna in a particular direction.

Equalizer
A circuit that processes or adjusts the overall frequency characteristics of an electrical signal.

Free-space optical communication
A technology used for propagating in free space where optical fiber cannot be installed.

Mobile fronthaul (FH) and backhaul (BH)
For mobile telephone lines, the fixed-line network connecting wireless base stations on the streets with the nearest basestation facility is called the "mobile backhaul," whereas the lines connecting the base station to the antennas - if they are separated - are, called the "fronthaul."

Optical submarine communication
Communication using optical fiber laid across the sea floor. In recent years, digitalization has progressed, and demand has increased; major companies are planning new lines to be installed one after another.

These digital signal processing technologies are not only being applied to mobile wireless communications but also to various other areas such as fixed wireless communication, free space optical communication, mobile fronthaul and backhaul (FH/BH), and optical submarine communication. Digital signal processing is becoming a key technology for increasing speed in all communication networks.

The use of commodity hardware in communication devices is increasing, and general-purpose CPUs are being used to perform a range of processing. However, large-scale computations such as advanced beamforming for multi-element antennas are also increasing rapidly, so GPUs and the vector processors used in super computers are promising for these tasks.

Multi-element antennas
Able to improve signal quality and data transmission speed by forming a beam, increasing power in a particular direction, and decreasing it in others. An important technology for implementing 5G requirements is increased capacity, speed, and quality.

Vector processor
A type of processor that is attracting attention because it can also be used with an ordinary desktop PC.

Graphics processing unit (GPU)
A processor specialized in 3D graphics and other image rendering operations.

Coverage expansion

In addition to expanding coverage of the relatively low-frequency band (Sub6) wireless technology used mainly in densely populated areas, a variety of other technologies to expand coverage will be needed to implement high-speed communications in many other areas of the world.

To deal with the insufficient coverage and instability of millimeter-wave and terahertz-wave communication in urban areas due to their straight-line propagation and high attenuation, as well as increased capital cost and risk due to the higher number of antennas, advanced planning of base station placement and advanced control of wireless communications is needed.

To expand coverage both widely and economically, including suburban and remote areas as well as areas at sea and in the air, various means of communication must be secured by linking wide-area communication methods such as low-earth-orbit satellites and HAPS as well as privately installed networks. For terrestrial coverage, in addition to receiving signals directly from satellites and other stations, the use of coverage integrating ad hoc communications will also be expanded. Customized coverage is also possible, combining carrier communication with local communication, such as Private 5G or other communication infrastructure built according to the specialized needs of local users or a particular community.

B. Wireless and optical sensing

To digitalize every corner of the real world, vast amounts of highly accurate sensing will be required. The speed, capacity, and multi-connectivity of wireless communications will also continue to increase to support the large numbers of cameras needed to digitize everywhere that people are active, as well as the large number of wireless devices required for sensing everything within real world environments. Also, sensing devices that utilize wireless and optical communication technology have great potential.

Wireless sensing

Spatial sensing using radio waves with strong directionality such as millimeter waves and terahertz waves for communication has promise. Existing technologies for the increasingly large numbers of antennas and precise control of narrow beams require no additional equipment when used for sensing. The technology can be used to obtain a range of information used to build digital twins, such as indoor positioning where GPS cannot reach and the position and movements of objects in space.

Optical sensing

Optical communication technology can also be used for sensing nearby conditions by detecting minute vibrations applied to optical fibers used for communications. The coherent optical sensors used in optical communication transmitters and receivers can also be used for sensing to measure the distance to far-away objects and their speed through the

Coherent optical sensor
Indicates characteristics of a light source in optical-fiber sensors and other systems.

Doppler effect
The phenomenon where the observed frequency of sound or electromagnetic waves changes in accordance with the speed of the relative motion of the source and the observer.

Doppler effect.

C. Network operation automation and optimization

Support for heterogeneous networks

Beyond 5G / 6G will bring about the evolution of more advanced mobile networks and combine various types of networks to create increasingly complex and heterogeneous ones.

Examples of such networks include:

- Ultra-dense, compact base station groups for millimeter-wave and terahertz-wave communication
- Complex multi-vendor systems in O-RAN and other open systems
- Private 5G and other private networks
- Ultra-wide-area systems with LEO satellites, HAPS, ad-hoc networks, etc.

These systems will require advanced, end-to-end integrated operations management and performance optimization as needed for each service and application. The process of optimizing networks of different types and administrators as a single network or slicing many types of networks and optimizing each with its own goals must be made easy. The value achieve through this type of optimization is expected to vary, be it a performance factor for the network itself, for the users of the networks, or for the operators providing the service. Some examples are:

- Achieving end-to-end performance objectives such as throughput, latency, or connectivity
- Optimization for a particular mission-critical application
- Efficient resource use or low power consumption
- Minimization of failure downtime or scope of impact
- Minimization of damage from unforeseen attacks
- Optimized system design to handle the uncertainty of demand fluctuation and minimize investment risk
- Maximize returns with admission control and dynamic planning

O-RAN (O-RAN Alliance)
An industry organization initiated to promote open and intelligent radio access networks (RAN)
.

Multi-vendor system
A system built with efficiency and flexibility, combining products from multiple companies and not concerned with uniformly using a particular manufacture

Throughput
The amount of data that a computer or network device can process per unit of time.

Mission critical
A core business information system, such as the online systems of a bank or transport facilities which, would have a major effect on the company if a fault occurred

All of these end-to-end objectives must be achieved on the entire heterogeneous network, supporting radio control of the huge number of densely placed millimeter-wave and terahertz-wave compact base stations and the various components with their own characteristics. To achieve this type of complex, large-scale operations management, a range of research and development, including AI technologies such as those described in the next section, will be needed in the future.

Raising the level of operations management automation

Network operations management must be provided that is optimized to meet the needs of the user. For example, by providing advanced intelligence to telecom carriers to ensure stable operation of increasingly complex systems operated by a small number of people; designing, building, and delivering turnkey systems to local users such as businesses and municipalities; and enabling unmanned operation in the field through advanced automation and operation from cloud centers. It is also desirable to increase the level of automation and operate as an unmanned system or with as little involvement from specialists as possible.

The TM Forum has discussed the following six levels of requirements for a distributed data processing infrastructure automation. Currently, automation at Level 2 or Level 3 has been achieved.

- Level 0 - Manual management
- Level 1 - Assisted management
- Level 2 - Partial autonomous network
- Level 3 - Conditional autonomous network
- Level 4 - High autonomous network
- Level 5 - Full autonomous network

However, with Beyond 5G / 6G, networks will become extremely composite and complex, as discussed earlier, and may already be unmanageable by humans. In that case, in addition to steadily raising the level of automation,

TM Forum
Tele-Management Forum. A global industry organization that studies industry standards in the operations field and promotes interconnectivity.

it may be necessary to use full automation that eliminates human involvement completely and does not require learning from human experience and intuition. When considering medium to long-term network advancement over the next five to ten years with the goal of full automation, it will be necessary to respond to a wide range of uncertainties and possibilities, such as major changes in people's movements and communication behavior and network damage on an unimaginable scale due to a natural disaster.

Advancement and use of AI technology

As described earlier, AI technology is highly anticipated for advancing operations automation and optimization. However, the scope and objectives of optimization and automation continue to expand, and it is difficult to envision a single "all-powerful AI" which solves every problem necessary to raise the level of automation. Flexible research and development will be required, combining a range of mathematical tools specialized for different objectives, such as neural networks (DNN, CNN, RNN, etc.), reinforcement and deep-reinforcement learning, Bayesian theory, genetic algorithms, evolutionary adaptation, graphical models, and Markov models. In the long term, we may also be able to anticipate discontinuous innovations, such as the use of quantum annealing to solve combinational optimization problems.

It will also be difficult to achieve the full automation described earlier by using only AI technology. Full automation requires automation that can handle unexpected events beyond human expectations, and this is difficult for AI trained with existing data or reinforced for particular conditions. AI capable of evolutionary adaption to environmental changes, just as living creatures evolved, may be necessary in the future

Deep neural network (DNN), convolutional neural network (CNN), and recurrent neural network (RNN)
Typical methods used for deep learning. Each is specialized for a particular field, and they can also be used in combination.

Reinforcement learning/ deep reinforcement learning
A machine learning method in which the system achieves optimal system control through trial and error by the system itself. When deep learning is applied to this process, it is called deep reinforcement learning.

Bayesian theory
A theory asserts that the probability of an event occurring in the future can be computed from the frequency that it occurred in the past.

Genetic algorithm/ evolutionary adaptation
Methods for manipulating data, finding optimal solutions, learning, or inferring based on evolutionary thinking.

Graphical model
Represents dependency relationships between probabilistic variables using a graph.

Markov model
A probabilistic model used for systems that change irregularly. The future state depends only on the current state and not on any prior occurrence

D. Distributed data processing infrastructure

At first glance, distributed data processing infrastructure and the various cognition AI or robotics tasks it is used to perform could be regarded as separate technical areas from Beyond 5G / 6G networks. However, to expand to hyper-realistic communication and digital twins, as described in Chapter 2, the integration of communication and AI will be necessary.

Real-time optimization of distributed AI processing

In a distributed data processing platform, the processing content, processing level, processing location, and allocated computer and network resources must each be optimally controlled according to the application or service requirements as well as the state of network and computer resources. This requires not only, for example, optimizing the processing location according to where there are free computer and network resources but also requires optimization that takes into consideration all kinds of conditions and possibilities, such as optimal levying of latency requirements on network latency and computer latency or accommodating probabilistic risk in anticipating fluctuations in radio environments or resource availability.

Co-evolution of communications and AI algorithms

In addition to optimizing processing resources as described earlier, it will also be important in the future to optimize at the algorithm level. AI algorithms that maximize performance according to the dispersive nature and dynamic state of communication environments will evolve. At the same time, various network controls that maximize the performance of the AI algorithms will also evolve.

For example, with image recognition that includes image processing, there are major trade-offs in terms of accuracy, frame rate, communication bandwidth, processing latency, and other factors due to the large amount of computation involved. As such, appropriate design of both the AI algorithm processing and distributed processing is needed so that the AI algorithm can be optimized dynamically according to the network state and that the network control can be adjusted to maximize the performance of the AI algorithm with both being optimized at the same time.

AI algorithms also generally have training and inference phases, each of which has very different patterns of producing and processing data. There are strong interrelations between what sort of learning and inference mechanisms are combined with wide-area distributed processing and how the communications infrastructure is optimized to accommodate them. Since an AI algorithm's performance (precision and processing time) is closely related to the communications infrastructure capabilities and structure, rather than just considering the optimization of processing resources, R&D on both communications infrastructure optimization and the AI algorithm must advance together in the same direction.

Another aspect of the relationship between communications and AI algorithms is the problem of uncertainty and indeterminacy. There are tradeoffs between time accuracy and recognition accuracy with AI algorithms. Communications have, for example, unpredictable delays on wireless segments, which can have real-time effects on the operation of a distributed system, and this must be considered.

If this sort of uncertainty and indeterminacy cannot be handled, the type of world described in Chapters 1 and 2 could become extremely unstable and dangerous. Unlimited system performance and unlimited algorithm accuracy cannot be a requirement, so a breakthrough to deal with these issues in some way is needed.

Large-scale computation platform

A large amount of computation required for AI processing can be accelerated by two types of platforms; either on the edge or in the cloud. In the past, using high-performance CPUs or GPUs with edge computing was difficult due to cost and power constraints. More recently, however, low-cost, high-performance AI processing engines have become available, and their performance will increase in the future. In the cloud, we can also anticipate new computing paradigms, such as using quantum annealing to process large-scale optimization problems. As the performance of edge and cloud platforms increases in these ways, it will also be necessary to optimize the distributed AI processing described earlier to handle data and processing platform characteristics that are more advanced.

E. Security, trust, and privacy

This Whitepaper divides the scope of Beyond 5G / 6G into communications infrastructure and distributed data processing infrastructure, and each of these must be considered with respect to security.

Communications infrastructure security

Security of communications infrastructure must be considered from a range of viewpoints, including maintaining stability in the face of external attacks on the infrastructure (handling a distributed denial of service (DDoS), etc.), preventing data leaks or falsification, as well as preventing spoofing or unauthorized use. Focusing on future environmental changes such as network systems becoming more open, the interconnectivity of various systems, heterogeneous network structures, and possible major effects from geopolitical issues, managing the reliability of communications infrastructure could become a major issue. Communications infrastructure is heterogeneous, with carrier networks, local networks, and satellite and ad-hoc networks, all composed of many different types of devices. Some of these devices can enforce security measures properly, as with an ordinary server device. Still, other devices, such as compact base stations and gateways, do not have the processing capacity to enforce full security measures easily. These

Ad-hoc network
A network composed of wireless connections between terminals only, not using access points or dedicated base stations. Because it uses direct connections without an intervening base station, it is promising for situations such as communication during a disaster

networks are also managed with differing policies for each management area and may adhere to different security levels.

However, communication itself is conducted end-to-end, and ordinary users cannot know or control what devices or management areas it passes through. This means that any vulnerability in a single network location can compromise security. As such, users for their entire end-to-end communication path and area managers for the entire networks under their management must ensure that all devices comprising the network and all software on those devices are authentic and that nothing posing a security risk has slipped into any of the regular updates. To achieve this, important technologies in the future will include scalable hardware and software tamper-detection technology that can handle servers and small devices, as well as scalable blockchain technology that can safely register and reference results of such detection across different management areas.

Data processing infrastructure security

The data processing infrastructure directly handles digital twins, which are copies or virtual representations of information in the real world. These, in turn, feed back into and affect the real world, and therefore security, trust, and privacy assurance in the data processing infrastructure are all crucial. As such, technologies that ensure the infrastructure can reliably address the concerns associated with digital transformation and technologies that visualize risks and automatically respond to risks will become important. In addition, in order to promote the utilization of data while maintaining security and privacy, technologies such as secure computation, which enables searches and computation of feature values while data is encrypted, will also become increasingly important.

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