Improving Mobile Communication Service Quality Using Non-terrestrial Networks

Hisayoshi Kano, Munehiro Matsui, Tomohiro Tokuyasu, and Fumihiro Yamashita

Abstract

At NTT, we aim to achieve ultra-wide coverage for mobile communication services using non-terrestrial networks (NTNs) in the era of Beyond fifth-generation mobile communication system (5G)/6G. This article introduces our efforts to provide customers with high-quality mobile communication services that meet the required conditions for throughput, latency, etc., even when using NTNs.

Keywords: non-terrestrial network (NTN), high-altitude platform station (HAPS), mobile communication

1. Introduction

The Innovative Optical and Wireless Network (IOWN) proposed by NTT as a future communications infrastructure positions the expansion of space communications as one of its pillars [1]. **Figure 1** shows the concept of the Space Integrated Computing Network proposed jointly by NTT and SKY Perfect JSAT Corporation. In this concept, multiple satellites and a high-altitude platform station (HAPS), which is an unmanned aircraft or airship that operates in the stratosphere, will be connected each other through radio-frequency wireless or optical wireless communications and share the processing load of data generated in space through distributed computing. This will enable the creation of an infrastructure that is independent and connectable in space, unaffected by disasters on the ground, by completing the processing and analysis of data generated in space in space.

The Space Integrated Computing Network will have three functions, and NTT is promoting research and development (R&D) to put each function to practical use [2]. The first function is space sensing to enable IoT (Internet of Things) communications in areas where terrestrial networks cannot reach and global-scale comprehensive sensing through satellite observation. The second function is a space datacenter to develop an infrastructure with large-capacity optical wireless communications and computing processing by achieving low power consumption of onboard satellite equipment through photonics-electronics convergence technology and enable the development of various more responsive applications. The third function is a space radio access network (space RAN) to achieve ultra-coverage and ultra-disaster resilience by integrating terrestrial communications infrastructures, such as mobile networks, with upper-air communications infrastructures, such as geostationary Earth orbit (GEO) satellites, low Earth orbit (LEO) satellites, and HAPSs, toward the Beyond fifth-generation mobile communication system (5G)/6G era. This article introduces the R&D on a space RAN that our R&D group is focusing on.

2. Space RAN

2.1 Concept

Research and development on mobile communication services in the Beyond 5G/6G era is being conducted

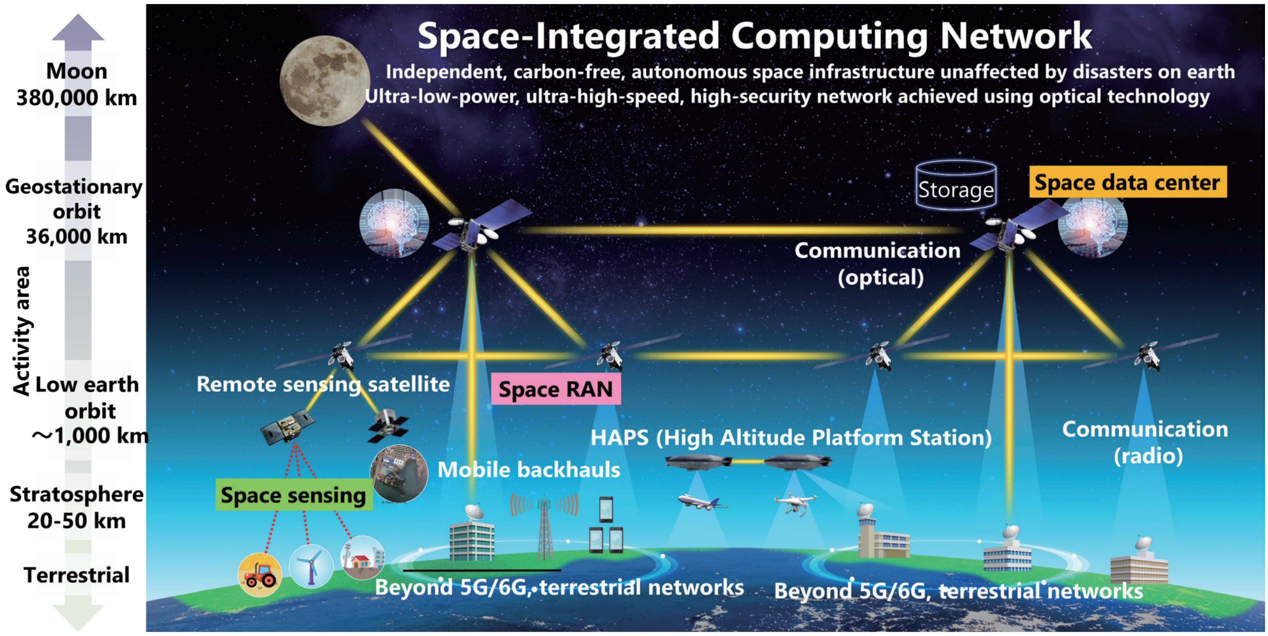


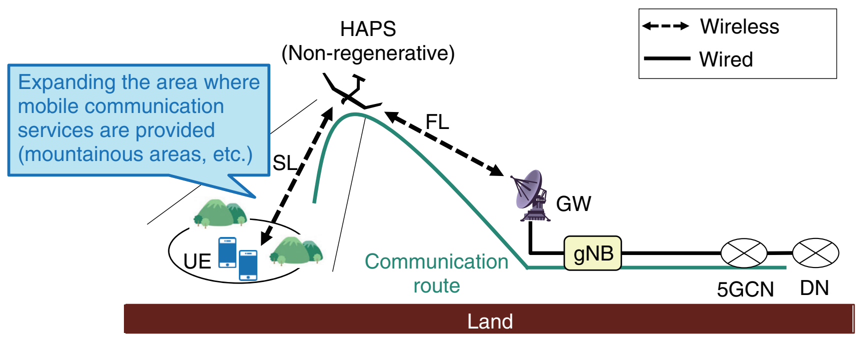
Fig. 1. Space Integrated Computing Network.

in various countries. One of the pillars of this research is providing services to rural areas on the ground, such as remote islands and mountainous areas, where it has been difficult to provide mobile communication services, as well as areas at sea, in the sky, and in space (ultra-coverage of mobile communications). The use of sky networks, such as HAPSs and satellites, commonly referred to as non-terrestrial networks (NTNs), is also being considered [3]. A space RAN aims to achieve ultra-coverage of mobile communications by using NTNs. A hybrid of ground networks and sky networks is assumed, where the terrestrial network is used in areas where it is available, and the NTN is used outside the communication area of the terrestrial network, and some traffic is offloaded to the NTN when the traffic volume of the terrestrial network is high. The protocol of satellite communications has been independent from that of mobile communications, and the interface specifications were also separate. With an eye on ultra-coverage, by installing general-purpose chips with some of the mobile communication specifications customized for NTNs in general-purpose terminals, such as smartphones and base stations, it will be possible to achieve seamless communication connections between the ground and sky using general-purpose smartphones. Ultra-coverage will not only be a disaster-prevention measure but also enable the expansion of communication areas to remote islands and areas and dramatically improve the communication environment on airplanes and ships, thus improving convenience and providing new added value to customers.

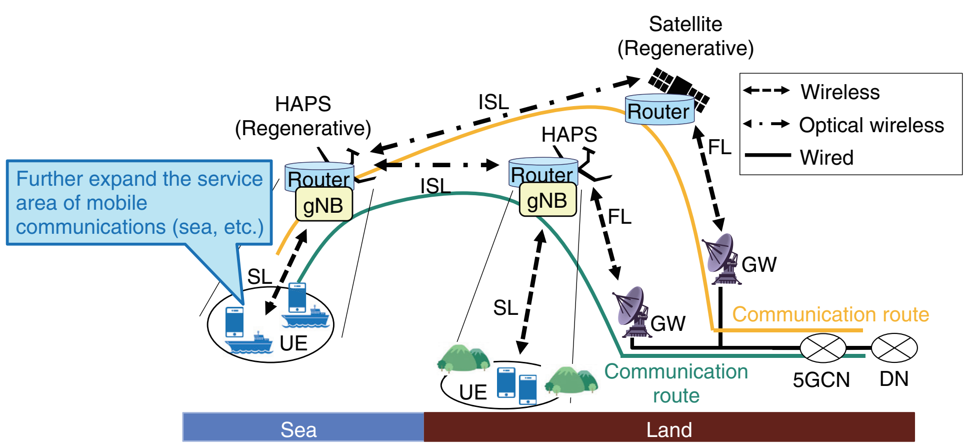
2.2 Single HAPS NTN

Figure 2(a) shows an image of the NTN configuration that NTT is considering at the start of service. GEO satellites (altitude about 36,000 km) and LEO satellites (altitude about 500–2000 km), which have been used in satellite communication services, have a much longer propagation distance compared with terrestrial communications, and it was necessary to use a dedicated user equipment (UE) to use the communication service. In contrast, a HAPS, which flies in the stratosphere (altitude about 20–50 km), has a lower altitude than GEO and LEO satellites, and the service link (SL), which is the communication link between a HAPS and UE, enables direct communication even if a general-purpose smartphone is used as the UE. For this reason, our space RAN will provide mobile communication services by forming a communication area from HAPSs.

A HAPS relies on natural energy (solar power) for power. Therefore, the amount of available power is less than that of systems operated on the ground. The total weight of the aircraft needs to be lightened to



(a) Single HAPS NTN



(b) Multi-layered NTN

Fig. 2. NTN configuration.

reduce the power required for navigation, and there are restrictions on the weight of the equipment that can be installed on the aircraft. These restrictions will be severe in the early stages of service launch, as the aircraft performance will be insufficient. Therefore, it is assumed that a HAPS will be operated alone, relaying traffic using a non-regenerative relay method. Non-regenerative relay is a simple traffic relay method that does not demodulate the received traffic but only executes frequency conversion and power amplification before transmitting it. Although it does not enable advanced control, it can reduce the number of devices installed on a HAPS as well as power consumption. The UE establishes a communication session with the data network (DN) such as the Internet for each service used. For example, for uplink communication, the traffic sent from the UE is sent to the terrestrial gNB (gNodeB: base station for 5G mobile communications) via the HAPS and connects to the DN via the 5G core network (5GCN).

In the NTN configuration at the start of service, a HAPS must be able to communicate directly with a ground gateway (GW) station. This means that the service area is limited to areas where GW stations can be installed, such as mountainous regions, and it is difficult to provide the service to areas where GW stations cannot be installed, such as offshore areas.

2.3 Multi-layered NTN

Figure 2(b) shows a configuration image of the multi-layered NTN. Assuming that the performance of HAPS will improve, NTT aims to expand the area where mobile communication services are provided to areas where it was difficult to provide services with the initial NTN, such as at sea, by using multi-layered NTN that connects multiple HAPSs and satellites with a communication link called inter-satellite/HAPS link (ISL) [4]. For the multi-layered NTN, we are considering linking three types of platforms (HAPS, LEO satellite, and GEO satellite), each of which has advantages and disadvantages in terms of communication area, cost, and propagation delay. GEO satellites have the widest communication area per satellite among the three platforms, but the propagation delay with the ground is the longest. LEO satellites, which are lower in altitude than GEO satellites, have a propagation delay that is about one hundredth shorter than that of GEO satellites. While GEO satellites and HAPSs can be constantly connected from a single point on the ground, LEO satellites move constantly in the sky, so to maintain constant connectivity, it is necessary to launch a large number of LEO satellites. A HAPS has the shortest propagation delay of the three platforms, but the communication area per satellite is the smallest. Therefore, to widen the communication area, a large number of HAPSs are required. We thus envision a future in which these three types of platforms will be optimally combined, taking into account the regional characteristics and communication circumstances of each country, and communication will be flexibly connected. To achieve this, NTT is promoting R&D for the practical application of the multi-layered NTN, which would be the world's first.

In the multi-layered NTN, both a HAPS and satellite relay traffic using a regenerative relay method. Regenerative relay is a relay method with which the received traffic is demodulated once then re-modulated before being transmitted. This requires more equipment and consumes more power than non-regenerative relay methods but allows for more advanced control. A gNB is assumed to be installed on a HAPS. If the feeder link (FL), which is the communication link between a HAPS and terrestrial GW station, is not able to communicate, or if the transmission capacity of the FL is insufficient for the total amount of traffic generated on the SL, the traffic is forwarded within the NTN to a HAPS or satellite that can communicate with the GW station after securing sufficient transmission capacity for the total amount of traffic. Traffic forwarding is assumed handled by the Layer 3 (network layer) router function installed on the HAPS and satellite.

3. Challenges and service quality improvement technologies of NTNs

3.1 Traffic priority control for single HAPS NTN

In mobile communications using an NTN, a general-purpose smartphone is used as the UE, and the SL frequency is assumed to be the 2-GHz band, which is less affected by weather, just like terrestrial mobile communications. In contrast, the FL is assumed to use the Q band (30/40-GHz band), which was newly allocated at World Radiocommunication Conference 2019 as the communication frequency. This is because, as the speed of the SL increases for mobile users, the FL that bundles them is required to have a higher transmission capacity. However, the Q band is easily affected by weather changes such as rain attenuation and cloud attenuation, and the received power decreases depending on the weather conditions. To communicate with appropriate parameters according to the environment, the FL is assumed to use adaptive modulation that changes the modulation and coding scheme (MCS) based on the received power, and when the received power is low, a low MCS is selected and the transmission capacity decreases. In previous satellite communication services, the decrease in received power was prevented using methods such as amplifying the transmission power of the satellite or GW station to cancel the attenuation of the received power or site diversity, which changes the connection destination of the FL to a GW station that is not affected by weather. However, a HAPS should be smaller and lighter than satellites, and there are stricter restrictions on the available power and the weight of onboard equipment than satellites, so it will be difficult for a HAPS to amplify the transmission power at the start of service. Site diversity requires multiple GW stations to be deployed for one HAPS, which will require high capital investment costs, so this will also be difficult to support at the start of service. As mentioned above, a HAPS has restrictions on the available power and the weight of onboard equipment, so its transmission capacity is smaller than that of terrestrial communications, even when it is not affected by weather. At the start of service, therefore, there will be insufficient transmission capacity for the total amount of traffic communicated on the HAPS FL, which may result in reduced throughput and increased delays, resulting in a decline in the quality of service provided to customers.

In response to this, NTT is engaging in R&D of traffic priority control as one of the elemental technologies to improve the quality of services provided to customers in the above-mentioned situations [5]. An example of traffic priority control is shown in **Fig. 3**. In this technology, the NTN controller installed on the ground collects the information necessary for control (such as the transmission capacity

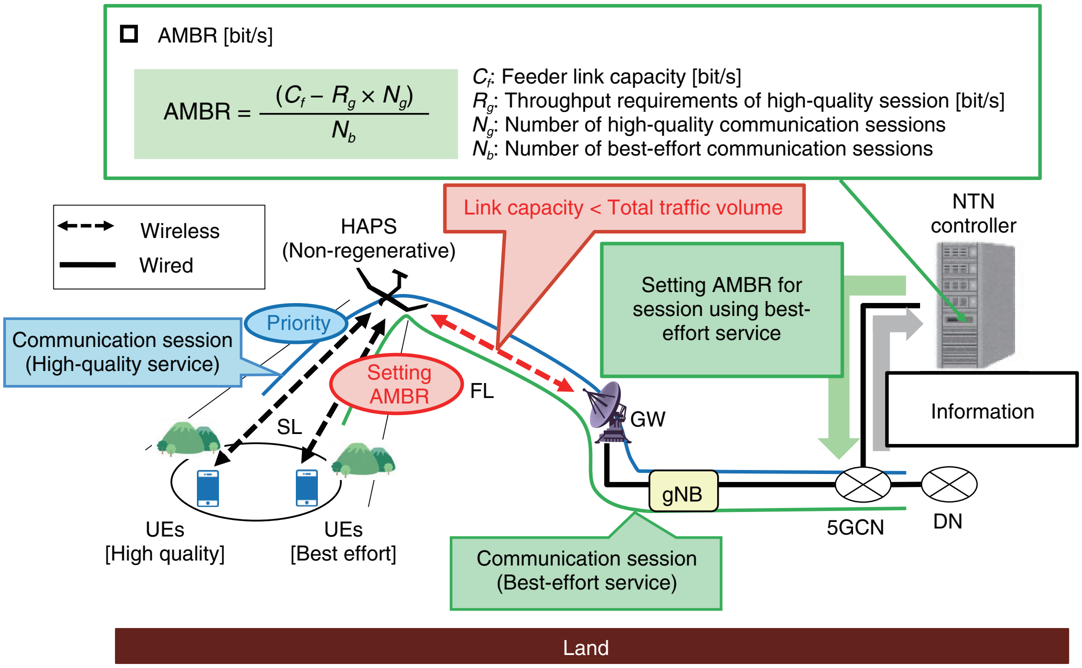


Fig. 3. Traffic priority control.

of the FL and requirements of the services used by the communication sessions) and calculates the session-aggregate maximum bit rate (Session-AMBR), which is the maximum transmission speed per session, on the basis of this information. When it detects that the total amount of traffic communicated on the FL exceeds a threshold (the threshold specified in advance as appropriate for the transmission capacity), it calculates the Session-AMBR and sets the maximum transmission speed of sessions that use services that meet the requirements on a best-effort basis to the calculated Session-AMBR. By setting an upper limit on the maximum transmission speed of sessions that use best-effort services, it is possible to prevent the total amount of traffic communicated on the FL from exceeding the transmission capacity and improve the service quality of sessions that use high-quality services that must meet the requirements.

3.2 Traffic route control for multi-layered NTN

Like HAPSs, GEO and LEO satellites rely on natural energy for power, so there are restrictions on the amount of power that can be used and the weight of equipment that can be installed. Therefore, the multi-layered NTN is a network with limited transmission capacity for each communication link compared with terrestrial networks such as optical fiber networks. The Ku band (14/12-GHz band) and Ka band (30/20-GHz band) used by GEO and LEO satellites as FL communication frequencies are also susceptible to weather effects such as rain attenuation, and the received power decreases, as with the Q band that a HAPS is expected to use as the FL communication frequency. Since the altitudes of HAPSs and satellites are significantly different, the multi-layered NTN is also characterized as a network in which communication links with significantly different latency times coexist. Therefore, if a long-latency traffic route from HAPSs via GEO satellites is assigned to a session that receives a service that requires low latency, the session will not be able to meet the service requirements, and the quality of the service provided to customers will decrease. To address these issues unique to the multi-layered NTN, operations must be flexible and adaptable to changes in the surrounding environment, such as rainfall or natural disasters, and to the requirements for various services.

To enable the above operation and improve the quality of services provided to customers, NTT is conducting R&D on traffic route control for mobile communication services using the multi-layered NTN [6]. An example of traffic route control is shown in **Fig. 4**. The NTN controller collects the information required for control (transmission capacity of

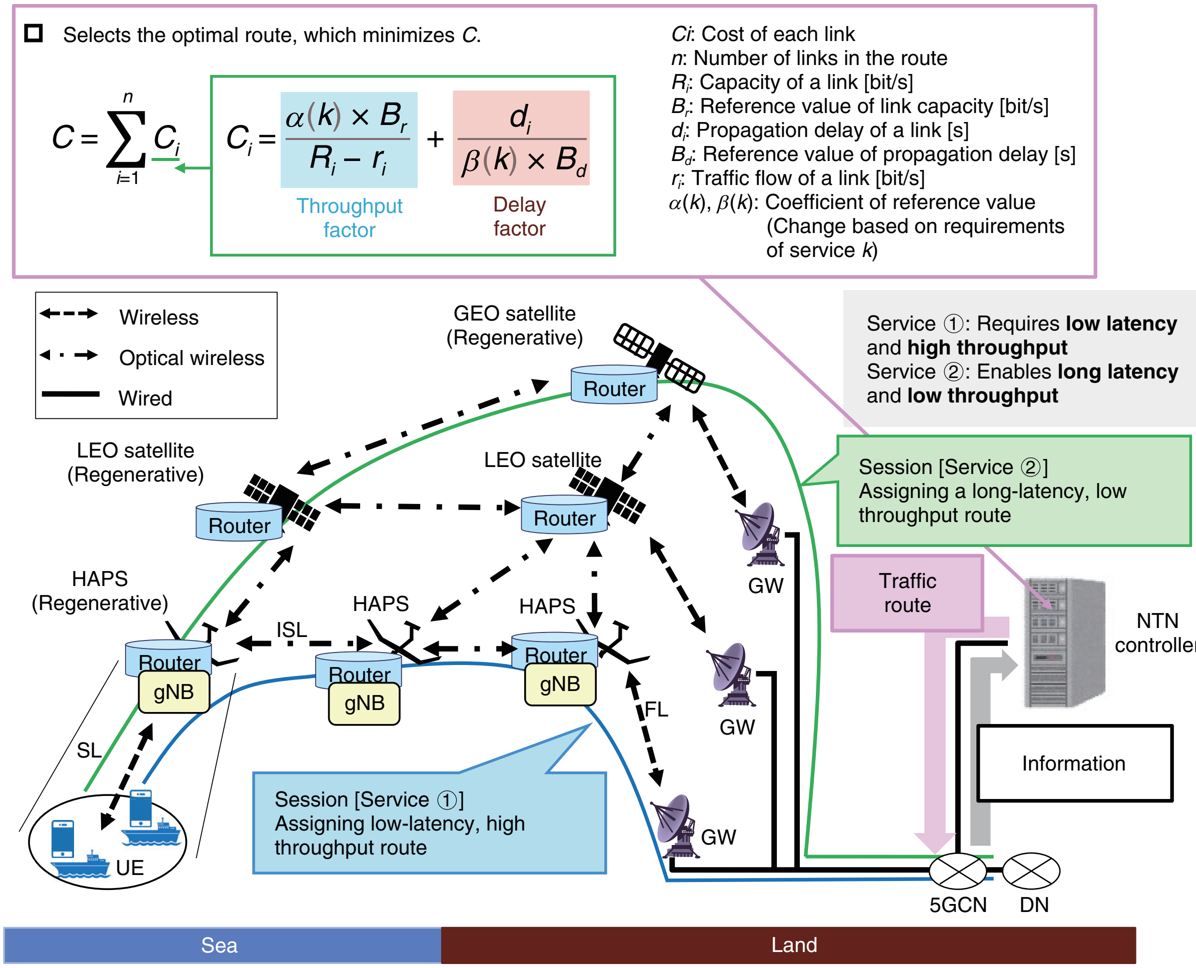


Fig. 4. Traffic route control.

each communication link, traffic volume being communicated, propagation delay, service requirements, etc.) and assigns a traffic route that takes these into account for each session. The NTN controller calculates the cost of each communication link and assigns the traffic route that minimizes the total cost to the session. By controlling using coefficients according to the requirements of each service, for example, for sessions that use services that require low-latency and high-speed communication, a traffic route that multi-hops multiple HAPSs without going through a satellite is preferentially assigned, and for sessions that use services that enable long-latency and low-speed communication, a traffic route that goes through HAPSs and GEO satellites is assigned. This makes it possible to provide high-quality services that meet the requirements of more customers.

4. Future prospects

This article introduced R&D efforts to improve the service quality of mobile communications using NTNs as one of the elemental technologies supporting the concept of the Space Integrated Computing Network. Since NTNs using HAPSs and satellites involve large-scale R&D, it is very difficult for NTT to lead alone. Therefore, we will work on the R&D of basic technologies with practical application in mind while collaborating with related organizations and operating companies.

Acknowledgments

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Hisayoshi Kano

Senior Research Engineer, Satellite Communications Group, NTT Access Network Service Systems Laboratories.

He received a B.E. and M.E. from Hokkaido University in 2009 and 2011. His current interests include the R&D of satellite communications system.

Munehiro Matsui

Senior Research Engineer, Satellite Communications Group, NTT Access Network Service Systems Laboratories.

He received a B.E. and M.E. in information engineering from Nagoya University, Aichi, in 1998 and 2000. He joined NTT Network Innovation Laboratories in 2000 and has been engaged in the R&D of wireless communications systems.

Tomohiro Tokuyasu

Senior Research Engineer, Supervisor, Wireless Entrance Systems Project, NTT Access Network Service Systems Laboratories.

He received a B.E. and M.E. in information and communication engineering from Nagoya University, Aichi, in 1996 and 1998. Since joining NTT in 1998, he has been involved in R&D of wireless access systems. In 2021, he moved to NTT DOCOMO, where he worked on vehicle-to-everything technologies. He has been with NTT Access Network Service Systems Laboratories since 2024, where he has been involved in R&D activities related to non-terrestrial networks. He received the Young Engineer Award from the Institute of Electronics, Information and Communication Engineers (IEICE) in 2005. He is a member of IEICE.

Fumihiro Yamashita

Executive Research Engineer, Supervisor, Project Manager of Wireless Entrance Project, NTT Access Network Service Systems Laboratories.

He received a B.E., M.E., and Ph.D. from Kyoto University in 1996, 1998, and 2006. He has investigated the modulation and demodulation schemes for broadband mobile satellite communications systems. His current interests include the R&D of disaster-relief and remote-island satellite communications systems and satellite multiple-input multiple-output and IoT systems using LEO satellites.