Beyond 5G White Paper Supplementary Volume “NTN Technologies”

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1.0	2024.3.7	Initial version	

Preface

In our published white paper “Beyond 5G White Paper ~Message to the 2030s~”, we are discussing that Japan is at the forefront of developing 6G technology, focusing on the integration of non-terrestrial network (NTN) to revolutionize connectivity from terrestrial to aerial and space domains. This endeavor aims to address several key challenges and unlock new use cases in various sectors such as unmanned systems, monitoring systems, IoT, backhaul for emergency services, and smartphone integration for human lives.

A primary challenge is achieving high throughput and capacity in NTN communications, especially with the adoption of higher frequency bands like millimeter and terahertz wave. These bands are susceptible to weather conditions, requiring Japan to develop robust communication solutions.

Reducing latency is crucial, as Japan's reliance on geostationary satellites introduces significant delays. The exploration of Low Earth Orbit (LEO) satellites and High Altitude Platform Station (HAPS) is seen as a solution to minimize these delays for time-sensitive applications.

We also recognize the need for massive IoT connectivity in Beyond 5G networks, necessitating efficient network configurations using a mix of satellite types to manage the surge in connected devices.

Optimal route connection via multiple terrestrial networks and NTN components with multi-connectivity technology are also required. Multi-routing with optimal route selection and simultaneous multi-connections provides better reliability and extension coverage, especially for higher demand areas.

Edge computing technology is another key area, crucial for handling large data volumes from IoT devices and ensuring low-latency communication in NTN environment.

To tackle these challenges and to realize new use cases, a lot of research and development activities in Japan. In this white paper, we show these research and development activities and its results with a lot of figures as follows.

- *“HAPS Technology: HAPS Flight and Communication Test Results Show Path to Unlock Stratospheric Communications”* describes a concept of HAPS and results of flight and communication tests using a fixed-wing type of HAPS aircraft.
- *“Extreme Coverage Extension in Beyond 5G and 6G: Cooperative HAPS Architecture Integrating Terrestrial Networks”* presents HAPS use cases and a cooperative architecture that focuses on the link between NTNs and terrestrial networks (TNs).

- *"Very Low Earth Orbit Satellite Networks for 6G* [1]*"* proposes the vision for the evolution of Very Low Earth Orbit (VLEO) satellites-based NTN towards 6G and describes the technical challenges and potential solutions.
- *"Multi-layer non-terrestrial network and its routing management for Beyond 5G /6G"* presents the concept of multi-layer non-terrestrial network (multi-layer NTN), which consists of HAPS, LEO and GEO and shows our routing management technology for multi-layer NTN.

In conclusion, Japan's engagement in NTN and Beyond 5G technology is not only addressing current challenges but also paving the way for a transformative leap in global communication networks, promising to unlock new applications and services.

This White Paper was prepared with the generous support of many people who participated in the White Paper Subcommittee. The cooperation of telecommunications industry players and academia experts, as well as representatives of various industries other than the communications industry has also been substantial. Thanks to everyone's participation and support, this White Paper was able to cover a lot of useful information for future business creation discussions between the industry, academia, and government, and for investigating solutions to social issues, not only in the telecommunications industry, but also across all industries. We hope that this White Paper will help Japan create a better future for society and promote significant global activities.

Kazunori Sakumoto, Fujitsu

I. HAPS Technology: HAPS Flight and Communication Test Results Show Path to Unlock Stratospheric Communications

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***Abstract*— In the Beyond 5G and 6G, "Ubiquitous Connectivity" is being considered for communication in all locations including air, sea, and space. NTN technologies, especially High Altitude Platform Station (HAPS), hold great potential in providing mobile broadband to unserved and underserved areas that have lacked sufficient coverage from terrestrial mobile networks. This article describes a concept of HAPS and results of flight and communication tests using a fixed-wing type of HAPS aircraft.**

I-1. Introduction

In order to realize HAPS, stable flight of the aircraft mainly in the stratosphere and appropriate communication from the aircraft hovering at a fixed point in the stratosphere to the ground are essential. To prove these points, tests have been conducted by various companies and organizations.

As an example, this article introduces the aircraft and communication equipment being developed by SoftBank Corp. (formerly HAPSMobile Inc.), as well as the HAPS flight and communication tests that SoftBank conducted in the United States from 2019 to 2020.

I-2. About HAPS

HAPS is an acronym for High Altitude Platform Station, which is a system that utilizes an unmanned vehicle, such as an aircraft, flying in the stratosphere as a communications base station. In doing so, the system is capable of providing communications services over an extensive area. The stratosphere is a layer of the atmosphere far above the clouds. Because of this, it is not affected by rain or snow and air currents have little influence. These characteristics enable the flight of a stratospheric platform to be more stable as compared to flight in other layers of the atmosphere. HAPS can provide a wide array of services which include connectivity, earth, atmosphere and climate monitoring, disaster response, mapping and humanitarian missions, search and rescue, infrastructure inspection, and more. HAPS can either be stationary (or quasistationary), or be mobile across large regions (e.g. for survey missions). In the field of telecommunications, HAPS is classified as a non-terrestrial network, equivalent to that of geostationary and low-earth-orbit satellites. This new network system is capable of covering a wider area more efficiently when compared to traditional ground base stations. It is also unaffected by damage caused by disasters such as earthquakes and tsunamis.

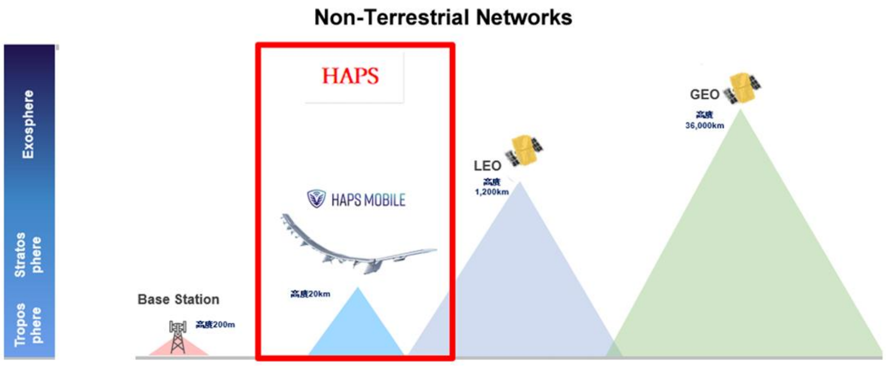

Fig. I-1 Non-Terrestrial Networks

I-3. HAPS Aircraft and Communication Equipment Development

I-3.1. HAPS Aircraft Development

The Sunglider is one of the large fixed-wing HAPS aircraft currently being developed and put into practical use. Its major feature is that it has no tail section, like Pathfinder and Helios, which minimizes induced resistance at the wingtips, thus enabling efficient flight. Additionally, meticulous planning ensued in order to reduce the weight of the airframe. As a result, despite its large size, Sunglider is capable of flight over an extended period of time.

The future use of Sunglider is illustrated below. A ground crew will control it visually when taking off from an airport. It will then gradually climb to the stratosphere while circling over the airport. Once it has reached the stratosphere, operation will be supervised remotely via a satellite command and control link. After reaching the destination, it will remain there circling at a fixed point in the sky. At this point in time, it will begin providing service as a network for terrestrial communications.

Sunglider is powered by solar energy. During the daytime, it generates electricity using the solar panels attached on the top of its wing. Using this solar energy, its propellers turn and communication devices mounted on the airframe are powered. At the same time, any surplus energy is stored in battery cells mounted in the airframe. As the stratosphere is located above the clouds, stable power generation is ensured during the daytime. At night, the propellers are kept turning by consuming the energy stored during the daytime. This is how it is planned to maintain continuous flight in the stratosphere for approximately six months.

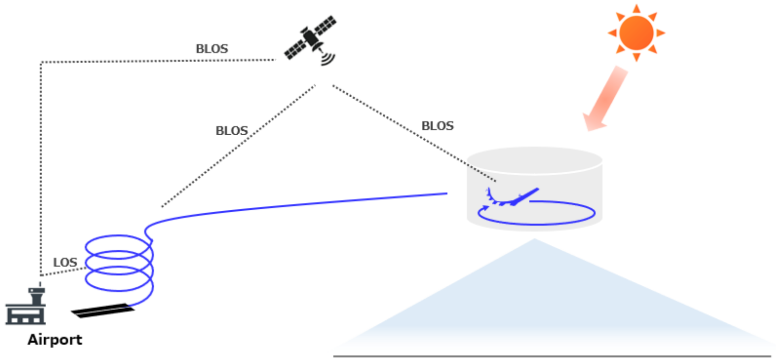

Fig. I-2 Sunglider operation

I-3.2. Payload Development

Here “payload” collectively means the equipment mounted on an unmanned aircraft, including communications devices, cameras and measuring instruments. In this section, it specifically refers to communications equipment used for a cellular phone network base station.

Payloads must be developed based on the assumption of being able to function in all environments from the ground to the stratosphere, the point from which services are delivered. Among all of the requirements, resistance to significant changes in temperature and air pressure is paramount. In addition, as the payload is to be mounted on a lightweight unmanned aircraft powered by solar energy, power consumption and weight need to be minimized. Payloads also need to be resistant to the vibration unique to lightweight unmanned aircrafts in order to provide a reliable signal.

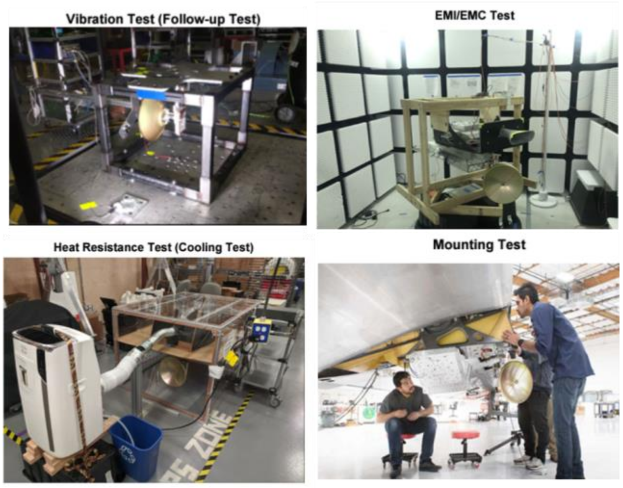
Vibration Test (Follow-up Test)
EMI/EMC Test
Heat Resistance Test (Cooling Test)
Mounting Test

Fig. I-3 Payload Development

I-4. Communications Tests

I-4.1. Network Structure

The payload transmitted service link (LTE) radio waves earthward to be received by smartphones. SoftBank secured two frequency bands to be used as the feeder link for transmitting data from the smartphones to terrestrial Internet lines, enabling the feeder link to operate with main and sub-channels and thereby having structure redundancy. Two more frequency bands were allocated exclusively for controlling the payload and data collection. The frequency bands used in the tests are listed below.

<Frequency bands>

- Service Link：700MHz (3GPP Band28)
- Feeder Link：70-80GHz (Main), 5.8GHz (Sub)
- Payload control & data collection channel：902-928MHz, 1200-1700MHz

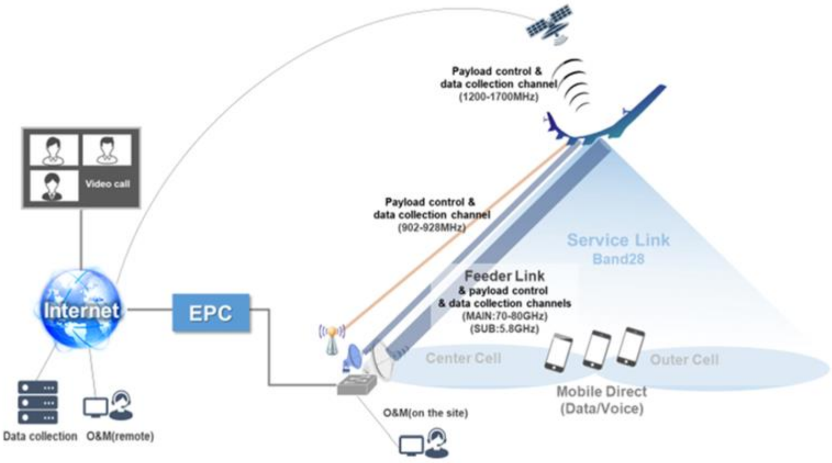

Fig. I-4 Network Structure

A ground gateway serves as the hub that connects a ground base station and a HAPS. A shipping container was temporarily transformed into a ground gateway (shown below). Feeder link antennas were installed on the roof of the container to conduct the communications test.

Fig. I-5 Terrestrial Gateway

I-4.2. Executing Communications Tests

SoftBank conducted communications speed tests, ping tests, and a video call using the network structure described above. For the communications speed tests, the presence of any fading effect was checked by comparing the difference between estimated signal received and that actually measured. The effectiveness multiple-input multiple-output (MIMO) in the HAPS environment was also verified. For the ping tests, messages were sent from a host computer to another computer. Round-trip time (RTT), which is the amount of time it takes for the host computer to receive a reply, was estimated, as well as the amount of delay in commercial use.

The testing environment for communications speed and ping tests is illustrated below. User equipment (UE) was controlled using personal computer connected via USB cable. Communications speed and pinging were measured using Iperf and a test server on the Internet.

Fig. I-6 Communications Tests

I-4.3. Test Results

I-4.3.1. Communications Speed Results

SoftBank conducted the tests using one UE connected at time, disconnecting the UE tested before testing the next. The results confirmed successful connectivity to all of the UEs, including the one located indoors. Additionally, fluctuation in signal reception was predicted, which would result in fading due to the HAPS being in motion. However, an analysis of the time variation in down-link (DL) reference signal received power (RSRP) obtained during the tests revealed that there was no fading effect. The analysis of communications speed also indicated that there were many cases in which the Rank Indicator values sent from UEs maintained a value of 2, which means MIMO is possible. There had been regarding MIMO capabilities due to the open-air nature of the HAPS environment; however, the data revealed that MIMO is feasible.

I-4.3.2. Ping Test Results

The following illustration shows from which node to which node verification was carried out during the ping test. The test was performed from a UE to the test server, as well as from the gateway to the test server, from the gateway to the Evolved Packet Core (EPC), and from Sunglider to the EPC. Using the values obtained, the RTTs for the Feeder Link (FL) and Service Link (SL) could be determined.

The FL RTT value turned out to be very small. Even if the transmission distance is farther than used in the test at SpA, HAPS systems can achieve RTT values significantly lower than 1ms. On the other hand, for the SL, partly because of the LTE protocols used, the scheduling request transmission cycle and grant allocation negatively affected the amount of delay. In order to expand the application of HAPS, it is imperative to lower the latency. SoftBank is also considering the utilization of 5G networks as a solution to reduce latency.

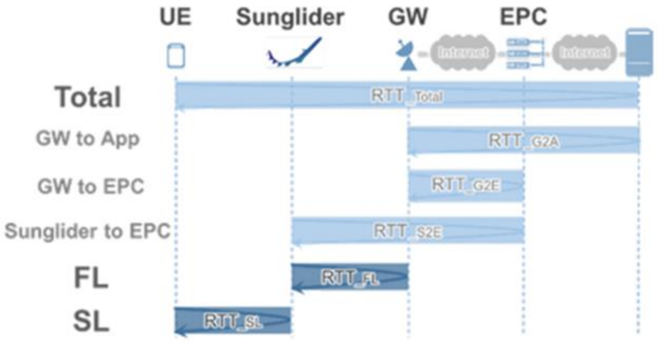

Fig. I-7 Ping Test

I-4.3.3. Video Call Test Results

Using a communications payload resistant to the demanding stratospheric conditions and smartphones equipped with the Zoom video-conferencing application, members of Loon and the AeroVironment team at Spaceport America successfully completed a video call with members of SoftBank in Tokyo, Japan.

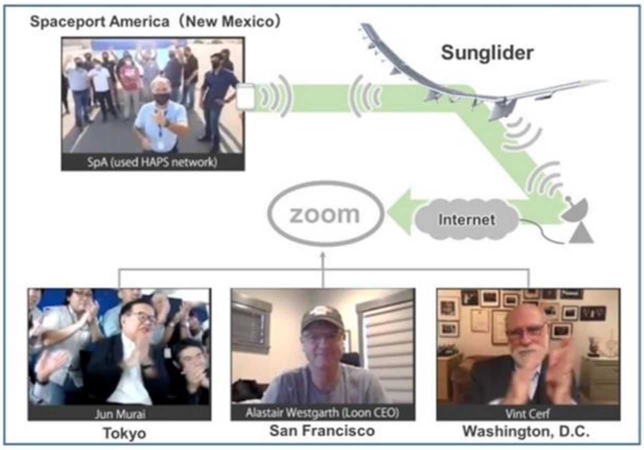

Fig. I-8 Voice Call Test Success

I-5. Challenges Towards Realizing HAPS

I-5.1. Flight Challenges and Measures Moving Forward

There are currently no established, internationally recognized, regulatory pathways for HAPS to operate in the stratosphere. In order to achieve the commercial use of HAPS systems in the near future, it is imperative that a regulatory framework, suitable for HAPS operations, be developed.

It is also important to analyze and clarify meteorological phenomena in the troposphere and stratosphere as a means of contributing to the safe flight of HAPS aircraft. Sharing meteorological information is one of the industry-wide issues for those involved in HAPS projects, as well as being required for improving the meteorological observation framework.

In order to address these issues, in cooperation with meteorological authorities in respective countries, a global platform should be established for obtaining meteorological data in the troposphere and stratosphere.

I-5.2. Communication Challenges and Measures Moving Forward

Since HAPS will provide coverage over extensive areas from the stratosphere, measures will need to be taken for radio-wave interference in the proximity of neighboring nations' borders. In order to conduct communications tests and provide smooth, stable services using HAPS at the global level, rules need to be established so that negotiations and arrangements with neighboring countries are conducted under cordial circumstances.

The public and private sectors should work together to establish rules that resolve the problems in each country.

I-6. Conclusion

This article describes the concept of HAPS and the results of a communications tests from the stratosphere using a fixed-wing type of HAPS aircraft.

This test demonstrated the concept that HAPS can be used with ordinal user terminals such as smartphones without modification, and that it can also be used for adequate data communications such as video calls. Based on these results, further technological development, standardization and regulatory activities are planned for implementing HAPS technology in the future.

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https://hapsalliance.org/wp-content/uploads/formidable/12/SpA_Flight_Communication_Tests_White_Paper_English_Final_2021.pdf

II. Extreme Coverage Extension in Beyond 5G and 6G: Cooperative HAPS Architecture Integrating Terrestrial Networks

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***Abstract*—The space radio access network is regarded as a communication infrastructure for the Beyond 5G and 6G, and extreme coverage extension is being studied for use cases in all locations including air, sea, and space. To achieve this extreme coverage extension, non-terrestrial network (NTN) technologies that use geostationary (GEO) satellites, Low Earth Orbit (LEO) satellites, and a High Altitude Platform Station (HAPS) are promising tools for providing high-quality communications services to areas that cannot be covered by conventional mobile communications networks. In this article, we present HAPS use cases and a cooperative architecture that focuses on the link between NTNs and terrestrial networks (TNs).**

II-1. Introduction

A key issue in the Beyond 5G and 6G eras is expected to be ubiquitously expanding the communications area where its benefits can be enjoyed. We are conducting research and development aimed at actualizing extreme coverage extension to all locations, including the sky, sea, and space, which have not been sufficiently covered by conventional mobile communication networks, using non-terrestrial networks (NTNs) based on geostationary (GEO) satellites, Low Earth Orbit (LEO) satellites, and High Altitude Platform Stations (HAPSs). For early implementation of extreme coverage extension, we are focusing on direct-to device communication services using HAPSs. In this article, we present HAPS use cases and a cooperative architecture that focuses on the link between NTNs and terrestrial networks (TNs).

II-2. HAPS use cases and network configuration/control technologies

We are researching and developing communication methods and network architectures that can flexibly link 5G networks and other TNs with stratospheric HAPS networks [1]. In addition to providing flexible support for a wide range of future use cases as envisioned in Beyond 5G and 6G, this project is conducting studies aimed at the implementation of communication systems that use HAPSs in terms of development and operation costs.

<u>HAPS use cases</u>

As shown in Fig. II-1, for the Beyond 5G and 6G era, it is expected that various use cases will involve using HAPSs to relay radio waves or emit radio waves as a base station. These use cases include fixed systems that provide services for backhaul applications and mobile systems that provide services to terminals either directly or via repeaters and relays. There is a need for flexible communication methods and systems that can support all use cases of fixed and mobile systems.

It is also necessary to flexibly control lines so that they can be adapted from normal business applications to public safety applications in the event of a disaster. Current disaster countermeasures are geared toward providing basic communication services such as voice calls and short message services, but it may also be necessary to consider use cases that require faster communication speeds, such as remote control of equipment at disaster sites, video transmission, and communication via drones. For disaster countermeasures, it will also be necessary to study network configurations and control technologies that assume the ability of a system to operate even if certain devices become unavailable.

Cooperative network configuration and control technology for HAPSs and TNs

Regarding the network configuration and control technology used when implementing backhauls to 5G base stations via HAPSs, we are focusing on the categorization of HAPS-mounted stations. They can be roughly divided into two types: (i) relay stations, which receive signals from ground stations and relay them back to other ground stations after executing necessary processes such as frequency conversion, and (ii) base stations, which are made by installing 5G network base-station equipment (or at least part of it) in a HAPS [2]. The relay type is effective when the number of onboard devices is relatively small and the size, weight, and power consumption of the HAPS-mounted station are strictly limited. The base-station type is formed by equipping a HAPS with an antenna device, together with many base-station functions. The more of these functions it includes, the greater the amount of control that can be executed within the HAPS, making it possible to reduce the amount of feeder-link information. However, installing more functions results in a station that is larger, heavier, and consumes more power.

Implementing more base-station functions on the ground-network side has the advantages of lower development costs and ease of operation, but implementing these functions on the HAPS results in greater resilience to natural disasters. In terms of performance, a HAPS-mounted station should at least implement certain functions, such as beam control, when using millimeter waves. It is also necessary to comprehensively study a wide range of requirements to be considered when incorporating HAPS systems into a 5G network. These include the size, weight, and power consumption of HAPS-equipped stations, their development and operation costs, the ability of these HAPS platforms to be shared by backhaul use and direct-to-device communication systems, and their ability to cooperate with GEO/LEO satellites.

An example of promising configuration using a relay-type configuration where a 5G radio repeater is installed in a HAPS is shown in Fig. II-2. In this configuration, the TN is used from the core network to the fronthaul, and the HAPS terrestrial system equipped with the radio unit (RU) function bundles and communicates signals for multiple beams. A broadband frequency, such as the Q-band, is used in the feeder link, and the HAPS relay system executes frequency conversion and power control. The HAPS can then establish service-link communications using multiple beams at the same time. As the service link, certain frequency bands below 2.7 GHz already identified for International Mobile Telecommunications (IMT) should be used according to the specifications approved at the World Radiocommunication Conference 2023 (WRC-23) [3].

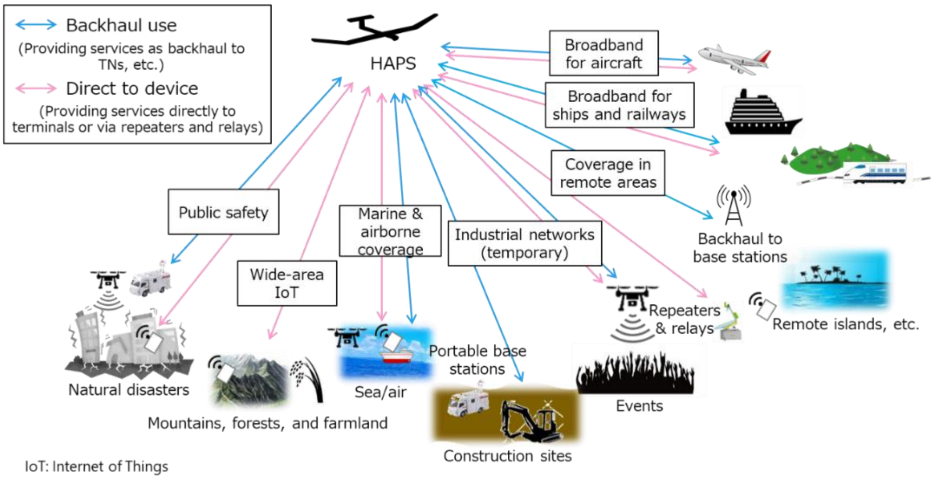

Fig. II-1 Various use cases expected for HAPS

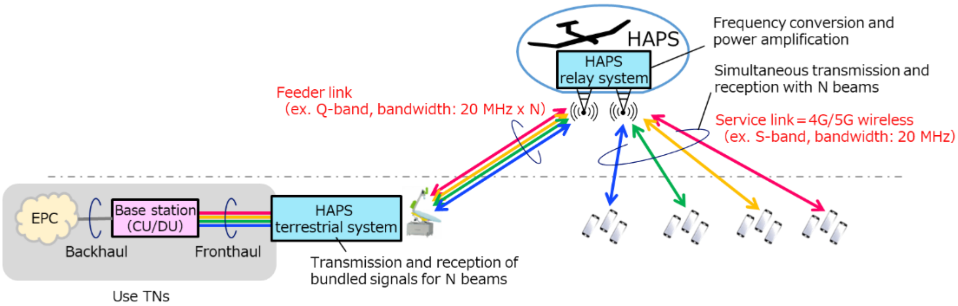

Fig. II-2 Example of cooperative configuration when HAPS is used for direct access

II-3. Cooperation between multi-layered NTN system and TN

As shown in Fig. II-3, the multi-layered NTN system, in which satellites and HAPS are connected to the terrestrial 5G (or future 6G) core network, is a larger scale three-dimensional heterogeneity network than previously achieved. It is expected that TNs, satellites, and HAPS will cooperate and provide seamless communications according to the location (including air, sea, and space) to offer service and the required communications speed and latency.

Two systems are being considered for access to mobile terminals in NTNs: (i) a relay system that accesses the mobile terminal from a satellite and HAPS through the relay station, and (ii) a direct access system that directly accesses the mobile terminal from a satellite and HAPS. As a derivative of system (i), a cellular backhaul (CBH) system in which satellites and HAPS support a backhaul between the core network and the BS as an independent tunnel line is conceivable. In the Beyond 5G and 6G eras, mobile devices can be accessed everywhere in various ways depending on use cases and optimization of the entire network.

The following are problems facing NTNs: expansion of the radio interface that is suitable for long-distance communications, an efficient frequency effective utilization method for the ground network, and a network design to actualize high-efficiency cooperation with the ground network. In addition, further investigation into wireless technologies such as handover, carrier aggregation (CA), and dual connectivity (DC) between the NTNs and TNs would be beneficial. On the other hand, since each NTN platform has different features such as capacity and propagation delay, it is necessary to examine routing and network construction considering the features of each platform. NTNs are also promising as a means to advance cost effectively future expansion of 5G network coverage already introduced, and they yield the possibility to optimize network development from the beginning in the 6G era.

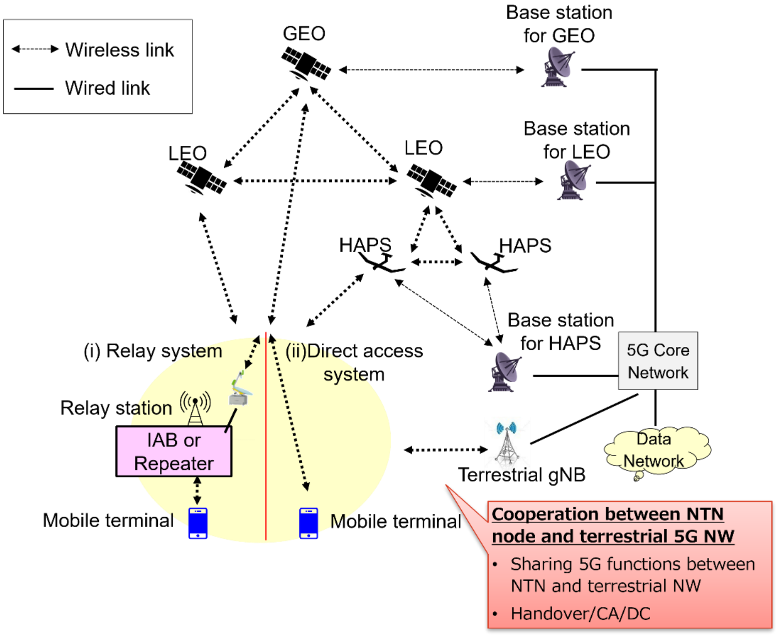

Fig. II-3 Multilayer network system using NTN platforms and cooperation with terrestrial 5G network

II-4. Conclusion

As part of our efforts towards implementing extreme coverage extension, we presented an architecture that integrates NTNs with TNs. Specifically, we described a cooperative architecture that focuses on the link between NTNs and TNs, and a cooperative configuration with a particular focus on HAPSs. We will continue developing NTN technology aimed at achieving extreme coverage extension and technology for actualizing HAPS networks.

II-5. Acknowledgements

Part of this research and development was carried out by the Ministry of Internal Affairs and Communications (Research and Development for Expansion of Radio Resources; JPJ000254).

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III. Very Low Earth Orbit Satellite Networks for 6G [1]

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***Abstract*—With the breakthrough of advanced satellite launching and manufacturing technologies in recent years, both the academia and industrial communities are making considerably efforts to study mega-constellations for Very Low Earth Orbit (VLEO) satellites. The non-terrestrial network (NTN) is widely believed to be a part of the 6G network. In this paper, the vision for the evolution of VLEO satellites-based NTN towards 6G is proposed, as well as the technical challenges and potential solutions.**

III-1. Introduction

The idea of Very Low Earth Orbit (VLEO) has the potential to change the paradigm for the Internet because it is much lower than the traditional Low Earth Orbit (LEO) or Geostationary Earth Orbit (GEO). Accordingly, communications based on mega VLEO constellations are envisioned owing to attractive features such as low transmission delay, smaller propagation loss, high area capacity, and lower manufacturing and launching cost when compared with traditional LEO or GEO satellites.

III-2. Driving factors and motivations

Integrating non-terrestrial and terrestrial communications systems will achieve 3D coverage of the Earth. They will not only provide communications with broadband and wide-range IoT services around the world, but also provide new functions such as precision-enhanced positioning and navigation and real-time earth observation.

A fundamental integration of TN and NTN will change the status quo and significantly improve user experience. By achieving unified design of TN and NTN, the barrier among different satellite systems will also be eliminated, allowing users to freely roam among terrestrial networks and non-terrestrial networks of different operators.

III-3. Usage scenarios and motivations

The VLEO-based NTN is expected to provide couples of usage scenarios and applications:

III-3.1. Extreme coverage

By using non-terrestrial network nodes, such as satellites, unmanned aerial vehicles, and high-altitude platforms, non-terrestrial networks can be flexibly deployed, connecting people through various devices such as smartphones, laptops, fixed-line phones, and televisions.

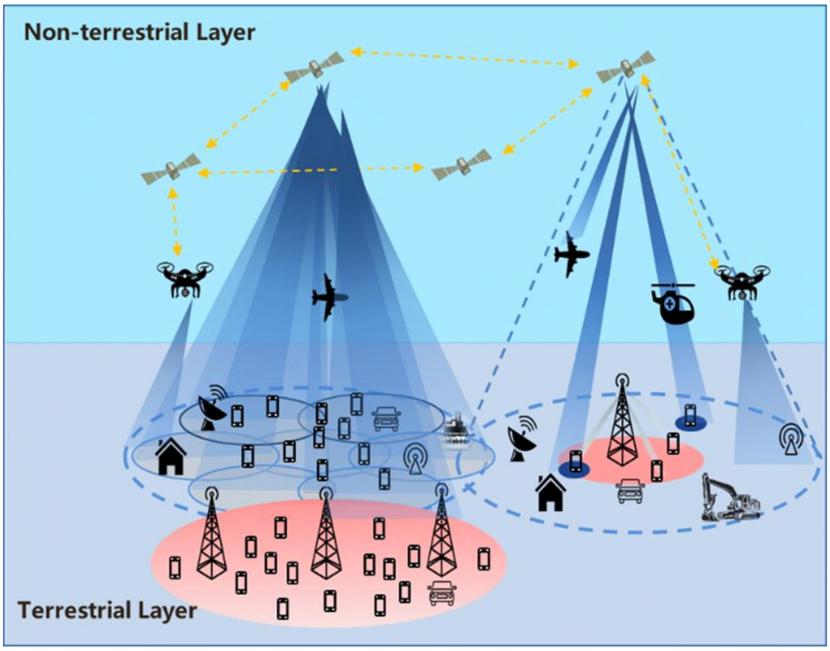

Fig. III-1 Usage Scenarios and Applications

III-3.2. Mobile broadband for the unconnected

Satellites can directly connect to mobile phones, providing broadband connectivity, with data rates similar to those of cellular networks in remote areas.

III-3.3. Broadband connection on the move

People should be able to access the Internet anytime, anywhere, no matter what kind of transportation they take. Future communications systems should provide MBB experience connections for all aircraft passengers.

III-3.4. Wide-range IoT services extended to unconnected locations

IoT devices should be able to connect and report information anytime, anywhere, such as the status of Antarctic penguins, the living conditions of polar bears, and animal and crop monitoring, from remote and uninhabited areas.

III-3.5. High-precision positioning and navigation

The integrated network can implement high-precision positioning and navigation and improve the positioning accuracy from meters to centimeters.

III-3.6. Real-time earth observation and protection

Earth observation can be introduced to more scenarios, such as real-time traffic dispatch, real-time remote sensing maps, and quick response to disasters.

III-4. Challenges and Solutions

III-4.1. Integrated network architectures

The following potential solutions are needed to provide unified services involving both TN and NTN with a single device, 1) 3D UE-centric cell-free communication where the cell boundaries can be eliminated efficiently; 2) Network slicing enables multiple logical networks to run as independent tasks on a common shared physical infrastructure; 3) A hierarchical control framework with very few ground stations and GEO satellites is used to achieve global network control, while MEO satellites and LEO/VLEO satellites with ISL capabilities are used for regional and local control.

III-4.2. Air interface technologies

Two potential solutions are provided to address this fundamental challenge and fully unleash the service capabilities.

III-4.2.1. On-demand coverage for imbalanced requirements

The beam-hopping concept is introduced to adapt the imbalanced requirements over the satellite coverage area [2]. Beam-hopping technology can use all the available satellite resources to provide services to specific locations or users. By adjusting the beams' illumination duration and period, different offered capacity values can be achieved, i.e., the imbalanced requirements in different beams can be satisfied, as shown in Fig. III-2.

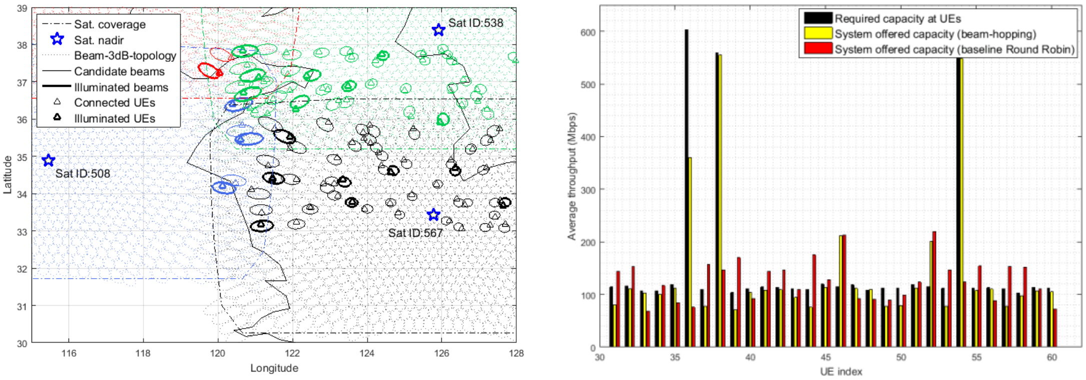

Fig. III-2 Beam-Hopping Scheduling scenario (left) and performance (right)

Multi-satellite cooperative transmission is another enabler to achieve on-demand coverage, as shown in Fig. III-3. Such a scheme makes sense considering the fact that only a very small percentage of the covered area is in service and multiple satellites are usually visible with a mega constellation. This technology enables one user to receive multi-satellite signals simultaneously. Accordingly, the user transmission rate or the peak capacity density can be increased when a user receives signals from multiple satellites at the same time, or when multiple satellites receive signals from the user.

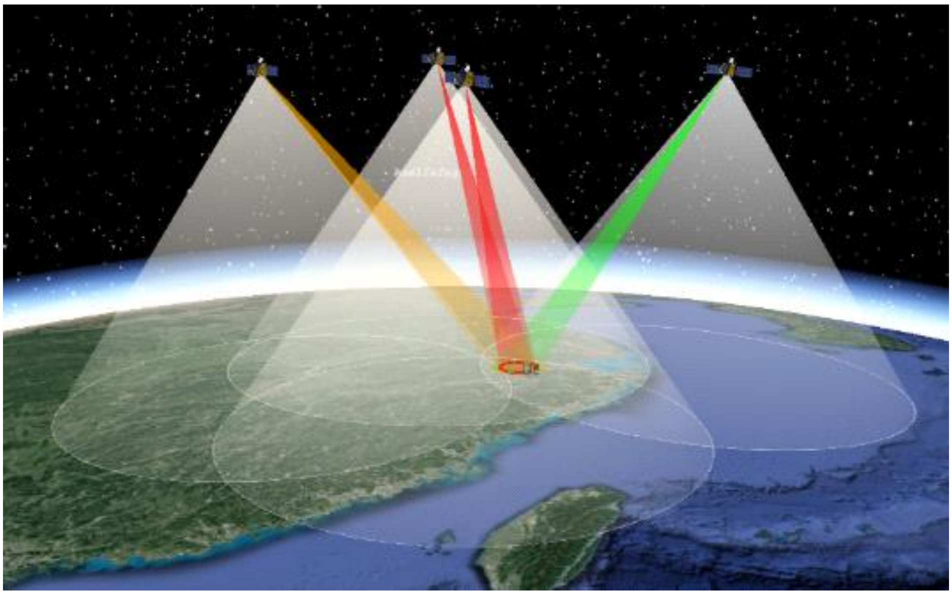

Fig. III-3 Multi-satellite Cooperative Transmission

III-4.2.2. Multi-beam precoding for high spectral efficiency

Multi-color frequency reuse is usually adopted to mitigate the co-channel interference in satellite communications, which leads to very low system spectrum efficiency. Multi-beam precoding can provide full-frequency reuse and improve the spectrum efficiency in VLEO/LEO satellite communications scenarios [3]. As the main characteristic of the satellite channel is Line of Sight, the multi-beam precoding matrix can be calculated based on the large-scale channel which is approximately decided by the relative location between the UE and the satellite. Multi-beam precoding can result in a huge gain in terms of total throughput during the time the satellite provides services.

III-4.3. Dynamic topology and routing algorithm.

Routing table sizes can grow dramatically as the satellite network grows in size, and the unpredicted link failure will lead the affected nodes with outdated topology for a long period of time. Orthodromic Routing (OR) is a promising solution to address the above problems by trading some packet losses against massive scalability [4], as shown in Fig.

III-4. OR consists of an addressing and forwarding plane, a path computation algorithm, and a limited flooding algorithm. The addressing plane of OR embeds the <X,Y,Z> coordinates of a point on the unit sphere for both the source and destination into the IP header thus obviating the need for constant translation of identification and location. The data plane then forwards packets to the closest satellite within a relatively small flooding vicinity along the shortest path to that satellite. All satellites also have coordinate-based addresses which are a strict function of time. Therefore, all satellites can calculate their own addresses and the addresses of the satellites in their flooding region as a function of time.

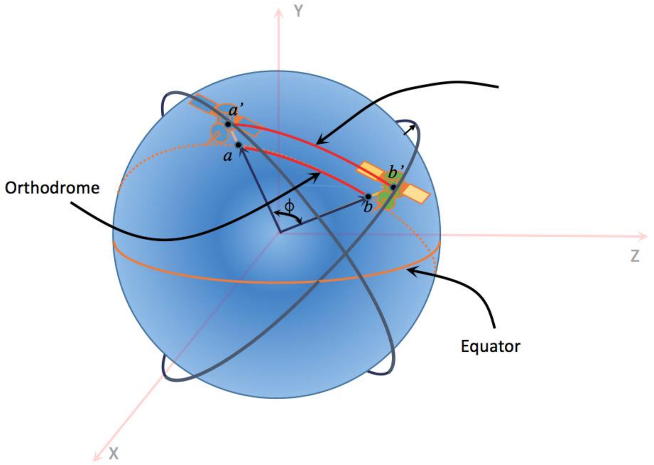

Fig. III-4 Orthodrome Relative to the Great Circle

III-4.4. Powerful on-board capabilities

The on-board capabilities call for thorough enhancements to accommodate communication requirements of NTN for 6G, mainly in on-board processors, radio frequency subsystem, antennas, and data transmission algorithms. Massive-beam satellites with on-board data processing capabilities and advanced algorithms will play a key role in future low-orbit satellite communications, providing more linking capabilities for users over the coverage area through frequency and beam traffic reconfiguration. In future NTN, massive-beam high-gain phased array antennas will be equipped to prevent the extremely high path loss from space to ground.

III-4.5. Low-cost manufacturing & service

A full integration of satellite communications into the cellular system is expected to be the most effective way to reduce the cost of communications components in ground segment devices like UEs, gateways, as well as the on-board processing system.

The service cost will also benefit from the full integration since it is also related to the economies of scale and the network capacity of a satellite system can be much better utilized to reduce the overall service cost.

There have been some explorations in recent years on using commercial-class devices i.e. the Commercial-Off-The-Shelf (COTS) parts in spacecrafts. Optimized processes, such as a better balance of the cost and reliability in the screening, new shield designs, and a fault detection and recovery mechanism, are needed to ensure the stability and commercial efficiency of spacecrafts.

III-4.6. Interference reduction and co-existence

Considering the fact that very limited frequency resources are available, it is more important than ever to design a frequency sharing mechanism from a technical neutral perspective. There are several hierarchical frequency sharing technologies

Space isolation: the same frequency resource can be allocated to both cellular and satellite networks that are geographically far away from each other.

Angle isolation: For scenarios targeting mmWave bands where only UEs with directional antenna are deployed, angle isolation can be considered to prevent the interference caused from different systems.

Scheduling-based interference coordination: with close interaction among neighboring base stations, joint decisions can be made among those stations to prevent interference.

III-5. Conclusion

The successful realization of LEO/VLEO-based NTN communications calls for joint efforts from the academia and industrial communities. The ongoing development of new technologies and the growing interest and investments in space applications is extending the boundaries of potential LEO/VLEO-based communications to new heights. In addition to the technical aspects of satellite communications itself, a fundamental integration of cellular- and satellite-based communications at the physical layer from day- one is also the key to the commercial success of LEO/VLEO-based satellite communications in 6G. The NR-based NTN discussion in 3GPP provides an excellent platform that traditional cellular and satellite communities can use to work together to build a fully integrated network.

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IV. Multi-layer non-terrestrial network and its routing management for Beyond 5G /6G

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Abstract—**This paper presents the concept of multi-layer non-terrestrial network (multi-layer NTN), which consists of geostationary orbit satellite, low earth orbit satellite and High Altitude Platform Station (HAPS). We also show our routing management technology for multi-layer NTN.**

IV-1. Introduction

Next-generation mobile communication systems such as Beyond 5G and 6G have been attracting the attention of mobile carriers and research institutes around the world [1–4]. One of the requirements for 6G is extreme coverage extension that spans places the mobile ground networks cannot reach, such as the sea, remote areas, and the sky [4]. The key technology to achieve this extreme coverage extension is the non-terrestrial network (NTN). In the NTN, satellites or High Altitude Platform Station (HAPS) networks are used to form service areas on the ground from space [4–6].

NTT is also studying to achieve the space integrated computing network shown in Fig. IV-1, which is an infrastructure that integrates multiple orbits from the ground to HAPS, Low Earth Orbit (LEO) and geostationary orbit (GEO) satellites [7]. They are connected to the ground by an optical wireless communication network to form a constellation, and distributed computing enhances various data processing. The space integrated computing network also provides access to terrestrial mobile devices for ultra-wide service coverage using space radio access network (Space RAN). We introduce the multi-layer non-terrestrial network (multi-layer NTN) as Space RAN in chapter 2. In chapter 3, we also show our traffic route control technology, which is one of our research results for multi-layer NTN.

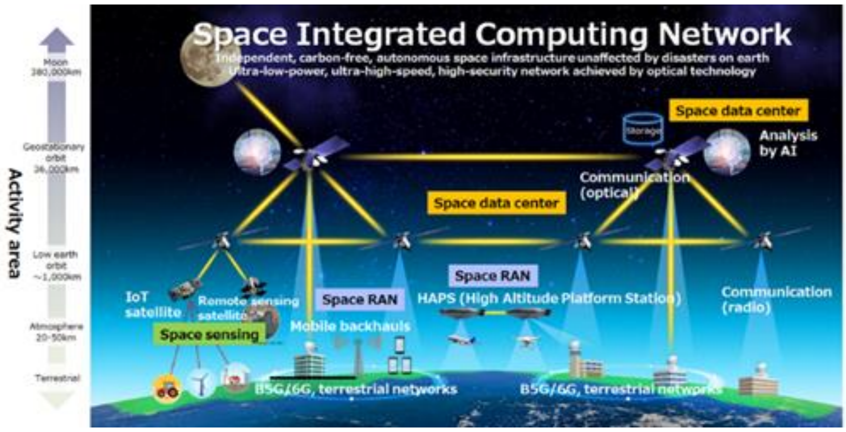

Fig. IV-1 Space integrated computing network.

IV-2. Multi-layer satellite network (Space RAN)

Fig. IV-2 shows an overview of the multi-layer NTN. It consists of GEO satellite, LEO satellite, and HAPS network. The GEO and LEO satellites in the GEO/LEO network and the aircrafts in the HAPS network are connected by a wireless link such as radio or free-space optics (FSO). These satellites and aircrafts form a service area that covers the surface of the earth and the sky. User equipments (UEs) on the ground connect to the satellite/HAPS networks, and the traffic generated by UEs are transferred to 5G core network (5GC) via ground base station.

The network controller controls the link connection between the satellites and aircrafts to build the optimum network topology on the basis of the position of the satellites/aircrafts, the state of the wireless link between satellites/aircrafts, and the ground base station. This improves the availability of the NTN. For example, a high frequency such as the Ka band and Q band is required to widen the bandwidth of a feeder link. However, the feeder link may be broken due to heavy rain because the attenuation loss of radio wave increases as the frequency increases. Therefore, the network controller controls the link connection on the basis of the link connection status and the rain conditions so that the network does not disconnect between UE and 5GC.

The network controller also controls the traffic routing. When feeder link is broken due to heavy rain, traffic might be 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 tackle the problem, we proposed a traffic-control scheme. In the next chapter, we present our traffic control technology in detail.

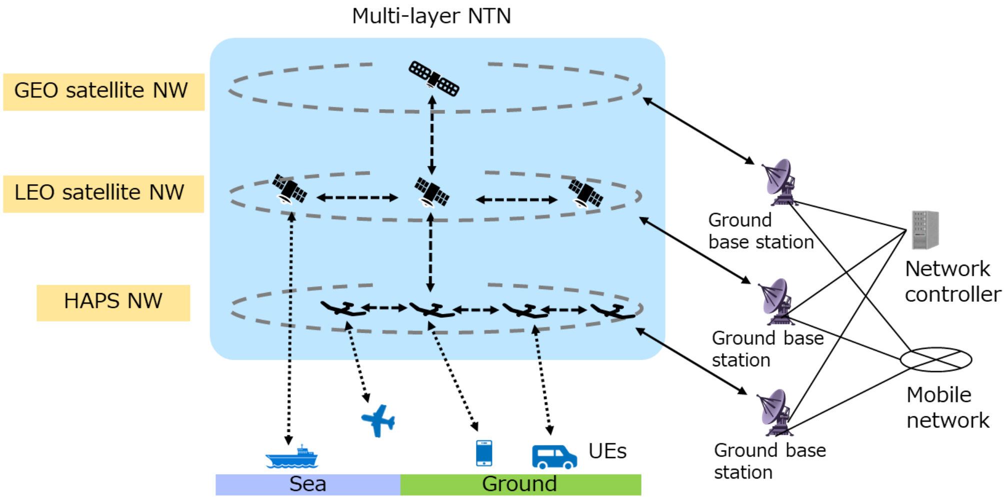

Fig. IV-2 Multi-layer NTN.

IV-3. Traffic control for multi-layer satellite network

In the proposed scheme, traffic route between UE and mobile network is derived at network controller. The network controller selects the optimal route from among the candidate routes by calculating the route cost, taking into account traffic congestion and delay time at inter satellite links (ISLs).

Route cost C is calculated using (1).

$$C = \sum_{i=1}^{n} Ci \quad Ci = \frac{Br}{R \ (1-\alpha)} + \frac{D}{Bd}, \qquad \ldots (1)$$

where α is defined as (2)

$$\alpha = \frac{r}{R}, \qquad \ldots (2)$$

Other variables are shown in Table IV-1.

Route costs are calculated for all candidate routes between UE and mobile network, and the route with the minimum route cost is derived as the optimal route. Finally, the network controller distributes routing tables to satellites and HAPS aircrafts.

We compared the performance with conventional OSPF (Open shortest path first) routing scheme and proposed scheme by computer simulation. Simulation model and parameters are shown in Fig. IV-3 and Table IV-2. Time-varying rainfall areas varied the communication availability of the feeder links, and then the network controller calculates the optimal route and update the route. Fig. IV-4 shows the throughput and delay time performance of conventional and proposed routing scheme. The results show that the performance of the proposed scheme is superior to that of conventional scheme in throughput and delay time.

Table IV-1 Variables in (1) and (2)

variables	Description
Ci	Calculated cost of link i
n	Number of communication links
Br	Reference value for link capacity
Ri	Transmission capacity of link i
αi	Congestion on link i
Di	Delay time in link i
Bd	Reference value of delay time
ri	Amount of traffic on link i

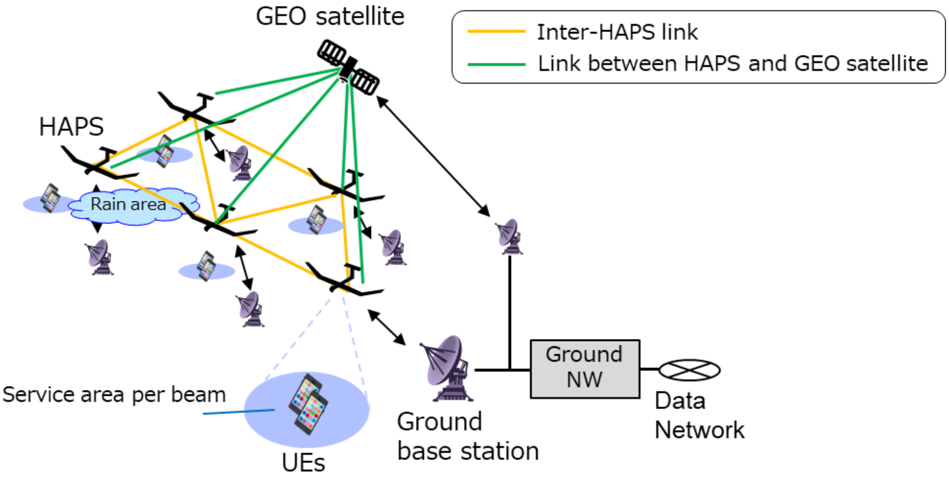

Fig. IV-3 Simulation model

Table IV-2 Simulation Parameters

Number of beams in service link per HAPS aircraft	4
Number of UEs per beam in service link	4
Amount of traffic per UE	5 Mbps
Capacity of feeder link	1 Gbps
Capacity of inter-HAPS link	1 Gbps
Capacity between GEO satellite and HAPS aircraft	1 Gbps
Feeder link frequency	38 GHz
Service link frequency	2 GHz

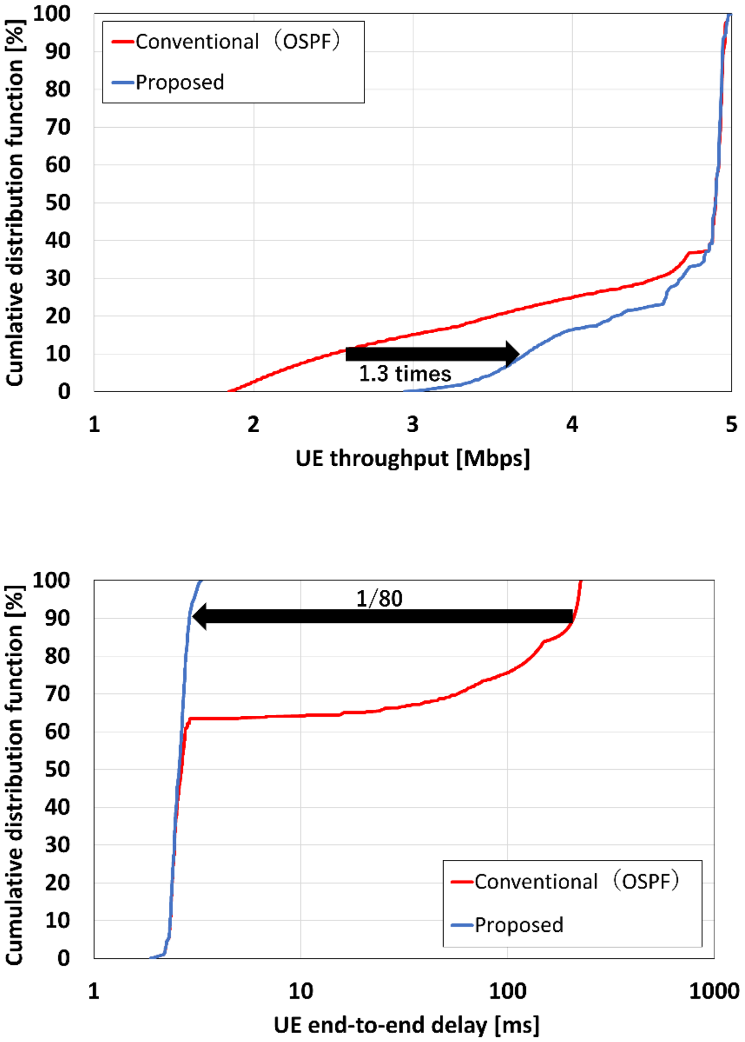

Fig. IV-4 Simulation results

IV-4. Conclusion

In this paper, we presented our concept of a multi-layer satellite network for NTNs (Multi-layer NTN). In addition, we introduced our routing management technology for multi-layer NTN.

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Abbreviation List

Abbreviation	Explanation
5GC	5G Core network
3GPP	Third Generation Partnership Project
CA	Carrier Aggregation
CBH	Cellular Backhaul
COTS	Commercial-Off-The-Shelf
DC	Dual Connectivity
DL	Down Link
EPC	Evolved Packet Core
FL	Feeder Link
FSO	free-space optics
GEO	Geostationary Earth Orbit
HAPS	High Altitude Platform Station
IMT	International Mobile Telecommunications
IoT	Internet of Things
IP	Internet Protocol
IPv6	Internet Protocol version 6
ISL	Inter Satellite Link
LEO	Low Earth Orbit
LTE	Long Tern Evolution
MaaS	Mobility as a service
MBB	Mobile Broadband
MEO	Medium Earth Orbit
MIMO	Multiple-Input and Multiple-Output
NR	New Radio
NTN	Non-Terrestrial Network
OR	Orthodromic Routing
OSPF	Open Shortest Path First
RAN	Radio Access Network
RSRP	Reference Signal Received Power
RTT	Round Trip Time

Abbreviation	Explanation
RU	Radio Unit
SL	Service Link
TN	Terrestrial Network
UE	User Equipment
VLEO	Very Low Earth Orbit
WRC	World Radiocommunication Conference