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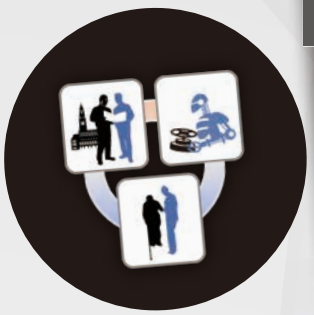
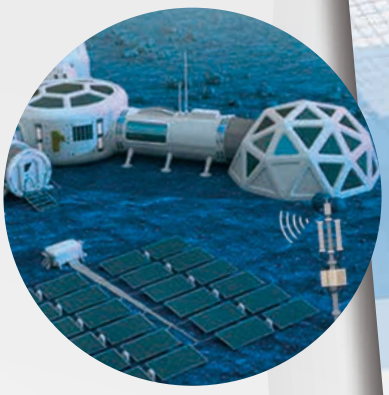
FEATURE

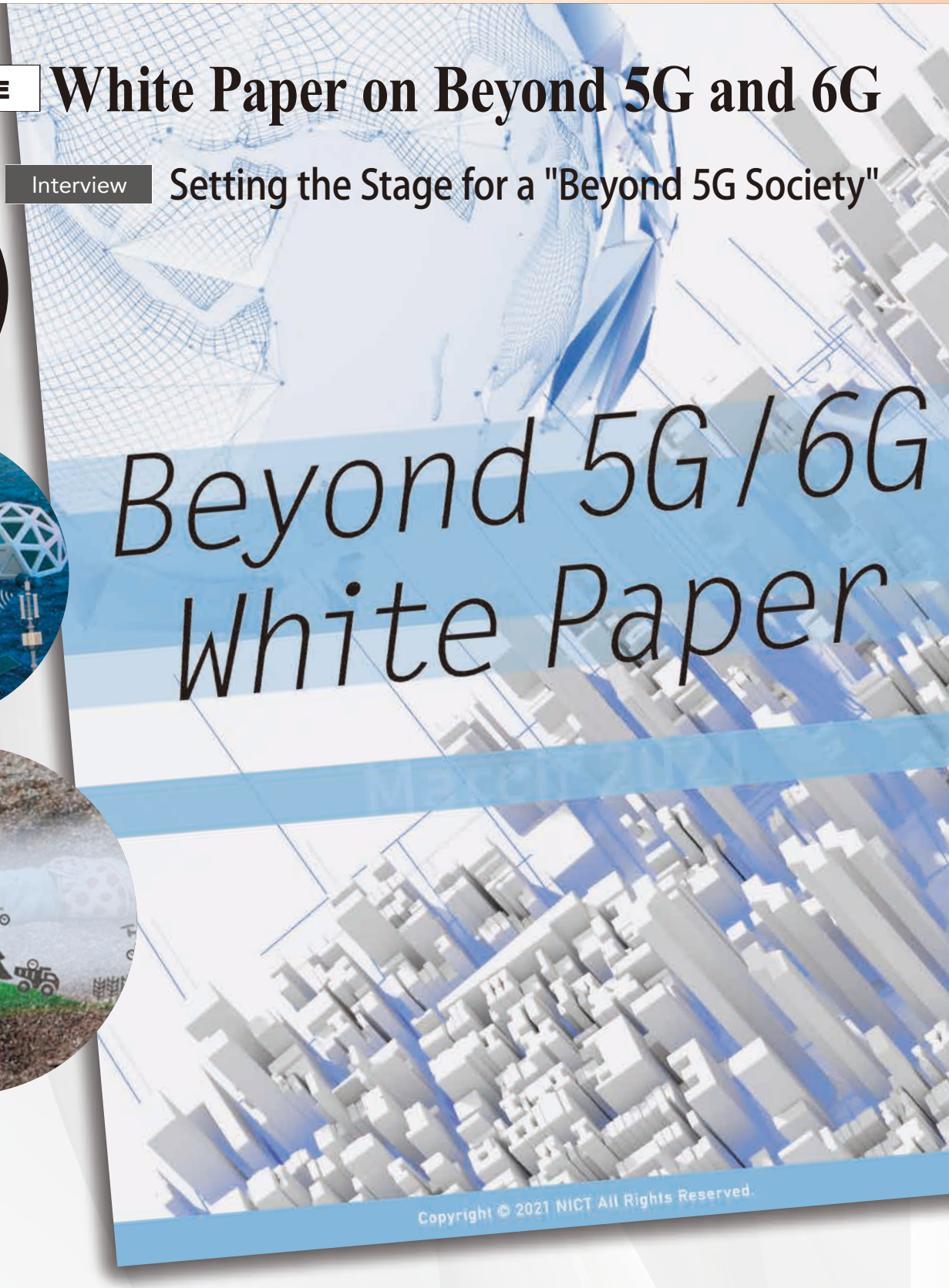
White Paper on Beyond 5G and 6G

Interview

Setting the Stage for a "Beyond 5G Society"







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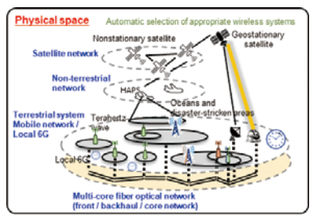

Cover Photo: The Beyond 5G / 6G White Paper introduced in this special feature

The Beyond 5G / 6G White Paper, published by NICT originally in Japanese in March 2021, is a discussion and compilation by volunteers at NICT that transcends research fields and occupations. The white paper, while imagining a future society around 2035 and showing it in a narrative format, backcasts from there and identifies the technical issues that need to be researched and developed going forward. The three illustrations on the left, "Cybernetic Avatar Society", "City on the Moon", and "Transcending Space and Time", show scenarios from the future society.

Upper Left Photo: Physical space in Beyond 5G / 6G

Beyond 5G / 6G will enable the creation of new applications that can solve social issues by removing a variety of restrictions via organically fusing physical space and cyberspace and then accurately controlling and using them. In physical space, terahertz communication systems, non-terrestrial / satellite mobile systems, optical networks, high-precision spatio-temporal synchronization, and infrastructure will be combined, and this will not only greatly improve the performance of mobile communications, but also greatly improve their range, flexibility, and mobility, etc.

FEATURE

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Interview

TOPICS

Interview

Setting the Stage for a "Beyond 5G Society"

HOSAKO Iwao
Executive Director of Unit, Beyond 5G Research and Development Promotion Unit
He joined the Communications Research Laboratory (currently NICT), under the Ministry of Posts and Telecommunications, in 1996. He has promoted R&D on terahertz technologies, including devices, cameras and communications systems, and has worked to achieve standardization of these technologies. Ph.D. (Science)

ISHIZU Kentaro
Director of Beyond 5G Design Initiative, Beyond5G Research and Development Promotion Unit
He joined NICT in 2005. He has been involved with R&D on cognitive radio, TV white space communication, self-operated 5G system such as Local 5G and so on. He is currently director of Beyond 5G Design Initiative and leading the strategy planning for Beyond 5G R&D of NICT.
Ph.D.(Information Science)

"Beyond 5G" means the technologies beyond the new standard for "5G" communication infrastructure, which is currently being introduced. In addition to bringing about major changes in society as a whole, including in our lives, industry, medical care, education, and disaster prevention, etc., Beyond 5G is also an important keyword for Japan's scientific, technological, and industrial strategies.

The Beyond 5G Research and Development Promotion Unit (Beyond 5G R&D Promotion Unit) was established in April 2021 as an organization that accelerates research and development while coordinating, both inside and outside of NICT, towards this Beyond 5G society. We spoke with HOSAKO Iwao, the head of the Beyond 5G R&D Promotion Unit, and with ISHIZU Kentaro, the head of the Beyond 5G Design Initiative, which is under the Beyond 5G R&D Promotion Unit, about the background of its establishment, its role, and the future development of Beyond 5G.

Organization and Role of the Beyond 5G R&D Promotion Unit

——The Beyond 5G R&D Promotion Unit was launched in April alongside the start of NICT's Fifth Medium-to-Long-Term Plan, so can you tell us about its role and the background to its establishment?

HOSAKO NICT's Fifth Medium-to-Long-Term Plan lists "AI," "Beyond 5G," "Quantum Information and Communications," and "Cybersecurity" as four areas of research that should be strategically pursued (four strategic areas). Beyond 5G is one of these strategic areas, and the Beyond 5G R&D Promotion Unit is a newly established organization that acts as a control tower for the research conducted by NICT as a whole.

In the rest of the four strategic areas, whether that be AI or Quantum Information and Communications, the individual organizations can deal with each other on a one-to-one basis, but Beyond 5G spans an extremely wide range of technical fields and needs to be addressed by NICT as a whole. Therefore, it can be said that the role we are expected to play is to bring everything together well by aligning all the various organizations in each area of research.

As for concrete movements leading to its establishment, originally, as NICT and with the aim of promoting research and development of Beyond 5G, volunteers gathered and held discussions about social images and use cases that will be realized by Beyond 5G, as well as the necessary elemental technologies and research and development roadmap to get there. These discussions were eventually compiled into a white paper and published in March 2021 as the "Beyond 5G / 6G White Paper (Japanese ver. 1.0)," and in August(English ver1.0).

At the same time as these discussions, NICT's Fifth Medium-to-Long-Term Plan

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was being formulated, and we think that the establishment of the organization was also conceived of in parallel.

——What kind of organizational structure does the Beyond 5G R&D Promotion Unit have?

HOSAKO Under the Beyond 5G R&D Promotion Unit, there is the General Planning Office and, as a large organization, there is the Terahertz Technology Research Center. The Terahertz Technology Research Center is located under the Beyond 5G R&D Promotion Unit because it is likely that extremely high-frequency bands will be used in the future mobile communications world.

On the other hand, outside of the Terahertz Technology Research Center, the Beyond 5G Design Initiative is an organization directly under the Unit, and, as stated earlier, they specialize in the role of "acting as a control tower for Beyond 5G."

Apart from these organizations, there are also projects, and, as one of our current projects, we are conducting research and development of radio wave emulators under commission of the Ministry of Internal Affairs and Communications' "Advancing Radio Wave Simulation System Technologies in Virtual Space" project. Radio wave emulators are real-time simulations of complicated and large-scale radio wave systems in a virtual space. It will be necessary to use radio waves in all directions, particularly in the world of Beyond 5G, which is why the large-scale verification of radio systems is extremely important and the reason why this project is under our Unit. Another reason may be that it is a horizontal process that involves people from a variety of research institutes at NICT.

ISHIZU The Unit was established as the core of promoting Beyond 5G, but, among its organizations, the Terahertz Technology Research Center is the section that actually promotes the research and development of the elemental technologies that will be essential for Beyond 5G. On the other hand, the Beyond 5G Design Initiative is formulating and executing a strategy for NICT to work together with the outside world.

A White Paper that Shares the Vision with Many People

——Under such circumstances, can you tell us about the meaning of the "Beyond 5G / 6G White Paper (ver. 1.0)" that was released this spring?

HOSAKO A variety of stakeholders are involved with Beyond 5G, and we think that it is important to make good use of the white paper as a tool for promoting discussions with those stakeholders.

Of course, we will continue to further discuss it within NICT and update the contents as needed, and, because our discussion partners are not limited to Japan, we are also producing an English version in addition to the Japanese version.

We released version 0.9 of the English white paper on April 30, approximately one month after we released the Japanese version. The meaning of the "version 0.9" is that English documents like this are usually proofread, but we wanted to release it "as soon as possible," so we produced it using an automatic translation system called "TexTra" that was developed by the Advanced Speech Translation Research and Development Promotion Center, so it also has the meaning of promoting NICT's technology. White papers come out one after another from a variety of institutions around the world, so it's better to get it out and read sooner instead of taking the time to publish a perfect English version.

——What has been the actual response to the white paper?

ISHIZU The number of downloads has increased into the thousands, and we have also directly received many opinions on it.

In chapter 3 of this white paper, entitled "What will the daily life be like in the Beyond 5G/6G Era?" we drew an image of a future society, assuming it to be around 2035, and particularly for this portion, we made it into a story without research elements, so that the general public can easily read and understand it. This received a lot of praise, with people saying, "It's easy to understand what you're aiming for."

Having a story like this may make it easier to imagine, not just for the general public, but also for researchers. Beyond 5G is not limited to mobile communications, but is a concept that will be the foundation of a new world, and we must attract more and more people from new fields. In that sense, the white paper is meaningless if it can only be read by "people who understand the language of the world of communication technologies," and instead, it must be something that people in completely different fields will read and become interested in, and that they will be able to think interesting things will happen by joining these efforts.

Actually, we didn't calculate it to that extent from the beginning, but, in the end, we think that a composition like this was a success.

HOSAKO In fact, at NICT, there have been instances until now when the individual laboratories that set the stage for the "Beyond 5G Society" issued white papers, but this Beyond 5G / 6G White Paper and the Quantum Networks White Paper, which was published

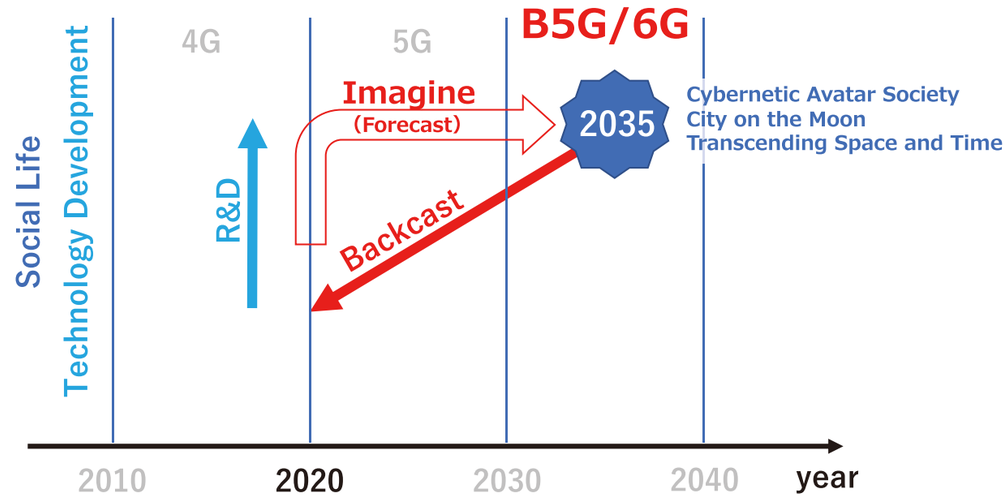

Figure 1 Imagining the future around 2035, and backcasting to identify technical issues for B5G

at the same time, are probably the first ones to be issued by the effort of NICT interdepartmental teams.

This was the first time we had taken on a challenge like this, but it was fairly quick in terms of time, and, as mentioned above, the content was very characteristic, so we are glad that we were able to publish it in a form that didn't get buried amidst the numerous other white papers that come out. It attracted widespread interest and also got us the opportunity to be invited to international lectures, etc., so it was a good start. In the future, we hope to make better use of this and provide opportunities for even further discussions.

In Order to Show a Presence in Beyond 5G

——Tell us about your future activities and prospects, etc.

HOSAKO We think that Beyond 5G, and especially 6G, will be implemented in society in the latter half of the 2030s, but how will Japanese technology fit into that, and how much can NICT contribute to that? We think that will measure the results of our activities.

Of course, we also just can't repeatedly issue white papers and nothing else, and we have to think about how we can be involved with the actual movements.

In the case of a private company, they are a business and the research results can be reflected in their own network. On the other hand, we are a national research institute, and we do not make products or services as output, so in that respect, it can be difficult to reflect our results. As such, standardization is still a major point when considering how to utilize our achievements in actual society.

This is a relatively easy example of a future time schedule, but, as a standardization step, discussions on what frequency bands can be used have begun within the Radiocommunication Sector of the International Telecommunication Union (ITU-R), and NICT is also participating in these discussions. In 2023, ITU-R will issue a Vision Recommendation, and how much you can reflect your opinions here is one aspect of the contest.

Furthermore, in response to the Vision Recommendation, 3GPP, which is a standardization organization for mobile systems that are common throughout the world, will need to establish it as an actual mobile phone system, and will proceed with getting agreement from each organization, and we hope that the concepts NICT considered will be implemented.

——Thank you very much.

NICT
Beyond 5G Research and Development Promotion Unit

Figure 2 Logo of Beyond 5G Research and Development Promotion Unit
The Beyond 5G R&D Promotion Unit's logo is characterized by the exciting future that fills the box, which was created by all the people who came up with ideas from the "various aspects of Beyond 5G," such as technologies and businesses in different fields. Its color tone is the blue in the NICT logo, and incorporates the passion of maximally utilizing NICT's wisdom.

Concept of Beyond 5G and its Open System Architecture
-A World to be Created by the Cyber Physical System

ISHIZU Kentaro

Director of Beyond 5G Design Initiative, Beyond5G R&D Promotion Unit

He joined NICT in 2005. He has been involved with R&D on cognitive radio, TV white space communication, self-operated 5G system such as Local 5G and so on. He is currently director of Beyond 5G Design Initiative and leading the strategy planning for Beyond 5G R&D of NICT. Ph.D.(Information Science)

In addition to increasing the sophistication and diversity of information communication systems in the real world (physical space) and by combining information learning and analysis in the virtual world (cyberspace), Beyond 5G will be a fundamental societal infrastructure that realizes things that were considered to be limits via conventional technologies. Together, let's consider what kind of world that will be and the composition of the systems that will realize it.

Changes in the Shape of Societal Infrastructure and the Form of Communications Systems

The various infrastructures and resources that support societal activities are undergoing major changes in usage patterns, from centralized to decentralized and from monopolized to shared. In the so-called sharing economy, concrete examples include car sharing for transportation, coworking for working environments, and crowd funding for finance.

Communications environments are not an exception to this trend. The use of so-called SDN (Software-Defined Networking) and NFV (Network Function Virtualization) have been promoted due to the emergence of highly scalable virtual machine configuration technologies such as white box hardware and open-source software, and it is expected that sharing network resources in smaller units will be possible. As for mobile radio systems, their functional compositions have been revised via architecture formulated by the 3GPP, and it is becoming easier for multiple operators to share base stations and control devices (radio access networks). Systems with new characteristics, such as NTNs (Non-Terrestrial Networks) which utilize satellites and HAPS (High Altitude Platform Stations) which fly in the stratosphere, are also physically limited resources, but they will be shared by numerous users and will play a part in end-to-end communications. For frequencies as well, there is consideration of systems that give priority according to location and time zone and that are capable of sharing interchangeable, dynamic frequencies with other systems, and it can be said that they are advanced resource sharing.

If infrastructure and resources can be shared in appropriate units in these ways, then, by combining the right people in the right places, the creation of innovative services and services linked with technologies from different fields will be accelerated. In order to make this possible, it will be necessary to define the systems via an open architecture, to provide functionality (an orchestrator) that instructs function assembly via a consistent policy according to service requests, and to establish a system that can operate those parts.

What is the Fusion of Cyberspace and Physical Space?

The Beyond 5G era requires the collection, learning, and analysis of large amounts of diverse information to optimize social activities. This information includes everything other than the communication environment, such as the locations and speeds of cars and drones, the flow of people within a city, and the weather. Additionally, services will be optimized by treating time and space, which have until now not been subject to active resource management in mobile communications, as a single entity. Taking drone delivery as an example, while deciding the optimal flight schedule based on aerial congestion and the predicted weather and while giving instructions to the drone, a series of controls can be considered, seamlessly switching between terrestrial and satellite communication systems in order to ensure stable communications on the drone's route. For that purpose, instead of merely simulating via a simplified model, after analyzing and verifying possible events in a virtual world (cyberspace) that faithfully simulates the real world (physical space) on a computer, the system will be required to drive physical space based on the information in cyberspace. A system like this, which fuses cyberspace and physical space, is called a Cyber Physical System (CPS), and is an important concept in Beyond 5G system compositions.

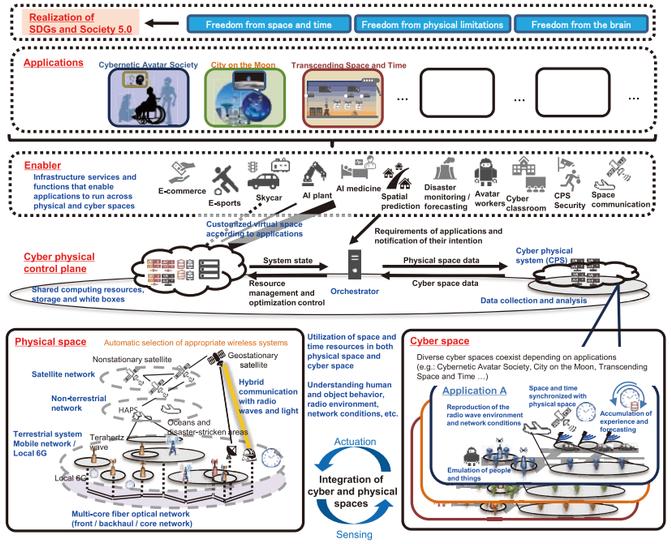

Figure 1 Overview of the functional structure of Beyond 5G / 6G to achieve the SDGs and realize Society 5.0

Beyond 5G System Compositions

Figure 1 shows a Beyond 5G system composition that realizes CPS. In physical space, the system not only integrates and handles conventional base stations for the mobile system, but also self-operating radio systems, such as local 5G and next-generation wireless LAN, and non-terrestrial radio systems such as satellites and HAPS. As mentioned above, next-generation optical networks and data centers will support these systems, and, by flexibly combining resources with each other, will provide applications with an optimal communications environment according to their needs and intentions. In addition to the frequencies up to 28 GHz that are currently being used for 5G, technologies for utilizing the terahertz band of 100 GHz and above will be pioneered, and it will be possible to use systems with diverse characteristics for different purposes.

In cyberspace, as shown in Figure 2, there will be a variety of sub-spaces that are simulated via computers, such as spaces that faithfully reproduce the real world in real time based on sensing information obtained from physical space, spaces that make high-speed and long-term forecasts from the past to the future, and spaces such as outer space that are difficult to actually visit. In cyberspace, by utilizing avatars and VR (Virtual Reality) technologies, users will experience scenarios that are not feasible to implement in reality, will engage in difficult collaborative work, and will repeatedly implement difficult verifications that are expensive to positively demonstrate, etc., and, based on the results, will drive (actuate) physical space.

In order to make the sensing-actuation loop between cyberspace and physical space functional, a cyber physical control plane will be defined. This is a group of functions that control, in an integrated manner, the resources and information that span both spaces. Enablers are groups of functions that realize applications across cyberspace and physical space, and, while providing an API (Application Programming Interface) to applications as middleware, provide a control interface for CPS. As an example of an enabler, in international collaborative work applications that use avatars, using an "Avatar Labor" enabler, so that multiple users can share a realistic workspace, will enable controls such as building workspaces within cyberspace while also providing customized functions for motion prediction and voice translation via AI. It is expected that Beyond 5G applications realized in this way will be freed from a variety of physical constraints and will solve an ever-increasing number of social problems.

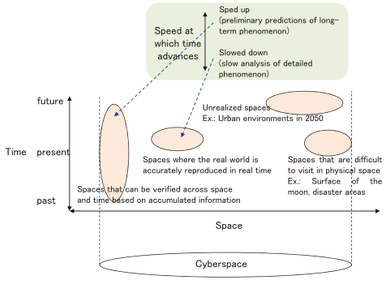

Figure 2 Cyberspace simulating a variety of spaces beyond space and time

Future Outlook

This paper is based on content that was detailed in the first Japanese edition of the Beyond 5G / 6G White Paper, published in March 2021, and, while introducing changes in societal infrastructure and the significance of CPS, also explained Beyond 5G system compositions that continue to be considered. In moving towards the realization of Beyond 5G and while bearing in mind that it will lead to the realization of applications in all fields, it is important, not just for companies and research institutions engaged in communication services, but also for stakeholders from different fields, to jointly discuss it and to actualize the system components and elemental technologies that will be used. NICT is continuing even further discussions in earnest and looks forward to future discussions with all relevant parties.

Toward a Cybernetic Avatar Society in the Beyond 5G / 6G Era : Challenges for Communication Beyond the Constraints of Space, Time, and Body

Hiroshi ANDO

Executive Researcher, Advanced Reality Technology Laboratory, Universal Communication Research Institute

After Receiving Ph.D. in Computational Neuroscience from MIT in the U.S., he joined the Advanced Telecommunications Research Institute International (ATR), where he worked as the senior researcher and the laboratory director before joining NICT's Ultra-Realistic Communication Project in 2006. After serving as the director of Multisensory Cognition and Computation Laboratory and the associate director of the Brain Function Analysis and Imaging Laboratory, he is currently the executive researcher of Advanced Reality Technology Laboratory. Engaged in research on brain and cognitive sciences, computational neuroscience, multisensory information processing, and ultra-reality technologies.

A Cybernetic Avatar Society is expected to be built through utilization of Beyond 5G / 6G, the next-generation information and communication technology. In such a society, people will make advanced use of their own avatars to engage in a variety of activities that transcend the constraints of space, time, and body. This article introduces new lifestyles and social values that will be created by the Cybernetic Avatar Society, as well as the research and development of the technologies and future efforts necessary to realize them.

What is the Cybernetic Avatar Society?

The term "cybernetic avatar" means your own realistic 3D image and alter-ego robot that you can control at will. If the next-generation Beyond 5G / 6G networks become widespread, it is expected that the advanced use of such avatars will allow us to "teleport" ourselves anywhere and perform activities equivalent to those in real space even from a distance. In other words, the Cybernetic Avatar Society is a future society in which people can create diverse connections beyond the constraints of space, time, and body, and in which the areas of activity of each person expand dramatically.

In the Beyond 5G / 6G White Paper released by NICT, a day in the life of a manager in a company's technology development section is illustrated in a diary-like manner in order to concretely depict the lifestyle of people in 2035 when such technologies are expected to spread (Figure 1). During the day, he uses his avatar to conduct a series of activities, such as remote meeting with multisensory information including the sense of touch, remote work using an overseas robot, remote assistance of his elderly father, simultaneous use of multiple avatars, remote mountain climbing via XR, and an overseas business negotiation. This scenario shows the possibility that, by making full use of avatars, anyone can effortlessly perform multiple roles by himself.

Creation of New Social Values

What kind of social value will be newly created by such avatar technology? One such value is the creation of a resilient society. When infectious diseases such as COVID-19 spread, non-contact activities are required. When natural disasters such as earthquakes occur, there are restrictions on the movement of people. Even in such unexpected situations, if we can maintain, via cyberspace, the activities equivalent to those in normal times, we can build a robust society that minimizes economic and social damage.

Another value is a dramatic improvement in labor productivity. Japan and many other developed countries are facing a crisis of economic and social weakening due to their rapidly aging populations and declining working populations. However, if the use of avatars improves the labor productivity of each individual, the entire society can be expected to maintain and grow even if the working population decreases. Furthermore, we can expect that it will enhance people's work-life balance, such as through remote work and remote care for parents while raising children or engaged in community activities.

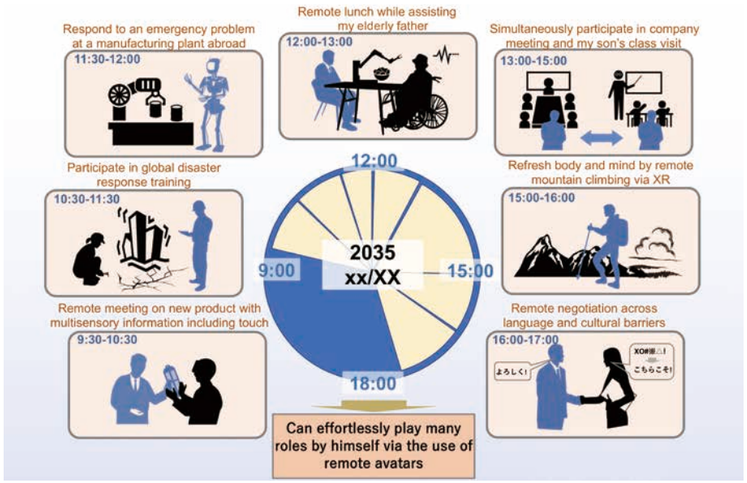

Figure 1 Cybernetic Avatar Society, a day in 2035: From the diary of a technology development manager

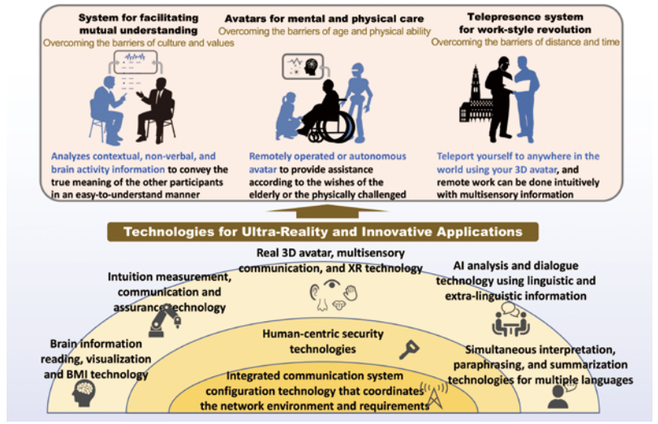

Figure 2 Cybernetic avatar use cases and the key technologies required to realize them

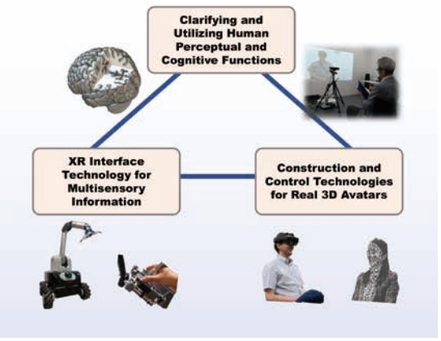

Figure 3 Research & development on core avatar technologies and initiatives at NICT

Research and Development Aiming at the Cybernetic Avatar Society

Now then, what kind of technological research and development is required to create the Cybernetic Avatar Society? Figure 2 shows the use case systems and the key technologies utilizing verbal, non-verbal, and brain activity information to achieve them. Among them, the following research and development is considered to be particularly important, and NICT is also proceeding with these efforts (Figure 3).

(1) Construction and Control Technologies for Real 3D Avatars

Currently, there are already commercial services that allow you to switch to CG characters in 3D virtual spaces and enjoy interactions as if you were playing a game. However, CG characters do not sufficiently convey ever-changing gazes, facial expressions, and gestures, etc., which makes it difficult to use such services in situations where it is necessary to read the subtleties of the other person's mind through non-verbal information, such as first-time face-to-face conversations, interviews to identify personality, and business negotiations with bargaining.

In contrast, our research group has developed a mixed reality (MR) telepresence technology that reconstructs and transmits a realistic 3D image of the other person in real time from depth sensor data, instead of using a CG character, to enable communication similar to face-to-face interaction in real space, and has demonstrated its effectiveness through behavioral experiments. Furthermore our research group is currently developing a new technology that can construct realistic 3D avatars only from camera images without the use of special sensors, and that can accurately convey subtle facial expressions and body movements, as well as control its posture.

(2) XR Interface Technologies for Multisensory Information

We perceive the reality of people and the environment not only from visual information but also from multisensory information such as hearing, touch, and smell. Therefore, if we want to perform remote activities with the same quality as in real spaces, we need to effectively convey non-visual information as well. For example, feedback of tactile information is indispensable for smooth remote operation of robots. Our research group is developing a technology that enables natural interactions by effectively integrating tactile and auditory information as well as visual information

(3) Clarifying and Utilizing Human Perceptual and Cognitive Functions

In order to efficiently and effectively transmit information on people and environments in remote areas, it is important to quantitatively clarify human perceptual and cognitive functions by analyzing psychological, behavioral, biosignal, and brain activity information, and to make the utmost use of that knowledge. For example, it is expected to clarify human tolerances for information delays and their fluctuations for efficient information transmission, and to develop technologies for identifying and preferentially conveying information that promotes mutual understanding and a sense of unity amongst people in remote communication.

Future Prospects

In the future, together with promoting industry-academia-government collaboration for the hardware and software development of avatar technologies and the development of new services, we believe that it will be necessary to create guidelines to avoid physical and mental stress (discomfort, fatigue, etc.) caused by the use of avatars and to create a personal authentication system to prevent other people from "impersonating" avatars.

Managing Space-time for Ultra-fast Networks and Edge Devices

Taking on the Barriers of Space and Time

HARA Motoaki

Senior Researcher,
Space-Time Standards Laboratory ,
Radio Research Institute

He worked in Fujitsu Laboratories Ltd. after receiving the Ph. D Degree. He has been an Associate Professor with the graduate school of engineering, Tohoku University. He has been working at NICT since 2016. His current research interest includes microfabrication technologies and their applications to micro devices. Ph.D.(Engineering)

A society in which all kinds of machines and equipment, from automobiles and drones to infrastructure, work together to assist our lives and to make them smarter[*1] (Figure 1) is one of the ideal images that technology pursues. Published in 1985, the science fiction manga comic Appleseed used the phrase "The principle is exceedingly simple, the structure is exceedingly complex, and the people are the most human"[*2] to describe a future city, and this aligns with the direction of technologies that we want.

With the advent of smartphones and smart speakers, interfaces have moved in a more sensory direction, and, under the concept of IoT, many devices have become able to collaborate to a high degree in 5G. At the opening ceremony of the Tokyo 2020 Olympics, artwork made out of light was drawn in the sky by numerous drones, and it left a brilliant impression on many people.[*3] This kind of drone signage uses signals from GNSS satellites to wirelessly control huge numbers of flying drones, and it is anticipated that this technology will lead to advanced autonomous control systems that are expected to develop in the future, such as unmanned factories, large-scale port management, and skycar systems. What will that process be like? How should "complexity of structures (systems)" and "simplicity of principles" be promoted so that they are "human-like"?

Increasing Network Speeds and Lowering Latency —The Barrier of "Real-time"—

Figure 2 summarizes the developments from drone signage, and Figure 2(b) assumes foremen that are remotely controlling the drones over a network. Each drone is equipped with a camera, and, in addition to saving the obtained images in the cloud to ensure traceability, AI processing (estimation of obstacles and human figures) is performed at the network edge for autonomous and real-time safety assurances. In applications like this, cloud networks are required to have even higher speeds and lower latency, with optically multiplexing lines and ultra-fast cloud processing systems giving, in principle, the simplest solution (direction). The IOWN concept, etc., is a good example of line opticalization,[*4] and ultra-fast cloud processing systems are currently one of the most dynamic research fields.

The amount of information processed in cloud networks is enormous, but, on the other hand, speedups due to the miniaturization of semiconductor chips are slowing down, and, from the viewpoint of thermal management, limits are starting to become apparent. Therefore, the emergence of new high-speed and energy-efficient computing methods are eagerly desired, with photonic computing[*5] and quantum computing[*6] as promising candidates. Platform holders that provide cloud services will most likely benefit the most from the increased speed of semiconductor chips, and, in fact, a trend can be seen in which the primary developers of high-performance semiconductor chips have shifted from chip makers with fabs, such as Intel, to platform holders, such as Google and Amazon.

Identifying and Comprehending User Devices —The Barrier of Complete Positional and Spatial Information—

The development of advanced SoCs (System on a Chip) by platform holders is similar to the former mainframe computer business. Then, if the performance of cloud networks is sufficiently improved, will devices such as automobiles and drones function as a kind of terminal to which an IP address is assigned?

There is also the concept of the "von Neumann bottleneck," in which the transmission of information between a computer's storage unit and execution unit limits the chip's processing speed. According to the paper in which the concept was first introduced,[*7] in a broader sense, it suggests that sufficient consideration and cost are required to improve the efficiency of information exchange between the storage and execution units in a system's design. If a cloud network is classified as the storage unit and the controlled devices are classified as the execution unit, then the development point (the bottleneck) is to improve the efficiency of information transmission between them. The devices that are the execution unit operate much more dynamically and distantly than humans, and will be widely deployed in suburbs, remote areas, the sea, and the sky. Therefore, in addition to an IP address, it is necessary to give accurate positional information and time information to devices in real time so that connected devices can be identified and comprehended more accurately, which will of course be more accurate than GNSS and ensure a stability that is not affected by the radio-frequency environment.

NICT is developing technology to make a chip-level-integrated atomic clock (Figure 3), one of the most stable forms of clock devices, and if this can be installed in devices, then, in combination with sensors, it will make stand-alone position and time identification possible. Furthermore, there is a great deal of research that is underway, such as positioning or setting time via wireless communications between nearby devices and the development of algorithms for absolute time estimation across multiple devices, and it is expected that the above positional and time information will make great contributions to strengthening equipment identification. These development areas require a high degree of technical consolidation, and we believe that this is an area in which Japan should demonstrate its competitiveness by performing mutually complementary work with a platform holder's cloud technology.

Conclusion

Appleseed, the science fiction manga comic mentioned in the beginning, depicts a non-ideal human struggling in an ideal social system. However, today, the image of an ideal human is not uniform, but has changed to one with fluctuations that "allow diverse individuality," and our white paper*1 also describes how a social system based on communications technologies follows the diversity of human life and makes it smarter, with the future progressing steadily, but more gently than in the science fiction of the past.

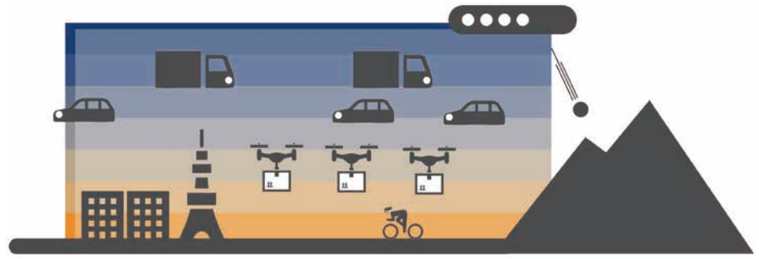

Figure 1 An example of an application image introduced in the NICT B5G / 6G white paper[*1]: on the highway on the sky, logistics, and transportation, people traffic are controlled smartly. Requires multiple safety systems to avoid incidents and accidents.

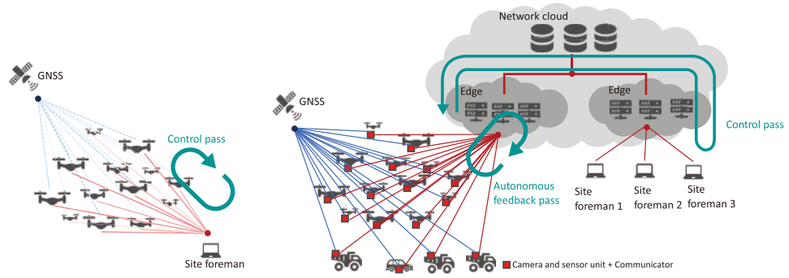

Figure 2 Challenges for unmanned large-scale factories and port facilities from drone signage technologies

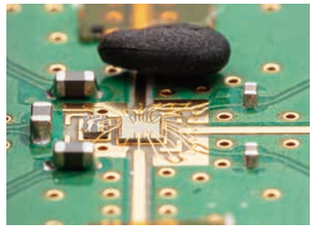

Figure 3 Developing an RF oscillator for the atomic clock with sesami

【Reference】

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＊2 SHIRO Masamune, " Appleseed," Senshinsha, 1985.
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Future Prospects of Wireless Network Technologies for Extreme Scalability in the Beyond 5G Era

TOYOSHIMA Morio

Director General of Wireless Networks Research Center,
Network Research Institute

Joined the Communications Research Laboratory, Ministry of Posts and Telecommunications (currently NICT), in 1994. After engaging in ETS-VI laser communication experiments, was transferred to NASDA (currently JAXA), and after doing research at Vienna University of Technology, worked on the research and development of onboard satellite communication systems for OICETS, SOTA and ETS-IX.
Ph. D (Engineering).

Discussions on information communication technologies in Beyond 5G and 6G are accelerating, and it is expected that they will expand communication networks globally and realize advanced information communications networks that seamlessly connect the ground and space. 5G has three characteristics -- enhanced Mobile BroadBand, ultra-reliable and low latency communications, and massive machine type communication, but in the Beyond 5G and 6G era, with the aim of extreme scalability, it will be important to enhance wireless communications with mobile stations called non-terrestrial networks.

Background

Satellite communications have recently become more sophisticated and more active worldwide, such as through the digitalization of communications satellites and launches of large numbers of small satellites in satellite constellations. On the ground, the 5th Generation Mobile Communication System (5G) was introduced in earnest in 2020, and research and development for so-called Beyond 5G and the 6th Generation Mobile Communication System (6G) has also begun in various countries around the world. In order to meet the requirements for enhanced Mobile BroadBand (eMBB) in terrestrial 5G, expansions of the conventional high-frequency band above 6 GHz are being considered, and frequency allocations in the Ka band, such as the 28 GHz band and the millimeter wave band, are being newly conducted. In the broadband mobile communication for non-terrestrial networks (NTN) millimeter wave and Ka-band frequencies are being assigned to high-altitude platform stations (HAPS) and earth stations in motion (ESIM). In the near future, when tens of thousands of satellites and drones are flying overhead and when communication speeds of the 10-100 Gbps class become commonplace even in mobile stations, securing wireless frequencies and wide communications bands will become an issue. The use of optical free-space / optical satellite communication technologies is expected to be a means to bring about an innovative leap in NTN communications, with high carrier frequencies, almost no bandwidth limitations, strong resistance to interference, and features that are suitable for miniaturization and weight reduction.

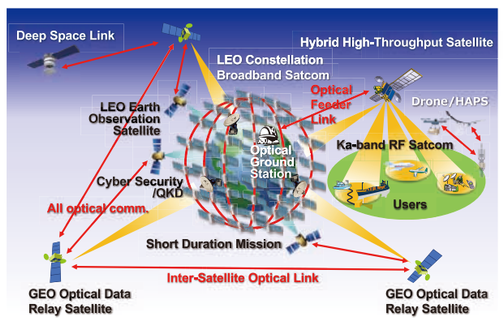
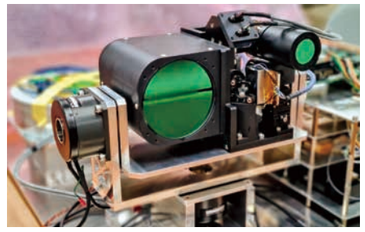


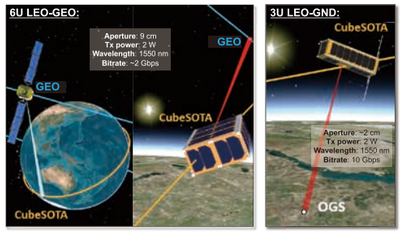
Figure 1 Major applications utilizing free-space optical/optical satellite communication technologies

Deployment of Free-Space Optical / Optical Satellite Communications to NTN

In recent years, the world's first successful in-orbit demonstration of optical communications with a CubeSat-class nanosatellite has shown the feasibility of the usage of optical communications with this class of satellite, and innovative changes are occurring in the field of satellite communications. In satellite constellations, the Starlink project from SpaceX in the U.S. has already launched more than 1,000 satellites into low earth orbit (LEO), and, in the future, SpaceX plans to put more than 10,000 satellites into orbit and provide internet connections of up to 1 Gbps on a global scale. Figure 1 shows examples of the major applications utilizing free-space optical/optical satellite communication technologies. There are a variety of forms for the application of optical communication technologies to NTN in the Beyond 5G/6G era, such as optical space communications on the ground using drones and HAPS, utilizing optical communications via the use of nanosatellites such as CubeSats, the application of optical communications to the backbone communication network in satellite constellations, and the construction of a backbone network for deep space communications.



(a)



(b)

(c)

Figure 2 Prototype model of the optical communications terminal (a) HAPS and (b), (c) overview of optical communication scenarios for 6U and 3U CubeSats

NICT is conducting research and development on ultra-compact optical communications terminals with the aim of applying them to a variety of NTN. Figure 2 shows an overview of a prototype optical communications terminal for HAPS and outlines a scenario of LEO CubeSats (CubeSOTA) equipped with optical communication terminals. As for the HAPS operating environment, onboard payload resources are limited and it is expected that services will be at an altitude of approximately 20 km, so the operating environment is harsh and consideration must be given to the design of the communications terminals. Additionally, CubeSOTA research and development is aiming for space demonstrations of 2 Gbps class optical communication between 6U (1U is a 10 cm per side cube) LEO and geostationary earth orbit (GEO), and of 10 Gbps class optical communication between 3U LEO and an optical ground station (OGS). In NICT's Beyond 5G R&D Promotion Program, research and development of onboard satellite optical communication technologies for small satellite constellations is being promoted, and it is expected that research and development in Japan will accelerate.

Beyond 5G Technologies in the 2030s that Connect to the Moon

NASA will play a central role in deep space development, and, with its long-term goal of manned space exploration on the moon, is seriously promoting the Artemis plan to construct a manned outpost in lunar orbit (Lunar Gateway) through public private partnerships and international cooperation. The construction of a 1 Gbps-class optical communications infrastructure is being considered for communications near the moon. NICT created a white paper that summarizes the societal image and use cases expected to be realized due to the progress of Beyond 5G / 6G technologies, as well as the fundamental technologies and research and development necessary for those purposes, and published it on April 1, 2021. The white paper assumes a City on the Moon (Moon City), considers the necessary use cases from a usage perspective, and takes a look at the elemental technologies necessary for that (Figure 3). It is thought that the development of Moon City will begin around 2035, and, making use of Japan's strengths in robot technology, that many robotic avatars will be on the lunar surface, with people controlling them from the Lunar Gateway and from the earth. In that era, eMBB optical communication technologies that connect the earth and the moon will be required, so steady research and development of communication technologies for the future is indispensable.

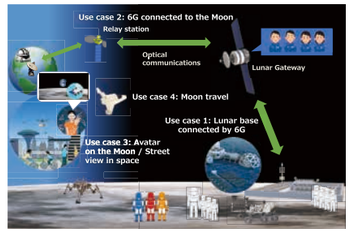


Figure 3 Use cases of Moon City in NICT's White Paper

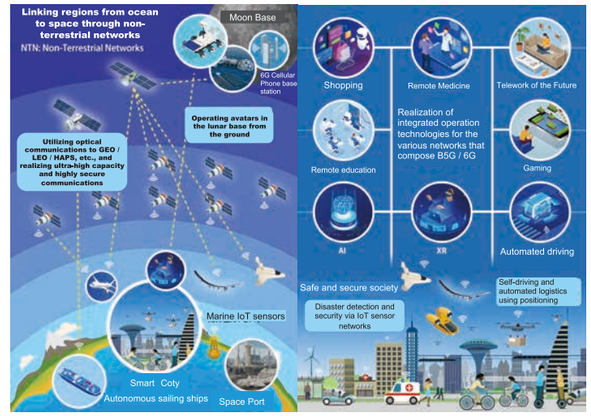


Figure 4 Future image of ultra-smart society in the Beyond 5G / 6G era

The Beyond 5G / 6G Era's 3D Seamless Network Society

In the society of the 2030s, it is thought that 3D networks will be constructed in which there are seamless and multilayered connections between various types of elements such as geostationary satellites, non-geostationary satellites, HAPS, aircraft, drones, ships, automatic cars and terrestrial stations. There is the problem of exhausted frequency resources between the innumerable mobile stations that will be flying, and it is thought that radio, terahertz, and optical communications will be used as the communications links, and in order to realize this kind of multi-layered network, it will be necessary to construct a network control infrastructure that manages these heterogeneous networks in an integrated manner. Figure 4 shows a future image of the ultra-smart society that is envisioned in the Beyond 5G / 6G era. NTN technologies will become mainstream, and 3D networks will see applications not just with conventional broadband communications, but also deployment to a lunar base taking advantage of the characteristics of space utilization, disaster monitoring via global-scale satellite IoT, and the practical implementation of autonomous navigation and automated logistics, etc. In the 2030s, using X-Reality (XR) technology that is achieved via ultra-high speed wireless communications, the future of telework and telemedicine from the COVID-19 era will be realized, there will be the full-scale introduction of ultra-realistic online games, shopping via avatars, remote education, and self-driving skycars, etc., and it is expected that an ultra-smart society will be realized in which people can seamlessly connect safely and securely.

The Story Behind the Publication of the Beyond 5G / 6G White Paper

ISHIZU Kentaro
Director of Beyond 5G Design Initiative, Beyond 5G Research and Development Promotion Unit

The creation of the Beyond 5G / 6G White Paper was a team effort by motivated and enthusiastic NICT volunteers, and here we would like to give a little peak at that behind-the-scenes effort.

Beginning of Discussions for Beyond 5G / 6G

It was in July 2019 that NICT began earnest discussions on Beyond 5G / 6G. NICT has an event called a "Salon" wherein a topic is decided on, staff members from across the organization gather, and then have discussions, including with executives. At the Salon, the main flow of the event is for people with "Thoughts" to give a presentation, to have a Q&A session, and then for participants to give more frank opinions on a table-by-table basis. The presentations come in a variety of forms, from ones with carefully prepared materials to more casual ones where the "Thought" is explained with only simple materials. Before the effects of COVID-19 were felt, we looked forward to gathering directly in the conference room from evening until night and being able to unexpectedly talk with people we would not normally meet.

At the Salon in July 2019, we treated 6G as a topic for the first time, and although each of NICT's researchers are steadily advancing the research and development of elemental technologies that can be utilized for Beyond 5G and 6G, this Salon was probably the trigger for us to start being aware of activities that share the same vision and produce synergistic effects. Then, by the fall of 2020, a total of six 6G Salons (including working discussions) had been held and nearly 200 participants had engaged in lively discussions. Continuing that atmosphere, we decided to create a white paper, with the goal of publishing it in March 2021.

Behind the Scenes in Creating the White Paper

White papers convey ideas that include not just technical details, but also vision, and this was probably the first attempt for interested parties from all over NICT to write and publish content like this. There was not a department in charge of the white paper, so the Strategic Planning Department, to which I belonged at the time, played a central role in stimulating the discussions and compiling the text. The authors, including some non-researchers, gathered together, regardless of their field or position, and there are also portions of the white paper where executives themselves worked on it. For the content, it was divided into several groups and lively discussions were held. For example, Chapter 3, which describes future images of the B5G era in a narrative format, is one of the major features of this white paper, and the teams in charge of each of the three scenarios had multiple web conferences about them. This made it quite difficult to put together thoughtful sentences for the white paper and then compile them. For consistency, it wasn't our intention to cut out sentences that expressed too much "Thought," so the white paper may still have some deep/dense sentences, and we hope that readers will take the situation into account when reading it.

With the publication of the white paper scheduled for March 2021, two months before that, we held an event called the "NICT Open Summit" where we invited experts, both domestic and international, who are active in Beyond 5G fields. We introduced the white paper that we were writing, received frank and honest opinions for the final compilation, and were able to discuss the direction that we should take.

Trying Something New with the English Version

Revisions, etc., to the white paper after it is published are being conducted by the Beyond 5G R&D Promotion Unit, which was newly established in April 2021, and we wanted to start by creating an English version, aiming to publish it by the end of April. For the translation, we used TexTra, a machine translation system that utilizes research results from NICT's Advanced Speech Translation Research and Development Promotion Center (ASTREC). Narrative text, etc., can be difficult to translate directly, so portions of it were edited by humans, and, via this method, we were able to publish the English version in a short period of about one month.

https://beyond5g.nict.go.jp/en/download/
(The Beyond 5G R&D Promotion Unit's materials download page)

Figure Scene from the management side of the 6G Salon (web conference)

Realizing Future Networks by Applying Information-centric Networking

MATSUZONO Kazuhisa

Researcher, Network Architecture Laboratory, Network Research Institute, Ph.D.(Media and Governance)

Biography

1982 Born in Nagasaki Prefecture
2005 Graduated from Keio University Faculty of Environment and Information Studies
2013 Completed a doctoral program at Keio University Graduate School of Media and Governance
2013 Joined NICT after working as a Postdoctoral Fellow at France's National Institute for Research in Digital Science and Technology
2021 Current position

Awards, etc.

FY2017 NICT Outstanding Performance Excellence Award (Individual)
FY2021 NICT Outstanding Performance Excellence Award (Team)

Q&As

Q What are you currently interested in outside of your research?
A Like it or not, I work with people from all around the world, so I get to do challenging work and also learn a variety of new things.

Q What is the biggest Failure in your life ?
A When I was a third-year high school student, in my final important basketball game, for the first time, I made four fouls in the opening 10 minutes of the game. I still dream about that from time to time.

Q What are you currently interested in outside of your research?
A I'm really focused on lifting weights, and I use ab rollers to focus on training my abdominal muscles. I'm working on it every day and aiming for a Beyond 6 Pack (B6P).

In the Beyond 5G era, a wide variety of network services will emerge, such as ultra-high-speed/ultra-low-latency applications and ultra-high-capacity content distribution. Therefore, we are focusing on a new communication technology called "Information Centric Networking (ICN)," which overcomes a variety of issues with current internet communications. Currently, I am researching communication quality improvement technologies that take advantage of ICN leveraging in-network coding, as well as network infrastructure technologies that integrate ICN and edge computing. In order to expand ICN to the real world, I am also developing open-source software called Cefore and am engaged in standardization activities at IETF/IRTF, which are international standardization organizations.

From this fiscal year, I am considering applying ICN to Quantum Key Delivery Networks (QKDN) as a new ICN use case. A variety of important information will be exchanged via networks in the future, so QKDN is expected to be a very important technology to secure critical data transmissions. However, technologies are required in order to efficiently use the limited secure keys that QKDN can provide and to avoid situations wherein secure key requests from users and applications are rejected. Therefore, I proposed using ICN-specific routing methods and in-network caching to improve the usage efficiency for secure keys when compared to conventional communications, then simulated and verified that this would contribute to solving the issue. I will present this basic concept and approach at IEEE GLOBECOM2021, which will be the first conference in the world to advocate for this technology. In the future, I will promote implementing the concept of networks that integrate ICN and QKDN, and will also work on standardization activities of related core technologies, aiming to realize the future network architecture.

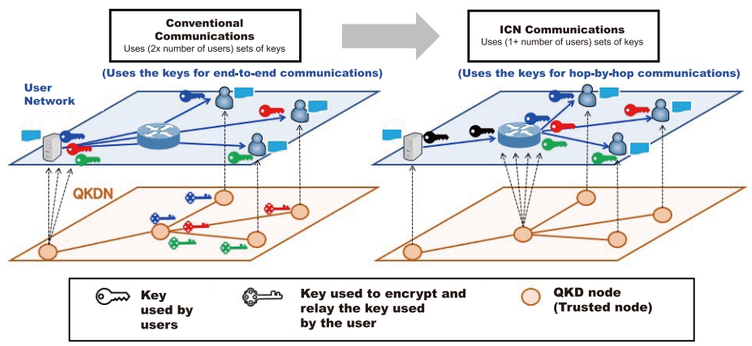


Figure Effective use of keys via ICN communications when compared to conventional communications

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