Multi-layer Non-terrestrial Network for Beyond 5G/6G Mobile Communications

Fumihiro Yamashita, Munehiro Matsui, Hisayoshi Kano, and Junichi Abe

Abstract

NTT is currently investigating the Space Integrated Computing Network, which is a novel infrastructure that will integrate multiple orbits consisting of the ground to high-altitude platform stations, low Earth orbit satellites, and geostationary orbit satellites. This article introduces the concept of this network and the current research and development status at NTT Access Network Service Systems Laboratories, especially on non-terrestrial network technologies.

Keywords: satellite communications, HAPS, NTN

1. Introduction

NTT has announced the concept of the Space Integrated Computing Network as an element of the Innovative Optical and Wireless Network (IOWN) [1]. This concept assumes the use of geostationary orbit (GEO) satellites, low Earth orbit (LEO) satellites, and high-altitude platform stations (HAPSs) for achieving space sensing, space datacenter, and the space radio access network (Space RAN).

Space sensing is an internet-of-things (IoT) sensor-data collection and processing platform that will use LEO satellites to collect many low power wide area (LPWA) sensor signals on Earth, including oceans and rural areas. The collected sensor data will be sent to base stations on Earth and demodulated. Space datacenter will be part of the computing platform and data storage on GEO satellites to cleanse satellite observation data, e.g., photos and leader data. Space RAN is a non-terrestrial network (NTN) consisting of GEO/LEO satellites and HAPSs. This network will enable extreme cellular coverage extension in the Beyond fifth-generation mobile communication network (5G)/6G era [2]. Therefore, actualizing Space RAN is key to implementing the IOWN Space Integrated Computing Network.

Figure 1 shows the concept of Space RAN. It is currently common to use GEO satellite communications where terrestrial mobile cellular services are not provided. The networks for satellite communications are independent of that for terrestrial mobile cellular services. Toward Beyond 5G/6G, an NTN will consist of multi-layer networks comprising GEO satellites, LEO satellites, and HAPSs (multi-layer NTN). These satellites and HAPSs will be connected to each other by inter-satellite links. Since Space RAN will build a mutually complementary network with satellites and HAPSs, availability will increase compared with stand-alone networks (only GEO/LEO/HAPS networks) and a wide coverage area will be established. Therefore, Space RAN is expected to enable multiple use cases such as Internet connection services in airborne/vessels, wide area IoT services, and disaster relief.

2. Multi-layer NTN

2.1 Concept

Since the communication protocol for satellite communications is independent of that for cellular-phone

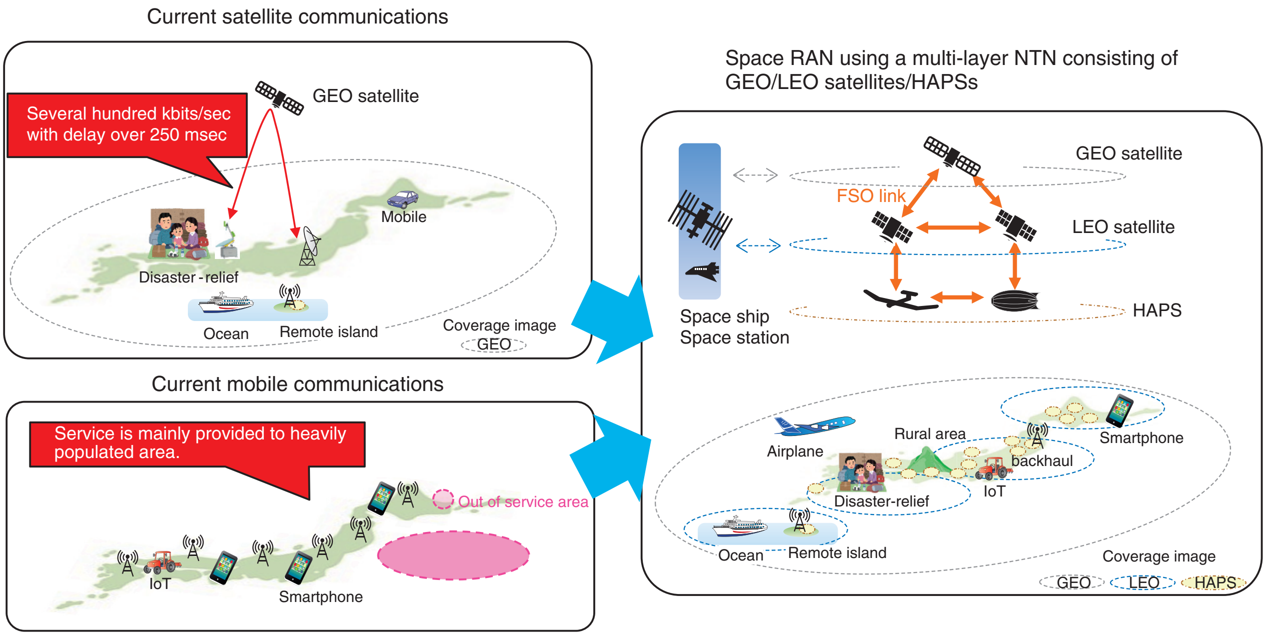


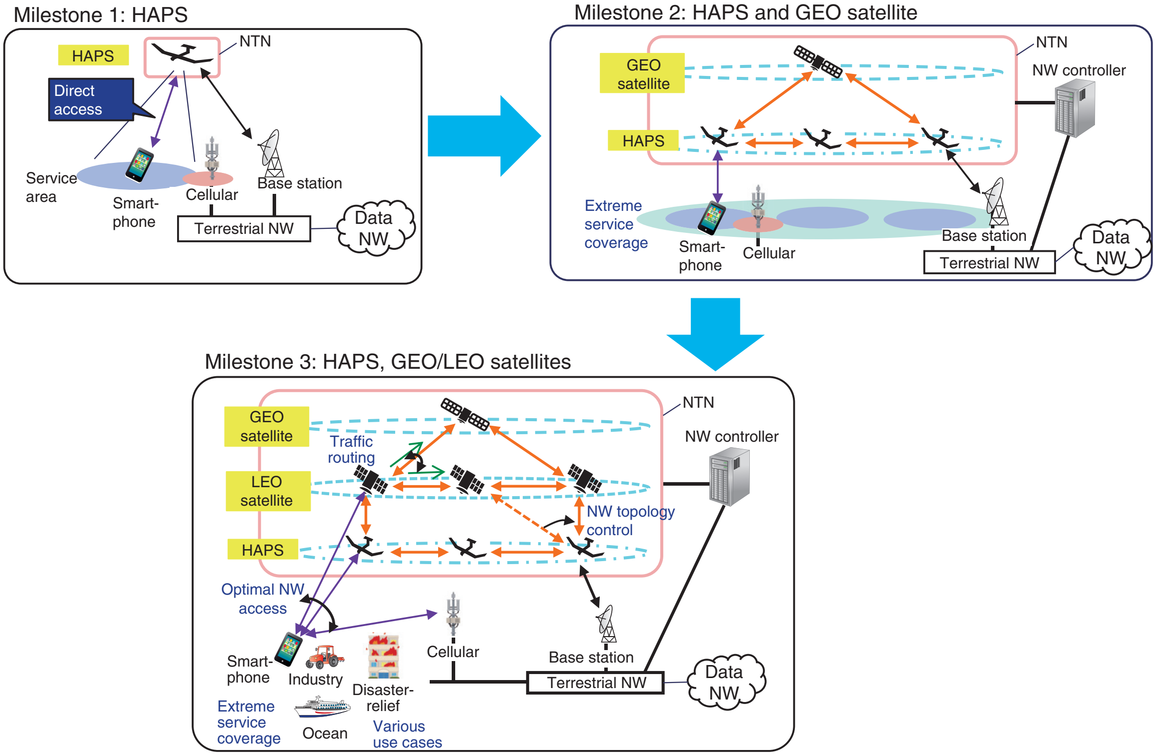
Fig. 1. Space RAN for Beyond 5G/6G mobile communication services.

services, the network for satellite communication services is also independent of that for cellular-phone services. The cellular-phone service area is currently limited to heavily populated areas, so such service is unavailable in rural areas or oceans. In the Beyond 5G/6G era, the goal is to provide extreme-coverage cellular-phone/smartphone services in new areas including space, sky, and oceans. It is highly expected that cellular phones/smartphones will be connected seamlessly to the core network via a GEO/LEO satellite or HAPS where the terrestrial network does not cover. For this purpose, a communication chip customized for using LEO satellites was developed and commercial services connecting smartphones and LEO satellites have begun. The current service is mainly message/text service for disaster-relief, but, the communication speed will increase in the near future for other services.

In the Beyond 5G/6G era, GEO/LEO satellites and HAPSs will have advantages and disadvantages in terms of service coverage, cost, delay, technical heritage, and so on. For example, the service coverage and delay time of GEO satellites are the largest. However, the delay time of LEO satellites is much smaller. To provide real-time communication services, hundreds or thousands of LEO satellites are needed. A HAPS flies much nearer the Earth compared with other satellites, so is expected to enable high throughput with small delay. However, its technologies are not yet matured and it takes longer to provide stable commercial services all year round. Therefore, Beyond 5G/6G communication services will be able to be provided by combining an NTN consisting of GEO/LEO satellites/HAPSs with a terrestrial network.

Figure 2 shows the research and development (R&D) milestones for achieving a multi-layer NTN. As we described above, to enlarge the service coverage using smartphones, HAPSs are the most promising NTN solution because it is possible to accommodate signals from smartphones at higher power compared with using satellites. For Milestone 1, service will start being provided in limited areas using a single HAPS.

However, since HAPS technologies are not yet matured, it is not practical to procure hundreds of HAPSs to cover the exclusive economic zone of Japan. Thus, it is reasonable to enlarge the service area of a HAPS using backhaul via satellite and provide services to limited areas. This configuration is considered Milestone 2 and will connect a HAPS with a GEO satellite as backhaul. Finally, a multi-layer NTN will be completed by including a broadband LEO network. This configuration is Milestone 3. In this milestone, GEO/LEO satellites will be vertically connected with HAPSs via free space optics



NW: network

Fig. 2. R&D milestones for achieving a multi-layer NTN.

(FSO). The smartphone traffic will be flexibly transferred via a multi-layer network on the basis of network congestion and application required quality.

2.2 NTN study items

GEO/LEO satellites and HAPSs are expected to be used to greatly enhance mobile-service coverage. This will contribute to the convenience and value of mobile communications. For example, a highly reliable messaging service and ultra-wide-area service coverage will be possible.

Figure 3 shows the joint R&D project for B5G (Beyond 5G)-NTNs funded by the National Institute of Information and Communications Technology (NICT) [3]. This project was promoted by SKY Perfect JSAT Corporation, NTT Corporation, NTT DOCOMO, INC., and Panasonic Corporation. This project consists of five study items.

(1) Research on NTN technologies:
  (1-a) Network-architecture design of B5G-NTNs
  (1-b) Network-control algorithm among multi-layered NTN nodes
  (1-c) Optical link for HAPS-HAPS connection
(2) Development of an NTN service:
  (2-a) Safety management system of small ships via the HAPS platform
  (2-b) In-flight communications by dual connectivity of a satellite and HAPS

2.2.1 Network-control algorithm among NTN nodes

NTT Access Network Service Systems Laboratories is mainly investigating item (1-b) in collaboration with other companies. For network control among NTN nodes, since the frequency band of the feeder link for a HAPS is the Q band, problems occur when the feeder-link communications are interrupted due to rain attenuation. In this case, traffic is concentrated on a specific link. When the traffic flows exceed the network capacity of a link, packet loss or transfer delay occurs due to traffic congestion. To overcome this problem, we proposed a traffic-control algorithm suitable for NTNs [4].

Our algorithm is shown in **Fig. 4**. For transferring traffic over the sea, two approaches are assumed, transferring traffic by hopping adjacent HAPSs and

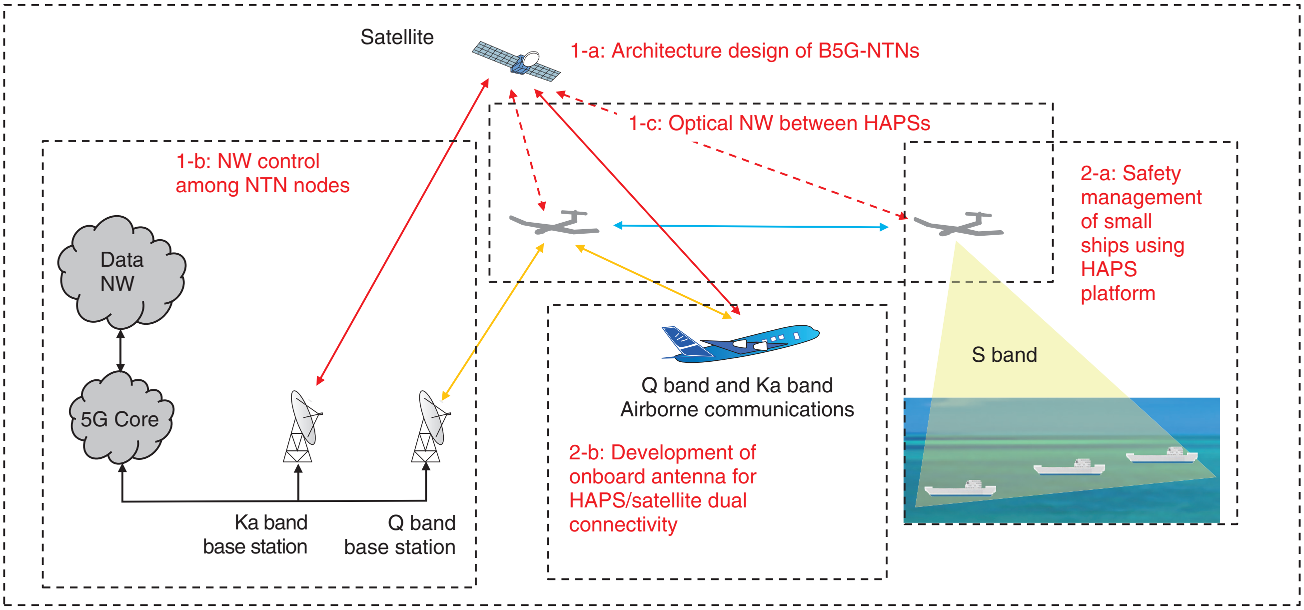


Fig. 3. NICT R&D project for B5G-NTNs.

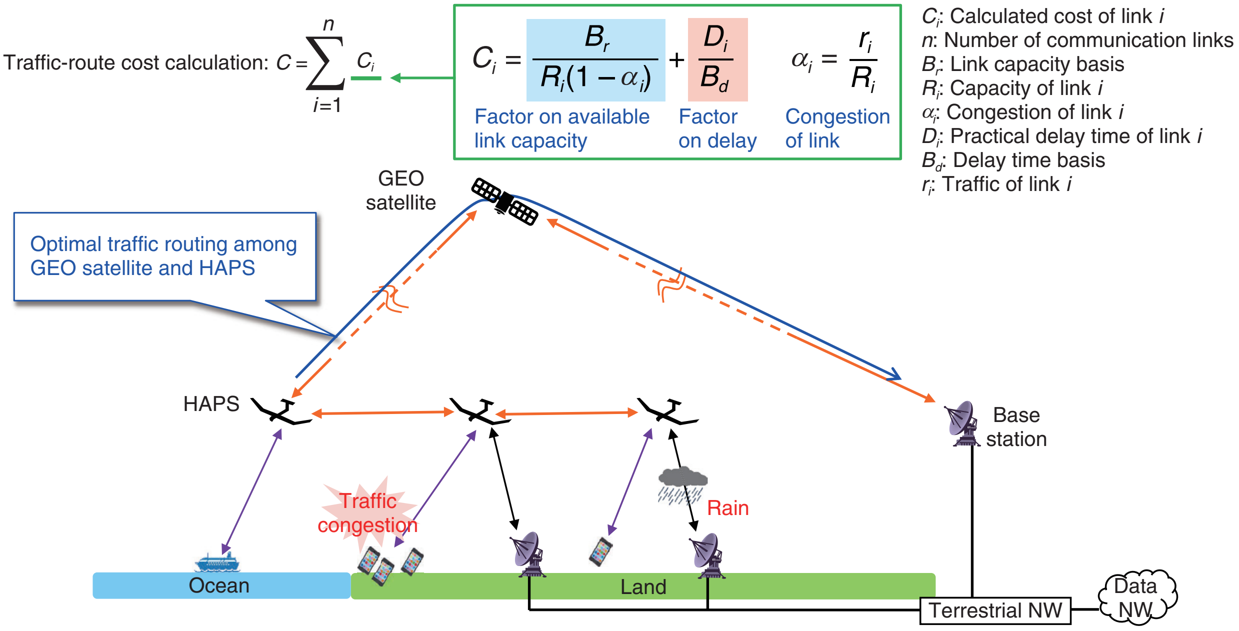


Fig. 4. An example of traffic control by using multi-layer NTN consisting of a GEO satellite and HAPSs.

transferring traffic by hopping satellites as well as HAPSs. Our algorithm calculates the network cost C on the basis of congestion and/or delay route by route then selects the optimal route that minimizes C. The simulation results indicate that the algorithm distributes traffic and avoids traffic concentration on a specific link even under rainy conditions [4].

2.2.2 HAPS technologies

The weight and power budget for onboard equipment of HAPS is so limited that it is difficult to carry out onboard signal processing such as in terrestrial base stations of cellular phones. HAPS technology needs to evolve to tackle this problem. For example, to enlarge the service area, multi-hop connection among HAPSs or satellites is needed. FSO is the key technology to connect adjacent HAPSs and is currently being investigated.

2.2.3 Communications using 30/40 GHz

To ensure high-speed communications in service links between a HAPS and smartphones, the communication capacity of feeder links between HAPSs and base stations needs to be increased. Thus, the frequency band around 30/40 GHz (Q band) was newly allocated for a HAPS in World Radiocommunication Conference 2019. It is advantageous to use a wider bandwidth at a higher frequency such as the Q band. However, millimeter waves are heavily attenuated by rain. To overcome this problem, a compensation method for rain attenuation is needed. We are currently researching a new proactive base-switching technique and traffic routing as well as conventional diversity techniques to avoid rain attenuation.

3. Summary

This article introduced study items focusing on NTNs, which NTT Access Network Service Systems Laboratories is currently investigating. NTT is currently promoting R&D for building the Space Integrated Computing Network by collaborating with other space research institutions and businesses.

References

[1] Press release issued by NTT and SKY Perfect JSAT, “NTT and SKY Perfect JSAT conclude collaboration agreement on new space enterprise to aid realization of a sustainable society,” May 20, 2021. https://group.ntt/en/newsrelease/2021/05/20/210520a.html

[2] NTT DOCOMO, “DOCOMO 6G White Paper,” https://www.docomo.ne.jp/english/corporate/technology/whitepaper_6g/

[3] Website of NICT, General Issue 01501 Development of NTN nodes networking technology & development and demonstration of coverage expansion use case systems (in Japanese), https://www.nict.go.jp/collabo/commission/B5Gsokushin/B5G_01501.html

[4] H. Kano, M. Matsui, J. Abe, Y. Hokazono, H. Kohara, Y. Kishiyama, and F. Yamashita, “Development of Extreme Coverage Communication System Extended by Non-terrestrial Network (NTN)--UE Availability Evaluation During Rainfall--”, IEICE Tech. Rep., Vol. 122, No. 163, SAT2022-37, pp. 43–57, 2022.

Fumihiro Yamashita

Senior Research Engineer, Supervisor of Satellite Communications Group, 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 worked on modulation and demodulation schemes for broadband mobile satellite communications systems. He has also been a part-time lecturer at Kanto Gakuin University and the Muroran Institute of Technology since 2018. His current interests include the R&D of disaster-relief and remote island satellite communications systems, satellite multiple-input multiple-output and Internet of Things systems using low-Earth orbit satellites, and NTN for Beyond 5G/6G.

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 in 1998 and 2000. He joined NTT Network Innovation Laboratories in 2000 and has been engaged in the R&D of wireless communications systems. He received the Young Engineer Award from the Institute of Electronics, Information and Communication Engineers (IEICE) in 2006.

Hisayoshi Kano

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 systems.

Junichi Abe

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

He received a B.E. in computer science and M.E. in international development engineering from Tokyo Institute of Technology in 2004 and 2006. In 2006, he joined NTT Access Network Service Systems Laboratories. He is currently engaged in R&D on NTN for Beyond 5G/6G communications.