Trends and Target Implementations for 5G evolution & 6G

Yoshihisa Kishiyama, Satoshi Suyama, and Satoshi Nagata

Abstract

In Japan, commercial 5th-generation mobile communication systems (5G) services first became available in March 2020. Studies of the next generation of communication services (6G) and the telecommunication technology of the 2030s are now gathering momentum. This article provides a summary of the domestic and international trends and schedule prospects for 6G research and development, and the 5G evolution & 6G concept proposed in the DOCOMO 6G White Paper.

Keywords: 5G evolution & 6G, requirements, wireless technology

1. Introduction

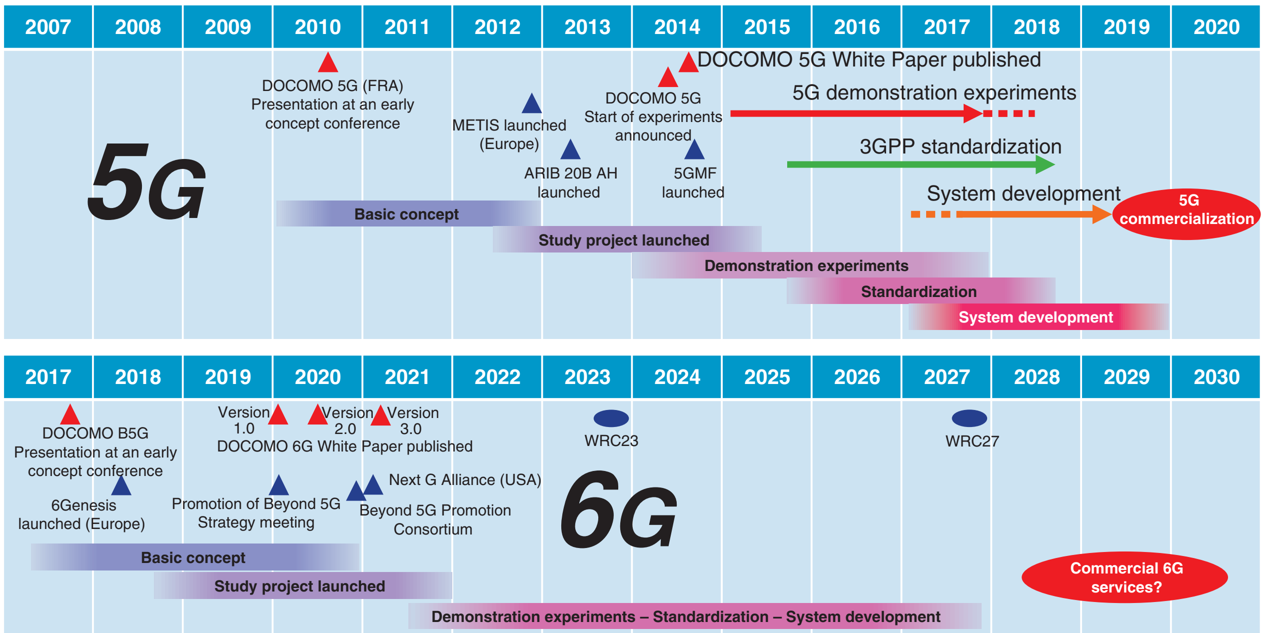
Mobile communication systems have been continuously developing and evolving, with a new generation of systems coming out roughly once every decade. In the 1980s and 1990s, the 1st and 2nd generations mobile communication systems (1G and 2G) mostly supported voice calls, with some support for simple messaging functions. With the arrival of 3G in the 2000s, it became possible for anyone to access multimedia content such as photos, music, and video. And from 2010, the launch of 4G with Long Term Evolution (LTE) technology capable of speeds in excess of 100 Mbit/s supported the explosive spread of smartphones. Then in March 2020, Japan's first 5G services were launched, offering maximum transmission speeds of over 4 Gbit/s.

5G includes technical advances such as high speed/large capacity communication, low latency, and the ability to connect to multiple terminals simultaneously. It not only improves on the multimedia communication capabilities of 4G, but is also expected to create new value as an infrastructure technology for business and society in the fields of artificial intelligence (AI) and the Internet of Things (IoT). In particular, the combination of 5G and AI technology is expected to lead to the creation of new services and solutions in diverse industrial fields by enhancing "cyber-physical fusion"*1 whereby the real world is recreated in cyberspace to facilitate future predictions and the acquisition of new knowledge. Since this trend is likely to continue until the 2030s, it is necessary to promote research and development so that 5G evolution and 6G can provide the fundamental technological infrastructure for industry and society in the 2030s. This article presents a summary of the domestic and international trends in 6G technology, and the expected schedules for the introduction of this technology. It also discusses the 5G evolution & 6G concept proposed in the DOCOMO 6G White Paper [1].

2. 6G trends and schedules

Figure 1 shows the development history of 5G and the schedule for the introduction of 6G. Following the launch of 4G LTE services in 2010, NTT DOCOMO began studying 5G with the aim of implementing services by around 2020. In our 5G White Paper of 2014, we announced the start of 5G demonstration experiments in cooperation with major global vendors. Discussions on the international standardization

*1 Cyber-physical fusion: Services and systems for realizing a better and more advanced society by collecting information in real space (physical space) from various sensors, etc. and linking it to virtual space (cyberspace).



ARIB 20B AH: Association of Radio Industries and Businesses 2020 and Beyond Ad Hoc
5GMF: The Fifth Generation Mobile Communication Promotion Forum
FRA: Future Radio Access
METIS: Mobile and wireless communications Enablers for the Twenty-twenty Information Society
WRC: World Radiocommunication Conference

Fig. 1. 5G development history and 6G schedule.

of 5G began at the 3rd Generation Partnership Project (3GPP) in around 2015, and the first commercial 5G services were launched overseas in 2019 based on the Release 15 specification (the first international 5G standard) [2].

In contrast, worldwide discussions on the standardization of 6G for the 2030s tended to start earlier. This can be attributed to the impact of global competition in the development of 5G. Projects studying 5G in Japan and overseas gradually took shape from around 2012, which preceded the launch of 5G by about 8 years. On the other hand, discussions related to 6G started in around 2018, which precedes the expected launch by 12 years. These include the 6Genesis Project led by Oulu University in Finland, and the efforts being made in the United States following then President Trump's call for stronger efforts in the development of 6G in 2019 and the decision by the Federal Communications Commission to make terahertz waves*2 available for research purposes [3]. In Japan, the Ministry of Internal Affairs and Communications (MIC) launched the Beyond 5G Promotion Strategy Roundtable in January 2020 to formulate a comprehensive strategy for Beyond 5G*3, and published a roadmap outlining the expectations for telecommunications infrastructure in the 2030s and the direction of policies to achieve these targets [4]. Then in December 2020, the Beyond 5G Promotion Consortium was established to promote strong and proactive collaboration between industry, academia, and government on 6G technology [5].

At NTT DOCOMO, we have been studying Beyond 5G since around 2017 [6], and released the first version of the DOCOMO 6G White Paper in January 2020. This is currently being updated to version 3.0 [1]. In addition, research institutes and major vendors in Japan and other countries have also released a slew of white papers related to Beyond 5G and 6G. Compared to the launch of 5G studies, it can be seen that there is a more positive trend towards 6G around the world.

In the future, it is expected that demonstration

*2 Terahertz waves: Electromagnetic waves with a frequency of around 1 THz. Often used to refer to frequencies ranging from 100 GHz to 10 THz.

*3 Beyond 5G: A term that is widely used to describe wireless communication systems that emerge after 5G. It is almost synonymous with "6G."

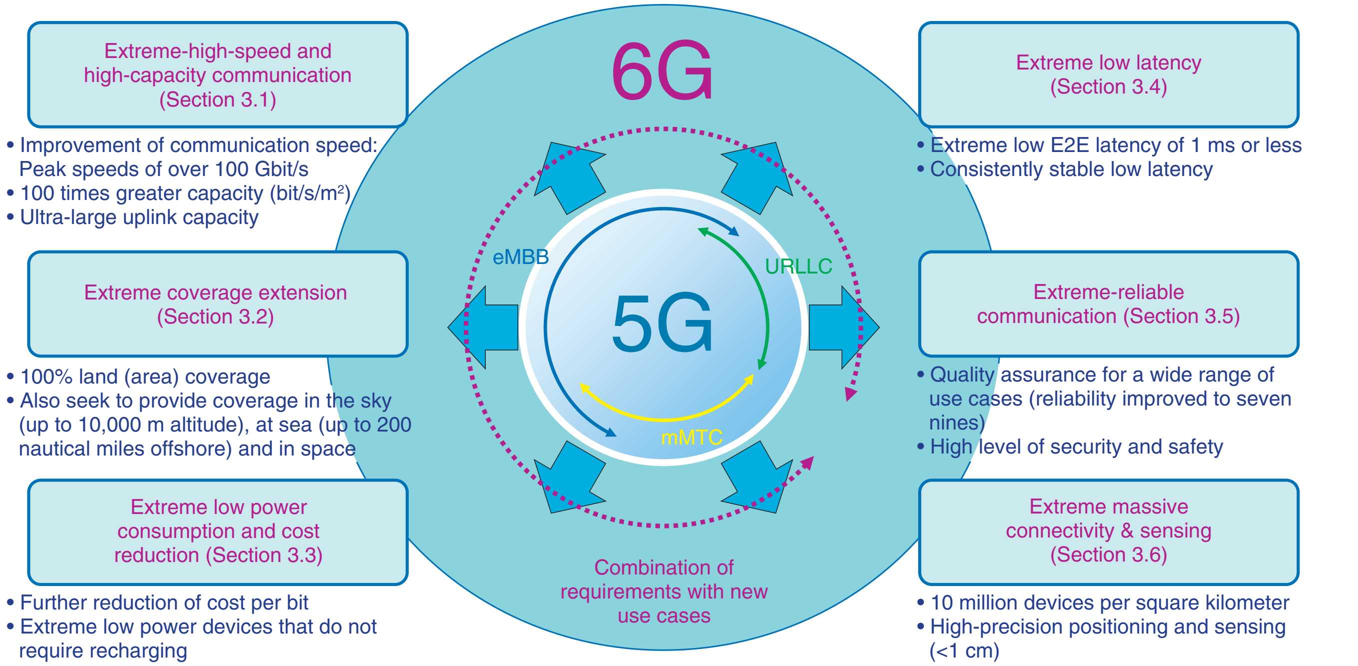


Fig. 2. Requirements for 6G.

experiments and international standardization efforts will be promoted with the aim of introducing 6G commercial services by 2030.

3. 5G evolution & 6G target implementations

In the following, we will describe the concept of 5G evolution & 6G as proposed in the DOCOMO 6G White Paper. **Figure 2** shows the six requirements that we aim to achieve in 6G based on 5G evolution. These include the requirement for further performance enhancements compared with 5G, and are expected to cover a wider range of features in new areas that are not supported by 5G or earlier systems. These requirements and their expected use cases are summarized below.

3.1 Extreme-high-speed and high-capacity communication

Communication systems with higher communication speeds and larger communication capacities are universal requirements for all generations of mobile communication systems. With 6G, it should be possible to combine extremely high speed and ultra-large capacity so that large numbers of users can enjoy services at the same time. As communication speeds approach the speed at which information is processed by the human brain, it should become possible to realize not only video (visual and auditory) transmission, but also sensory communication that conveys a sense of reality by involving the five senses, and "multi-sensory communication" that includes other sensations such as atmosphere and a sense of security. In order to implement these unprecedented extreme-high-speed and high-capacity communication services, user interfaces will have to exceed what can be implemented on a smartphone. For example, it is expected that new interface technologies will evolve to support features such as three-dimensional holographic playback and wearable devices such as eyeglass-type terminals. It is also expected to be possible to share these new sensory-type services among multiple users in real time through the use of ultra-high capacity communication, thereby facilitating new synchronized applications such as shared experiences and cooperative work in cyberspace. Furthermore, if industrial use cases and trends such as cyber-physical fusion are taken into consideration, it is particularly important to achieve much higher speeds and capacities in the uplink*4 because it will be necessary to transmit diverse real-world information in real time to the cloud and AI processes that constitute the

*4 Uplink: The flow of information from terminals to the network.

"brains" of the network.

3.2 Extreme coverage extension

In the future, communications will become as ubiquitous as the air, and will provide a lifeline of equal or even greater importance than electricity and water supplies. 6G should therefore aim to provide the maximum possible service area so that mobile communications services are available everywhere. For this reason, the aim is to provide 100% coverage over all the world's lands. With the establishment of communication areas in other environments and the commercial development of space, there are also plans to extend this coverage to include air, sea, and space environments where existing mobile communication systems do not operate. As a result, we can expect further expansion of the environment for activities involving people and things, and the creation of new industries. Promising examples include logistics applications such as drone home delivery, and the use of unmanned and/or more sophisticated technology in primary industries such as agriculture, forestry, and fisheries. In the 2030s, it could also be applied to more futuristic use cases such as flying cars, space travel, and underwater travel.

3.3 Extreme low power consumption and cost reduction

Reducing the power consumption and cost of networks and terminals in mobile communication systems is an important challenge for realizing the sustainable society that the world needs in order to address global environmental issues. Assuming that network traffic will continue to increase in the future, we aim to significantly reduce the per-bit power consumption and cost of communication. For example, if communication traffic increases a hundredfold, the per-bit capital investment and operating costs should be reduced to less than 1/100th to achieve both high performance and economy.

Furthermore, there are also expectations that the terminal devices of the future will not require charging due to the development of power supply technology using wireless signals and technology for reducing the power consumption of devices. The need for this technology will become even greater if (as expected) the number of terminals such as sensor devices grows due to the increased sophistication of cyber-physical fusion and the growth of use cases involving wearable user interfaces.

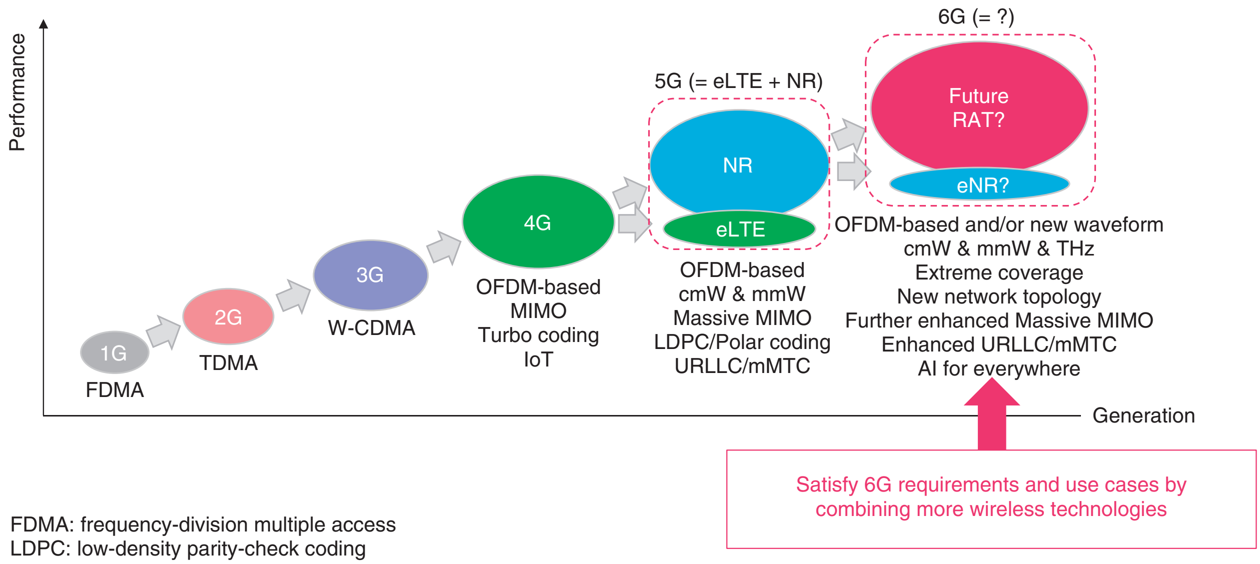
3.4 Extreme low latency

In cyber-physical fusion, the wireless communication that connects between AI processes and devices is equivalent to the nerves that transmit information in the human body. To implement more advanced remote services based on real-time interactive AI, a basic requirement is end-to-end (E2E) communication with low latency that is always stable. Our goal is to achieve E2E with extremely low latency of 1 ms or less. This will enable lag-free services to provide immediate feedback from cyberspace, and will allow robots and other devices that are remotely controlled by AI to approach or exceed the capabilities of humans in terms of performing agile movements and/or understanding subtle cues. For example, a robot controlled remotely by AI may be able to instantly determine a user's needs based on cues such as the user's tone of voice and facial expression, allowing it to respond with at least the same level of consideration as a human would be able to achieve. This could be particularly important in the post-coronavirus era, when extreme low-latency communication will be essential in such fields as teleworking, remote control, telemedicine, and distance learning.

3.5 Extreme-reliable communication

When radio communication is used for industrial and lifeline applications, reliability is a key requirement. In particular, in some industrial use cases, such as the remote control of industrial equipment and factory automation, the quality and availability of communication have a significant impact on safety and productivity. Extreme-reliable communication is therefore an important prerequisite for ensuring the required levels of performance and safety, and 6G is expected to surpass 5G in terms of reliability and security. For ultra-reliable and low latency communications (URLLC), researchers are studying how to achieve a "six nines" level of reliability (99.9999%) in 5G. For 6G, a target of "seven nines" (99.99999%) is assumed.

Attention is also being drawn to non-public networks that are specialized for industrial use and depart from the best-effort services of public networks such as private 5G. URLLC technology is mainly being considered for limited areas such as factories. On the other hand, in the future, as robots and drones become more widespread and wireless coverage expands to the air, sea, and space, it will be necessary to provide reliable communication over a wider area.



FDMA: frequency-division multiple access
LDPC: low-density parity-check coding
mMTC: massive machine type communications
TDMA: time-division multiple access
W-CDMA: Wideband Code Division Multiple Access

Fig. 3. Technological development of mobile communication systems towards 6G.

3.6 Extreme massive connectivity & sensing

With advances in cyber-physical fusion, there is expected to be a massive proliferation of communication-related devices used by people and things, and it is considered that 6G will have to support ten times the connectivity of 5G (i.e., 10 million devices per km^2). For human users, there are expected to be use cases in which cyberspace provides real-time support for people's thoughts and actions via wearable devices and micro-devices attached to the body. It is also expected that cyberspace will provide links between all manner of things, including cars and other vehicles, construction machinery, machine tools, surveillance cameras, and diverse sensors. This will make it possible to realize a world where cyberspace supports industry and transportation, provides solutions to social issues, and helps people to enjoy safe, secure, and affluent lifestyles.

Furthermore, the wireless communication network will itself be equipped with functions for sensing the real world, such as using radio waves to measure the position of terminals and detect surrounding objects. These position measurements are expected to achieve ultra-high accuracy with an error of no more than a few centimeters in some environments. In wireless sensing, it is expected that the combined use of radio waves and AI technology will be able to support object identification and behavior recognition in addition to highly accurate object detection.

4. Development of wireless technology in 5G evolution & 6G

Figure 3 illustrates the development of technology from previous mobile communication generations to 6G. Earlier generations had a single representative technology (RAT: radio access technology)*5 that they used for radio access, but since 4G, mobile communication has used multiple technologies based on orthogonal frequency division multiplexing (OFDM).*6 As a result, RAT now comprises a mixture of wireless technologies, resulting in extended technological development. This is because OFDM-based radio technology has already achieved frequency utilization efficiency*7 close to the Shannon limit*8, while the requirements for mobile communication systems, frequency bands, and use cases are

*5 RAT: Radio access technologies such as New Radio, LTE, W-CDMA, and GSM (Global System for Mobile Communications).
*6 OFDM: A digital modulation method where information is divided into multiple orthogonal carrier waves and sent in parallel making for high spectral efficiency in transmission.
*7 Frequency utilization efficiency: The number of bits of information that can be sent per unit time and unit bandwidth.
*8 Shannon limit: The theoretical maximum rate at which information can be transmitted through a communication channel of a given bandwidth and signal-to-noise ratio.

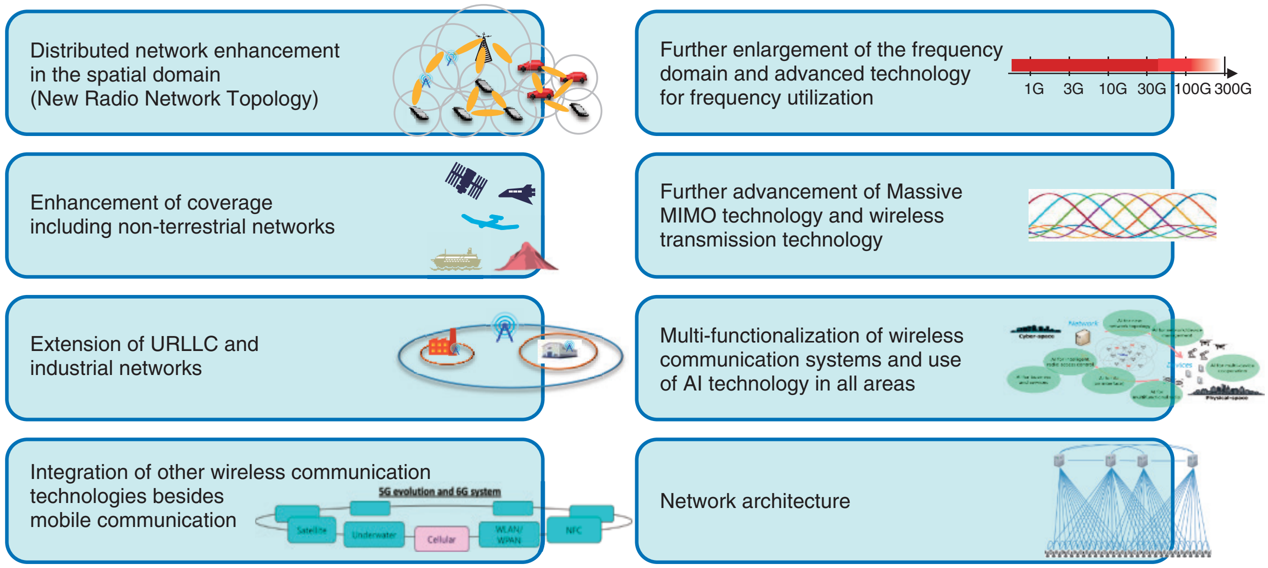


Fig. 4. Technology areas that need to be considered for 5G evolution & 6G.

continuously being expanded.

Therefore, 6G will require the combination of even more radio technologies after 5G evolution, and it will also be necessary to consider how these combinations can be extended to include technologies other than mobile communication in order to fulfil the above requirements and various use cases. In addition, whereas 5G was defined by the combination of LTE enhancements and New Radio (NR)[*9], the NR aspect of 5G is designed to be highly expandable to accommodate the future introduction of new technologies. It will therefore be necessary to discuss the definition of RAT in 6G.

The technology areas that need to be considered for 5G evolution & 6G are shown in **Fig. 4** [1]. With an advanced spatially distributed network technology (New Radio Network Topology), communication will be performed via the shortest possible distance and by line of sight (the path of least loss) wherever possible. Also, as many communication paths as possible will be created to provide a broader selection of paths (greater redundancy). In this way, we will pursue wireless communication with extreme high speed, high capacity (especially in uplinks) and improved reliability. To achieve this, we need to figure out how to economically implement a distributed antenna deployment to build a distributed wireless network topology[*10] in the spatial domain.

This extended coverage technology will include non-terrestrial networks (NTNs) by incorporating geostationary satellites, low-orbit satellites, and high-altitude platform stations (HAPSs), allowing it to provide coverage in remote mountainous areas, out at sea, and even in outer space. 3GPP has already begun studying the use of satellite and HAPS systems to expend NR to NTNs.

For further expansion in the frequency domain and technology for making more advanced use of frequency resources, we will establish wireless technology for 6G that is capable of working with millimeter waves and terahertz waves in the 100 to 300 GHz range (above the frequency bands used by 5G). To study these frequency bands, we will also need to clarify their radio wave propagation characteristics, build propagation models, and address any technical issues that arise in devices using these frequencies.

With the multifunctional use of wireless communication systems and the pervasive use of AI technology, it will be possible to analyze not only information obtained by radio waves, but also video pictures and information obtained by diverse forms of sensing, thereby facilitating various benefits, including advanced control of wireless communication, high-precision measurements of positions and distances, object detection and wireless charging systems.

*9 NR: A radio system standard formulated for 5G. Compared with 4G, it enables faster communication by utilizing high frequency bands (e.g., 3.7 GHz and 28 GHz bands), and low latency and highly reliable communication for achieving advanced IoT.

*10 Topology: The location and network configuration of devices.

We will also need to carry out a fundamental review of the 6G network architecture in order to accommodate additional future requirements and keep abreast of changes in the market, while considering how to optimize the deployment of functions and the generalization of equipment across the entire network, so there are still many network design issues that need to be resolved.

Although this article has skimmed over the details of each technical area, discussions of related research and development activities can be found elsewhere in this issue [7–9].

5. Conclusion

In this article, we have presented an outline of domestic and international trends and schedule prospects for 5G evolution & 6G, and the concepts proposed in the DOCOMO 6G White Paper. At present, studies are being vigorously pursued by the Beyond 5G Promotion Consortium and 6G-related projects in Japan and overseas, and we hope to continue contributing to discussions of 6G among various stakeholders from industry, academia, and government.

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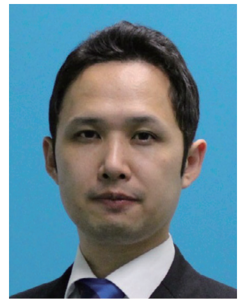
Trademark notes

Yoshihisa Kishiyama
Manager, 6G-IOWN Promotion Department, NTT DOCOMO, INC.

He received a B.E., M.E., and Ph.D. from Hokkaido University in 1998, 2000, and 2010. Since joining NTT DOCOMO in 2000, he has been involved in the research and development of 4G and 5G radio access technologies, including concept development, standardization, and trials. He is currently working on "5G evolution & 6G" and is the main author of "DOCOMO 6G White Paper." He has more than 400 granted patents in the area of mobile communications. In 2012, he received the ITU Association of Japan Award for his global contributions to LTE.

Satoshi Suyama
Manager, 6G-IOWN Promotion Department, NTT DOCOMO, INC.

He received a B.E., M.E., and Dr.Eng. from Tokyo Institute of Technology in 1999, 2001, and 2010. From 2001 to 2013, he was an assistant professor at Tokyo Institute of Technology. Since joining NTT DOCOMO in 2013, he has been involved in research and development of 5G/6G radio access technologies. He received the Best Paper Prize from the European Wireless Technology Conference (EuWiT) in 2009, the Best Paper Award from the International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) in 2016, and the Paper Award from the Institute of Electronics, Information and Communication Engineers (IEICE) in 2012.



Satoshi Nagata
Senior Manager, 6G-IOWN Promotion Department, NTT DOCOMO, INC.

He received a B.E. and M.E. from Tokyo Institute of Technology in 2001 and 2003. In 2003, he joined NTT DOCOMO, where he was engaged in research and development of wireless access technologies for LTE, LTE-Advanced, and 5G. He is currently a manager working for 5G and 3GPP standardization. He has been contributing to 3GPP over 10 years. He served as a vice chair of 3GPP TSG-RAN WG1 from November 2011 to August 2013, and a chair from August 2013 to August 2017. He also served as a vice chair of 3GPP TSG-RAN from March 2017 to March 2021. He has been a vice chair of 3GPP TSG-SA since March 2021.