Report Issued by the Study Group on the Integration of Satellite Communications and 5G/Beyond 5G

January 2021

Study Group on the Integration of Satellite Communications and 5G/Beyond 5G

National Institute of Information and Communications Technology (NICT)

Contents

※ When citing this document

This document was created at conferences of the Study Group on the Integration of Satellite Communications and 5G/Beyond 5G as held by the National Institute of Information and Communications Technology (NICT). This document should be clearly specified as the source whenever it is cited or referenced.

January 2021

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Outline of conferences held by the Study Group

Conference	Date and time, location, attendees	Agenda
First	Date and time: August 29, 2019 (Thursday); 14:00 to 16:30 Location: NICT Otemachi Conference Room (Innovation Center TCR) Attendees: Outside members: 28 individuals from 15 organizations, 4 individuals from 2 observer organizations	(1) Explanation of the main objectives being pursued by the Study Group and a specification of the theme of the first conference (2) Group discussions (3) Presentation given by and questioning of each group
Second	Date and time: September 26, 2019 (Thursday); 14:00 to 17:00 Location: TKP Tokyo Station Nihonbashi Conference Center (Conference Room 322) Attendees: Outside members: 29 individuals from 15 organizations, 2 individuals from 2 observer organizations	(1) Explanation of the main objectives being pursued by the Study Group and a specification of the theme of the second conference (2) Introduction of satellite-based 5G technology (3) Group discussions (4) Presentation given by and questioning of each group
Third	Date and time: October 25, 2019 (Friday); 13:30 to 17:00 Location: TKP Tokyo Station Nihonbashi Conference Center (Hall 316) Attendees: Outside members: 29 individuals from 16 organizations, 3 individuals from 2 observer organizations	(1) Plenary session (2) Group discussions (3) Presentation given by and questioning of each group
Fourth	Date and time: November 28, 2019 (Thursday); 14:00 to 16:30 Location: TKP Tokyo Station Nihonbashi Conference Center (Hall 316) Attendees: Outside members: 28 individuals from 17 organizations, 4 individuals from 2 observer organizations	(1) Overview of discussions held up to the third conference and a specification of the theme for the fourth conference (2) Standardization study (3) Trial study (4) Approach to compiling this report (5) Other matters
Fifth	Date and time: January 23, 2020 (Thursday); 15:00 to 17:00 Location: NICT Otemachi Conference Room (Innovation Center) Attendees: Outside members: 29 individuals from 17 organizations, 6 individuals from 2 observer organizations	(1) Checking of the Study Group Report (draft) (2) Other matters

List of Abbreviations

・3GPP：Third Generation Partnership Project

・5G：Fifth-generation mobile communication system

・5GPPP：5G Infrastructure Public Private Partnership

・ASIC：Application specific integrated circuit

・ARTES：Advanced Research in Telecommunications Systems

・BER：Bit error rate

・D2D：Device to Device

・DVB-S2X：Digital Video Broadcasting - Second Generation Satellite Extensions

・eMBB：enhanced Mobile Broadband

・ESA：European Space Agency

・EIRP：Equivalent isotropically radiated power

・ETSI：European Telecommunications Standards Institute

・GEO：Geostationary orbit

・gNB：Next-generation Node B

・HAPS：High Altitude Platform Station

・HTS：High throughput satellite

・IoT：Internet of Things

・LAN：Local Area Network

・LEO：Low earth orbit

・MEC：Mobile edge computing

・MEO：Medium earth orbit

・MIMO：Multiple-input and multiple-output

・NFV：Network functions virtualization

・NR：New Radio

・NTN：Non-Terrestrial Networks

・QoS：Quality of service

・RAN：Radio Access Network

・SDN：Software-defined networking

・TR：Technical Report

・TS：Technical Specification

・TSG RAN：Technical Specification Group Radio Access Network

・TSG SA：Technical Specification Group Service and System Aspects

・URLLC：Ultra-Reliable and Low Latency Communications

・VM：Virtual Machine

・VNF：Virtual Network Function

1. Introduction

With the impending arrival of the fifth generation of mobile communications (5G), the role to be played by satellite communications in the context of 5G is drawing attention. In Europe in particular, joint public-private projects are actively being implemented, and studies are being carried out on satellite connections with respect to the standardization of 5G within the 3GPP.

On the other hand, activities for the introduction of 5G in Japan are proceeding at a dynamic pace, but no studies on the use cases and technologies in which satellite communications have been integrated with 5G to that end have begun (*In response to the recent mention by Ministry of Internal Affairs and Communications of connections with satellite and HAPS for communication area expansion as a policy of Beyond 5G on June 2020, the studies have begun in Japan). Satellite communications have traditionally been effective for services that take advantage of broad spectrums and multicasting and broadcasting characteristics, emergency communications employed in the event of a disaster, and broadband services for moving bodies, such as ships and aircraft. In recent years, we have achieved high-speed, high-capacity flexible link control and a reduction in the costs of communications and have seen expectations for improved satellite services rising thanks to high-capacity satellites, such as high-throughput satellites (HTS) based on the use of multi-beam technology for which empirical testing with Engineering Test Satellite-9 has been planned with mega-constellations comprising a large number of low-orbit satellites described as being on the cusp of commercial viability.

Under these circumstances, the Basic Space Planning Schedule (revised in fiscal year 2019) clearly stated that empirical testing tied to 5G, the IoT, and other terrestrial systems would be conducted on Engineering Test Satellite-9.[1] In addition, the 2019 Workshop on Integrating 5G with Satellite Communications was held in March 2019 by the NICT with concerned parties from Europe and Japan. The updated status of project activities being conducted in Europe for which studies had been carried out in advance (European projects), along with the fact that integration with satellite communications in the context of standardization activities related to 5G was being investigated by the 3GPP, were reported to concerned parties in Japan. This was followed up by a Conference for the Sharing of Opinions on the Integration of Satellites and 5G, which was held in May and June 2019. Discussions led to a decision to hold conferences of the Study Group on the Integration of Satellite Communications and 5G/Beyond 5G, which consists of domestic terrestrial and satellite communications providers, manufacturers, potential users, research institutes, and other parties, and which operates with the objective of engaging in more specific studies of, among other matters, effective use cases facilitated by integrating 5G with satellite communications, necessary technical issues and implementation methods, evaluations and demonstrations, and standardization with a view to also establishing connections with earlier European projects.

Conferences of the Study Group were held a total of five times by the NICT between August 2019 and February 2020. Effective use cases were studied at the first conference. At the second conference, the technologies required for integrating satellites with 5G were introduced, use cases were accordingly divided into three categories (smart cities, mobility, and emergency disaster response), and system concepts were investigated. For the third conference, the effectiveness of systems studied at the second conference, as well as technical challenges and matters concerning future standardization, were studied. Expected use cases and matters concerning standardization were examined at the fourth conference, and the results of these studies as carried out by the Study Group were summarized at the fifth conference.

The contents of these studies as carried out by the Study Group are hereby presented in this report.

This report has updated several points to reflect changes in circumstances that have occurred since the end of the Study Group.

2. Background behind the integration of satellites and 5G

In this chapter, we will first look at key 5G technologies that European projects seek to incorporate into the integration of satellites and 5G as a way to provide some context behind the integration of satellite communications and 5G. Next, we will outline recent changes in terms of circumstances as a way to provide some context to explain how the integration of satellites and 5G came to be expected. Subsequently, an outline of European projects will be given to indicate trends in the development of the integration of satellite communications with 5G. Finally, network architecture for the integration of satellites and 5G for which key 5G technologies have been deployed will be mentioned.

2.1. Key 5G technologies

In this section, key 5G technologies will be discussed. European projects to integrate satellites and 5G aim to apply the following technologies, which are to be deployed with 5G, to satellites.

- SDN (Software Defined Network)
  - ・Dynamically controls network configuration, functions, performance, and more with software.
  - ・Consolidates functions for controlling network equipment.
  - ・Enables network operations to be changed by dynamically changing network configurations according to traffic status and app requests.
  - ・Enables reductions in operating costs and capital investment costs for managing equipment settings.
- NFV (Network Function Virtualization)
  - ・Technology that expands virtualization technology into network infrastructure. Decouples software functions from dedicated hardware and runs them on general-purpose servers as VNF (virtual network function) software.
  - ・Launches a VM (virtual machine) and controls network equipment functions to realize network functions on general-purpose servers with the use of virtualization technology.
  - ・Can expect to improve the flexibility of an entire system, reduce hardware costs, and improve the rate of operation.
- Network slicing
  - ・Technology realized by SDN/NFV as basic elements.
  - ・Technology that multiplexes virtual independent logical networks onto the same physical network architecture.
- Orchestration
  - ・Network services and resources are managed and controlled on an integrated basis and optimized.
  - ・Time spent on processes is shortened by rapidly and flexibly allocating networks and resources.
- Edge computing
  - ・Technology for lower latency, high-volume data processing, and the offloading of terminal loads.
  - ・Elevating the multicasting and broadcasting functions of satellites.

An outline of network slicing is depicted in Figure 2-1, use cases are shown in Figure 2-2, and implementation methods are presented in Figure 2-3.[2] The application of these technologies is also expected to have a significant impact on the integration of satellites and 5G.

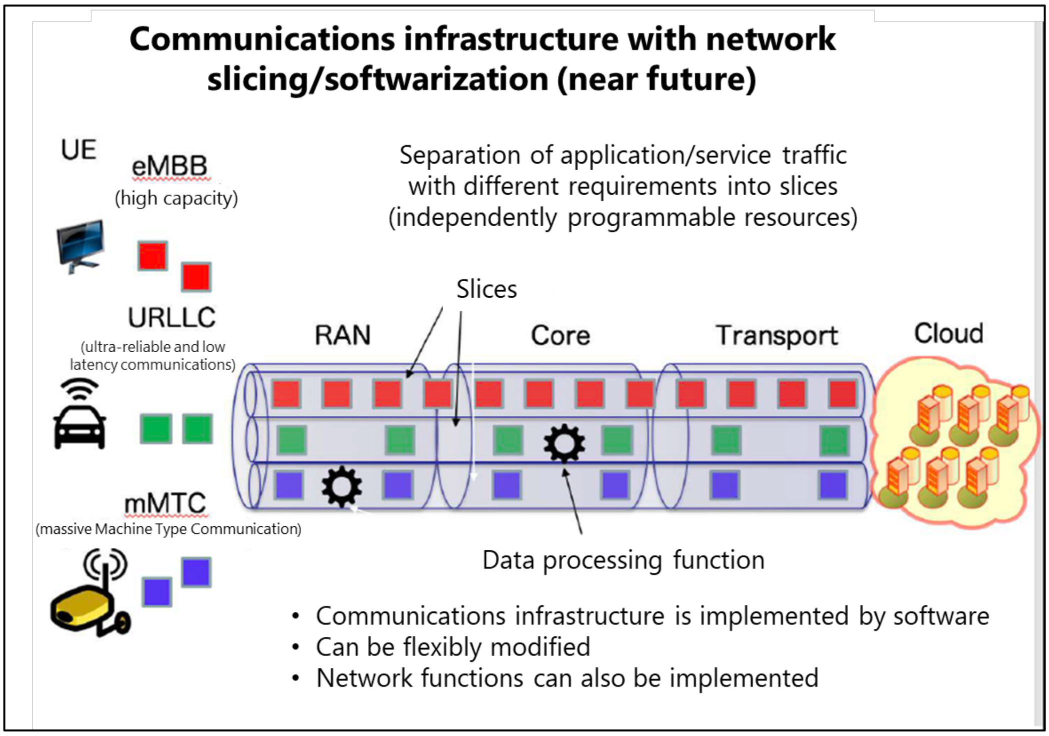


Figure 2-1: Outline of network slicing[2]

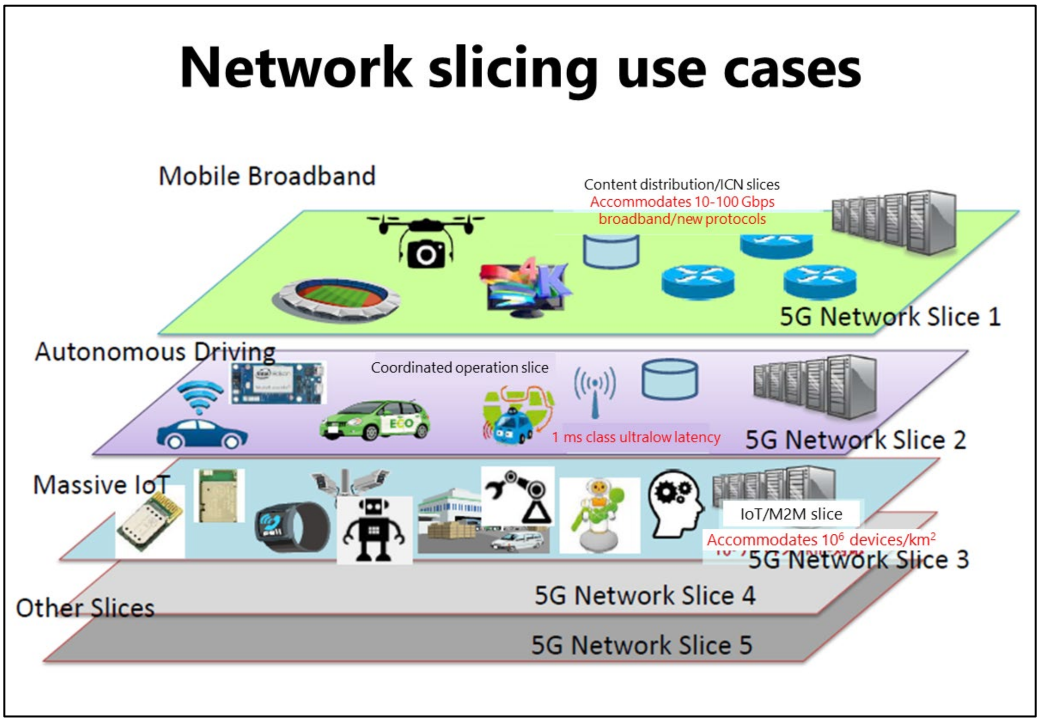


Figure 2-2: Network slicing use cases[2]

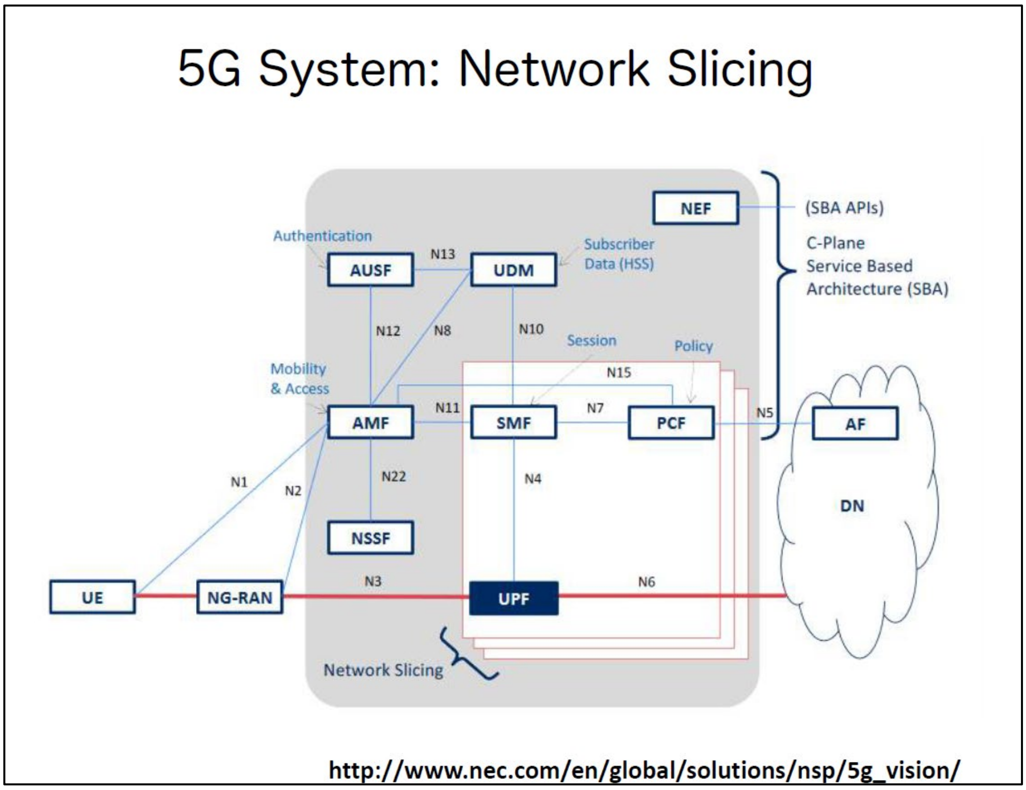


Figure 2-3: Methods for implementing network slicing[2]

2.2. Expectations for the integration of satellites and 5G

As presented in Figure 2-4, there are at least three motivations to consider the need for integrating satellites and 5G. The first is the evolution of satellite communications. In recent years, we have seen lower-cost, faster, higher-capacity links being offered as made possible by increasing the frequency utilization efficiency through the emergence of high-throughput satellites (HTS) outfitted with large numbers of multi-beams and the implementation of plans for mega-constellations comprising huge numbers of low-earth orbit (LEO) satellites, and terminals becoming significantly miniaturized and consuming less power.

Next, by deploying the softwarization and virtualization of networks, network slicing, and orchestration technologies characterizing 5G technology as noted in 2.1 into satellite systems, it is possible to realize the integration of satellite communications and 5G efficiently.

The last is standardization. The architecture of satellite communications has to date been built independent of terrestrial systems, and no efforts to standardize connections with terrestrial systems have ever been undertaken. With 5G, however, standardization encompassing non-terrestrial networks (NTN) with the inclusion of satellites has been pursued through the 3GPP, and unprecedented developments can be seen in this area. Accordingly, progress in terms of the adoption of plug & play features and development of ASICs can be expected as non-terrestrial networks continue to undergo standardization.

Against this backdrop, groundbreaking improvements to conventional use cases and the creation of use cases that have never before been seen can be conceivably expected through the integration of satellite communications and 5G.

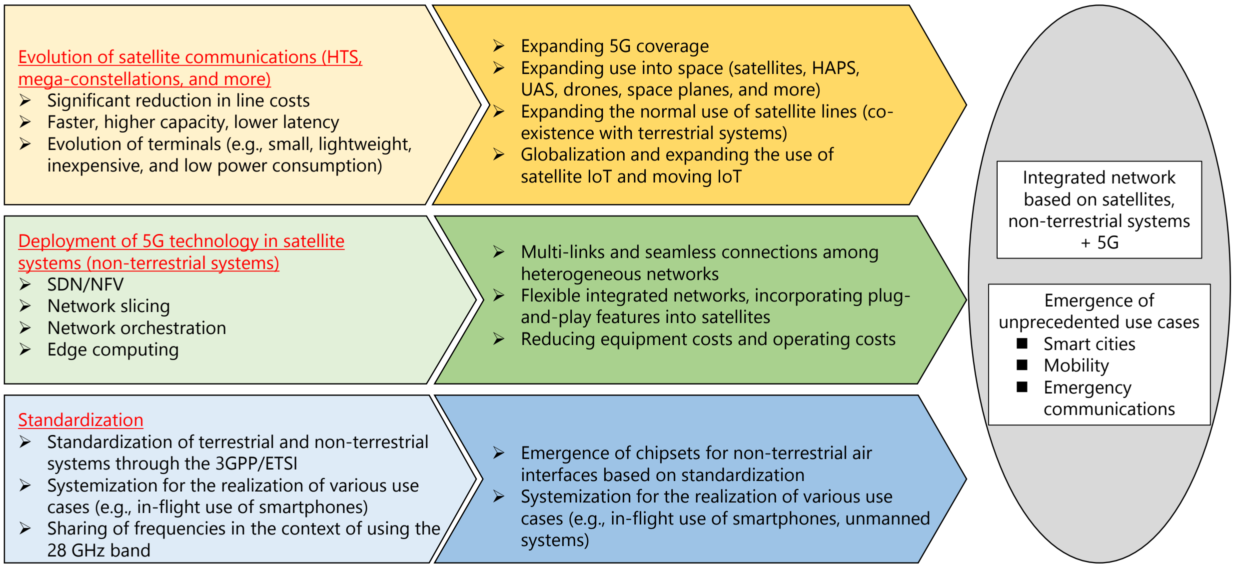


Figure 2-4: Motivations for the integration of satellites and 5G

2.3. Outline of European projects related to the integration of satellites and 5G

In Europe, development programs for the integration of satellites and 5G have been active since around 2015. As shown in Figure 2-5, the Horizon 2020 program has been operating SaT5G,[3][4] which was launched in 2017 as a large consortium, and the European Space Agency (ESA) promoted SATis5[5] through the independent ARTES program. Horizon 2020 also launched a joint EU-South Korean project (5G ALLSTAR[6]) in 2018 while a new project (Space 19+[7]) was proposed through the ESA's ARTES program in 2019. In these and other ways, initiatives have been ongoing.

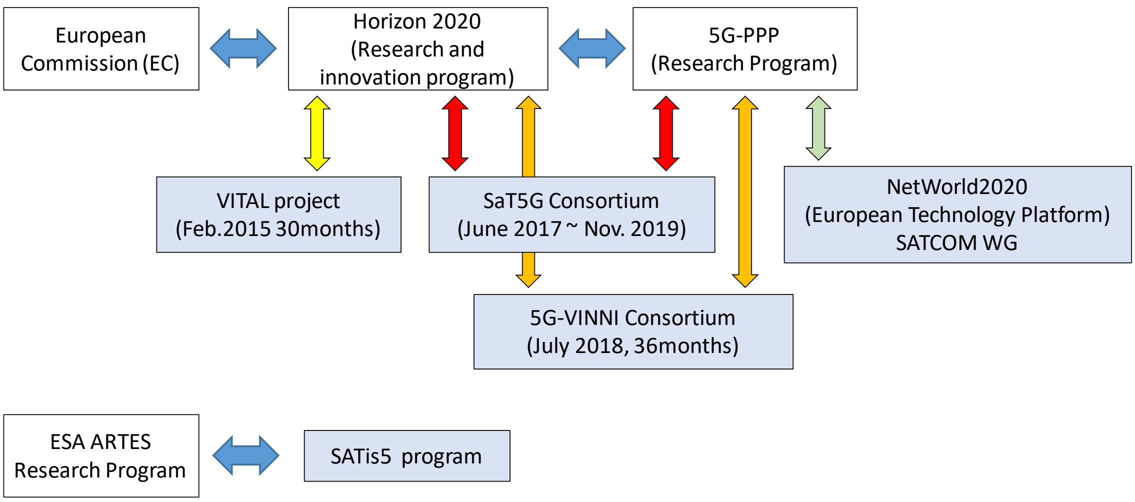


Figure 2-5: Activities for the integration of satellites and 5G in Europe

3. Studying use cases expected for the integration of satellites and 5G

3.1. Japan in the age of 5G/Beyond 5G

In Japan in the age of 5G/Beyond 5G (2020 to 2040), the following circumstances are envisaged, and various challenges are expected to arise.

・Japan's population has been declining since it peaked in 2005 and is expected to decline to approximately 111 million people by 2040 (Figure 3-1).

・Super-aging society (approximately 40% of the population are elderly).

・Changes in social structure.

・More elderly people are living alone or with low levels of income.

・Elderly people account for about half of the consumer market.

・Municipalities and tangible goods are disappearing throughout the country.

・Shortages of retail outlets in rural areas are increasing.

・A shrinking population of productive-age workers is making it harder to maintain productivity.

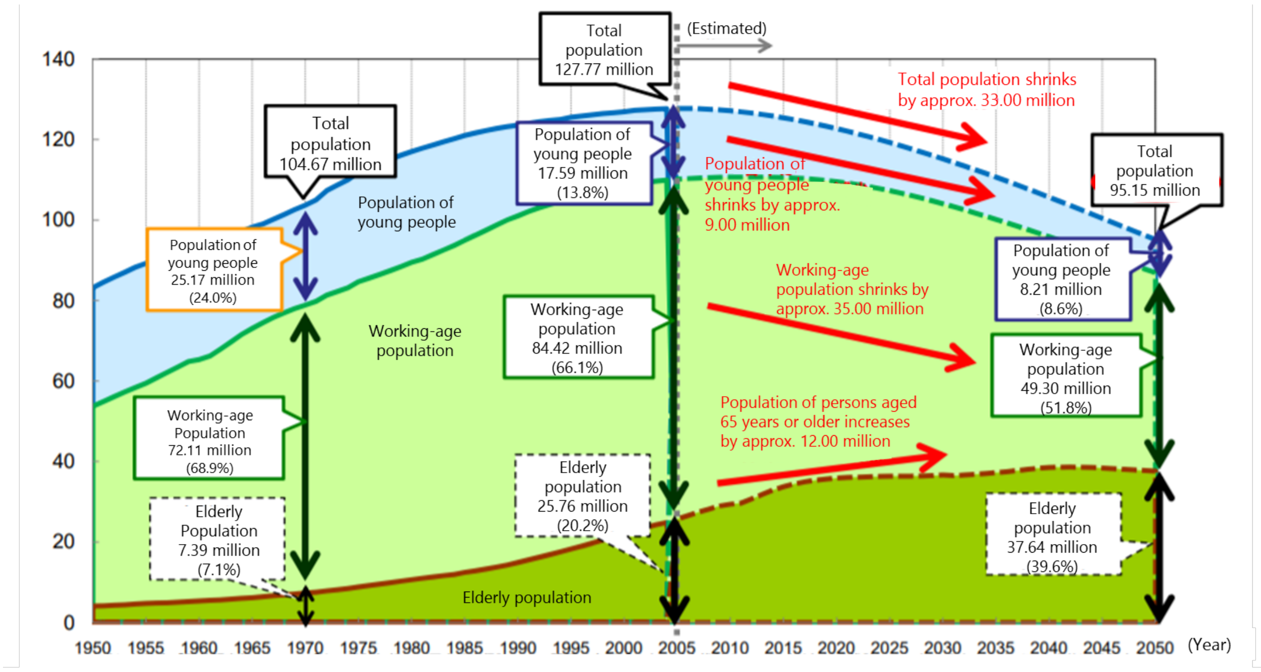
・At the same time, the need is growing for remote medicine, autonomous driving options, and online shopping services (home delivery) in areas where conditions are unfavorable.

・Measures to improve productivity are a challenge.

As indicated in Figure 3-2, inhabited areas are projected to become uninhabited over time as outlined below.

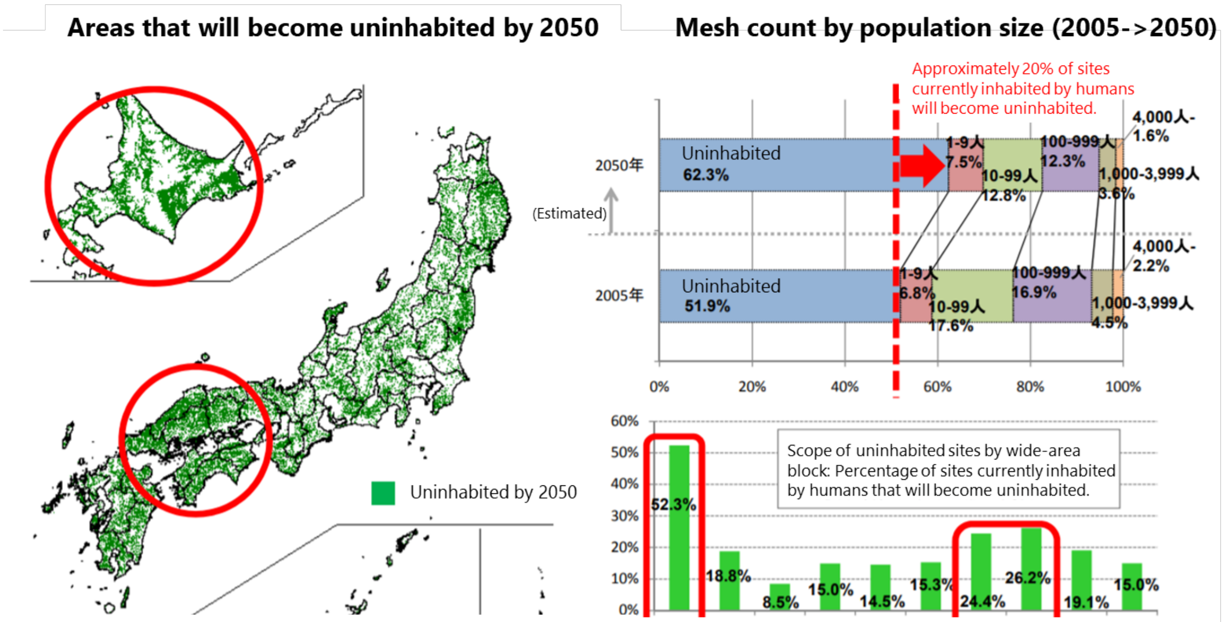
・Approximately 20% of areas currently inhabited by people will become uninhabited by 2050.

・While approximately 50% of the country is currently inhabited, this figure will drop to approximately 40%.



Source: Produced by the National Regional and Planning Bureau, Ministry of Land, Infrastructure, Transport and Tourism based on median birth (median death) estimates from the *National Census Report* (Ministry of Internal Affairs and Communications), *Population Projections Annual Report* (Ministry of Internal Affairs and Communications), and the Population Projections for Japan (Estimates as of December 2006) (National Institute of Social Security and Population Studies).
Note 1: "Working-age population" is the population of persons between the ages of 15 and 64 years; "elderly population" is the population of persons aged 65 years or older.
Note 2: Figures indicated in parentheses denote the percentage of the total population accounted for by the population category in question (population of young people, working-age population, or elderly population).
Note 3: For 2005, the population of persons of indeterminate age has been allocated to different age brackets and included therein.

Figure 3-1: Changes in the aggregate population of Japan (three age brackets)[8]



Source: Produced by the National Regional and Planning Bureau, Ministry of Land, Infrastructure, Transport and Tourism based on estimates determined by the Bureau (future population figures by mesh).

Figure 3-2: Changes in inhabited areas and uninhabited areas[8]

3.2. Investigating use cases in Japan

In investigating use cases for integrating satellites and 5G in Japan, the state of communications based on an assumption of circumstances described in the preceding section will need to be investigated. In this connection, it was decided that the use of the integration of satellites and 5G to address challenges facing Japan that are slated to emerge by around 2040 would be treated as one of the central themes. In addition, while various fields might be expected to constitute fields of use cases, it was thought that IoT, smart cities, transportation infrastructure in the maritime and aviation sectors, and emergency disaster response are effective use cases.

In this connection, use cases for satellite-based 5G were discussed by the Study Group with a focus on the following five themes:

- Theme 1: Use of satellite-based 5G to address challenges that Japan faces and that will emerge by around 2040
- Theme 2: Use of satellite-based 5G in the age of the Internet of Things (IoT)
- Theme 3: Use of satellite-based 5G for realizing smart cities
- Theme 4: Use of satellite-based 5G in the maritime and aviation sectors and for transportation infrastructure
- Theme 5: Use of satellite-based 5G in responding to emergency disasters

In investigating use cases, use cases investigated through the earlier 3GPP were referenced. The results of investigations carried out through the 3GPP are set forth in Chapter 5 of TR22.822, and various use cases have been broken down into twelve different use case categories.[9] The relationship between use cases investigated through the 3GPP and the aforementioned investigative themes for discussion by the Study Group are presented in Figure 3-3.

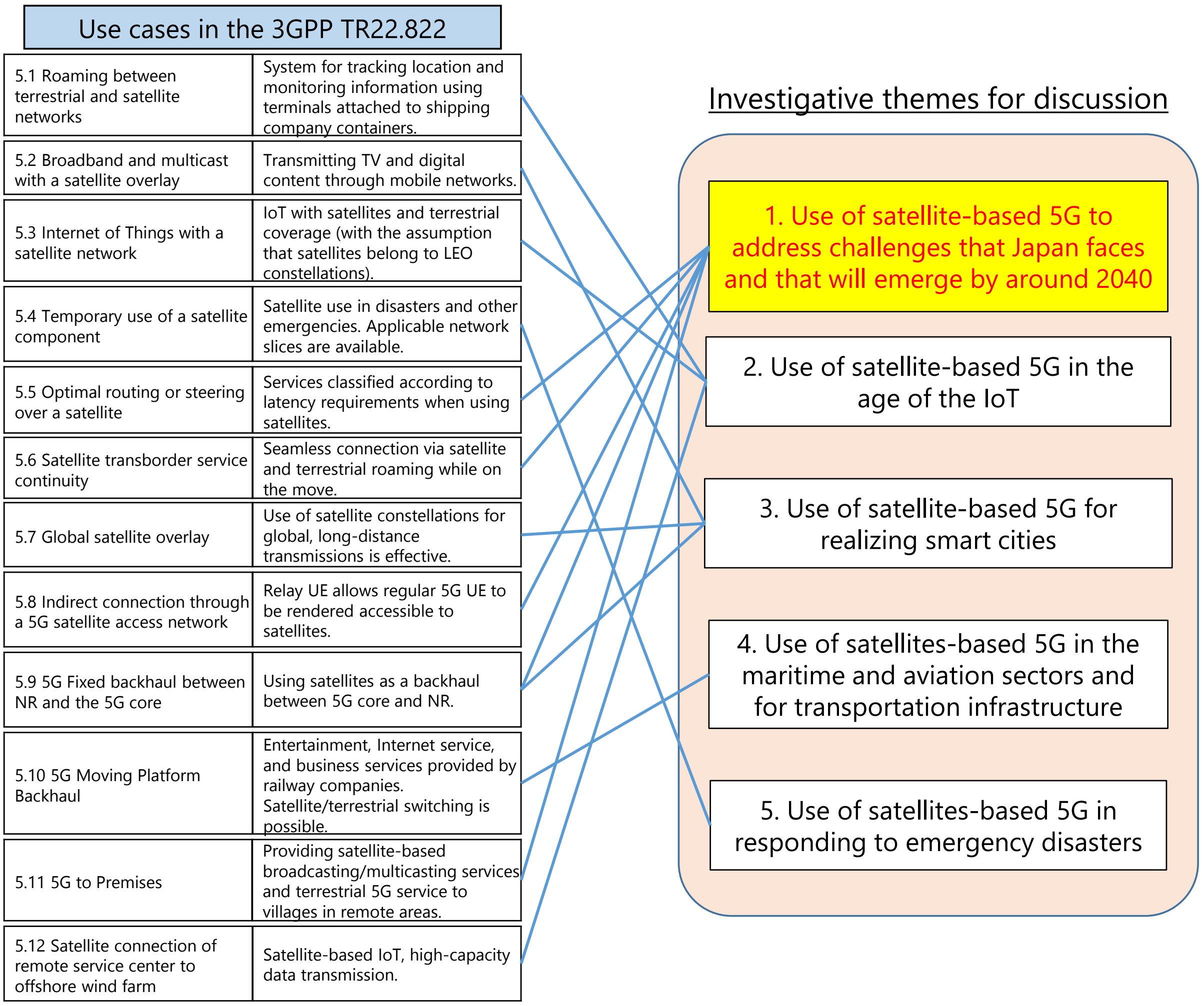


Figure 3-3: Relationship between use cases investigated through the 3GPP and the investigative themes for discussion

The contents of discussions concerning Theme 1, which is a high-level concept, and Themes 2 through 5 are presented below.

Theme 1 + Theme 2: Use of satellite-based 5G in the age of the IoT

● Summary of discussion contents

・Utilization for IoT.
・Ways of using in uninhabited places will become new ways of using satellites.
・Deploying traffic lights as satellite-based 5G base stations.
・Use cases that leverage the ability of satellites to cover wide areas and broadcast content.
・Satellites as a means of expanding area coverage.
・Data collection through sensor network systems.
・Disseminating satellite communications through the simplification of link-construction methods.

・Direct communications with satellites based on the use of mobile terminals.
・Landslide detection using local IoT systems, dam monitoring, and maritime communications.

<u>Theme 1 + Theme 3: Use of satellite-based 5G for realizing smart cities</u>

● Summary of discussion contents
・Converting depopulated areas into smart cities.
・Developing communications infrastructure to attract tourists to depopulated areas.
・Providing emergency notifications and medical services to depopulated areas.
・Applying network slicing to emergency links and other links, such as YouTube, when traffic is concentrated in the event of a disaster.
・High level of point-to-point confidentiality.
・Urban planning based on the use of earth observation image data created in LEO.
・Harnessing satellites and HAPS to cover space that cannot be covered by 5G.
・Use cases in which the advanced security features of 5G have been used (advanced security that is unsupported by Wi-Fi).

● Specific examples of use cases and services

Security measures for personal information

Medical Monitoring of the Elderly

・Communication links for tourists in depopulated areas
1. Simultaneous multiple-count use at tourist attractions
2. Accommodation facilities in depopulated areas

・Emergency notifications and remote medical services for residents of depopulated areas
1. Security measures applicable to personal information
2. Medical monitoring of elderly persons

・Monitoring of the natural environment
1. Collecting information for predicting natural disasters using distributed installed sensors
2. Providing information on disasters to tourists

・Urban planning in depopulated areas
1. Urban planning that combines positioning and communications
2. Expanding 5G coverage across the sky with satellites and HAPS

● Concerns
・Delays in the adoption of 5G due to insufficient funds available to local governments.
・Poor usability of satellite terminals.
・Not easy to ascertain the radio wave environment as required to expand coverage in areas of the sky by satellites and HAPS.

<u>Theme 1 + Theme 4: Use of satellite-based 5G in the maritime and aviation sectors and for transportation infrastructure</u>

● Summary of discussion contents

・A communications infrastructure to accommodate the distribution of smaller cities is required.

・Satellites are needed for maritime and aviation purposes but the scope of usage can be expected to grow even further in the future as 5G continues to be adopted.

・While satellites are needed as a terrestrial backup option, low latency is an issue.

・Low-orbit satellites and HAPS provide low latency, which means that they can be expected to function as disaster-resistant base stations.

・Using in order to maintain bus routes in rural areas.

・Remotely carrying out construction in depopulated areas by satellite.

・Broadcasting services through 5G multicasting.

・Satellites should ideally be operated as core infrastructure in accordance with the relevant national policy (and can also be used as infrastructure for autonomous driving).

・Costs of satellite links are high.

・5G base stations reduced through the use of multi-beam satellites.

● Investigating use cases

・It is difficult to currently connect aircraft services. Ship and aircraft services need to accommodate higher speeds and higher capacities (such as through the application of beamforming).

・Application to flying cars.

・Support for autonomous driving in areas that cannot receive terrestrial coverage.

・Incorporating satellites into a seamless system of logistics by sea, air, and land.

<u>Theme 1 + Theme 5: Use of satellite-based 5G in responding to emergency disasters</u>

● Summary of discussion contents

・Expanding 5G coverage.

・Maintaining seamless connections.

・Temporary infrastructure backups.

● Contents of Theme 1 discussions

・Autonomous driving: Effective in rural areas where the population is shrinking.

・Improving end-to-end communications.

・While the population will shrink in the future, there will still be people, which means that the expansion of areas receiving 5G coverage is important; remote medicine will also be required.

・High-functionality at sea.

・Maritime IoT.

・Beyond line-of-sight drone operations by satellite.

・Using satellites for local 5G (such as on construction sites).

・Autonomous robots.

・Support for foreign workers: Using satellites where 5G coverage is not available in areas where the population is declining (such as for the provision of translation services).

・Using satellites as backhaul components for terrestrial base stations.
・Using satellites as a maintenance-free option for base stations: The maintenance of base stations imposes a significant burden; satellite backup is an effective option.
・Drones and HAPS as backup options.
・Enhancing communications infrastructure: Effective if flexible coverage and multiple frequencies can be used.
・Wide-area IoT.
・Using satellites for temporary base stations.
・Large-scale agriculture.

● Contents of Theme 5 discussions

・Connecting D2D and smartphone relays to satellites: Satellite costs are an issue.
・Current smartphones can be connected even in the event of a disaster (low speed is acceptable).
・Disaster countermeasures based on the use of IoT terminals.
・Seamless terminals (dual).
・Backup option for remote islands.
・Specially installed public telephones.
・Applications for which terrestrial coverage cannot be provided: resource management, increased capacity, lower costs.
・Always available earth observations (disaster prediction).
・Using observation satellites in the event of a disaster.

3.3. Summary of use cases

Since there were differences in levels corresponding to themes discussed in the preceding section, theme categories were carefully examined, whereupon each theme was reclassified in accordance with the following three categories as presented in Figure 3-4. The correspondence of use cases discussed in the preceding section and these categories is shown in Table 3-1.

- Category A: Smart cities
- Category B: Mobility
- Category C: Emergency disaster response

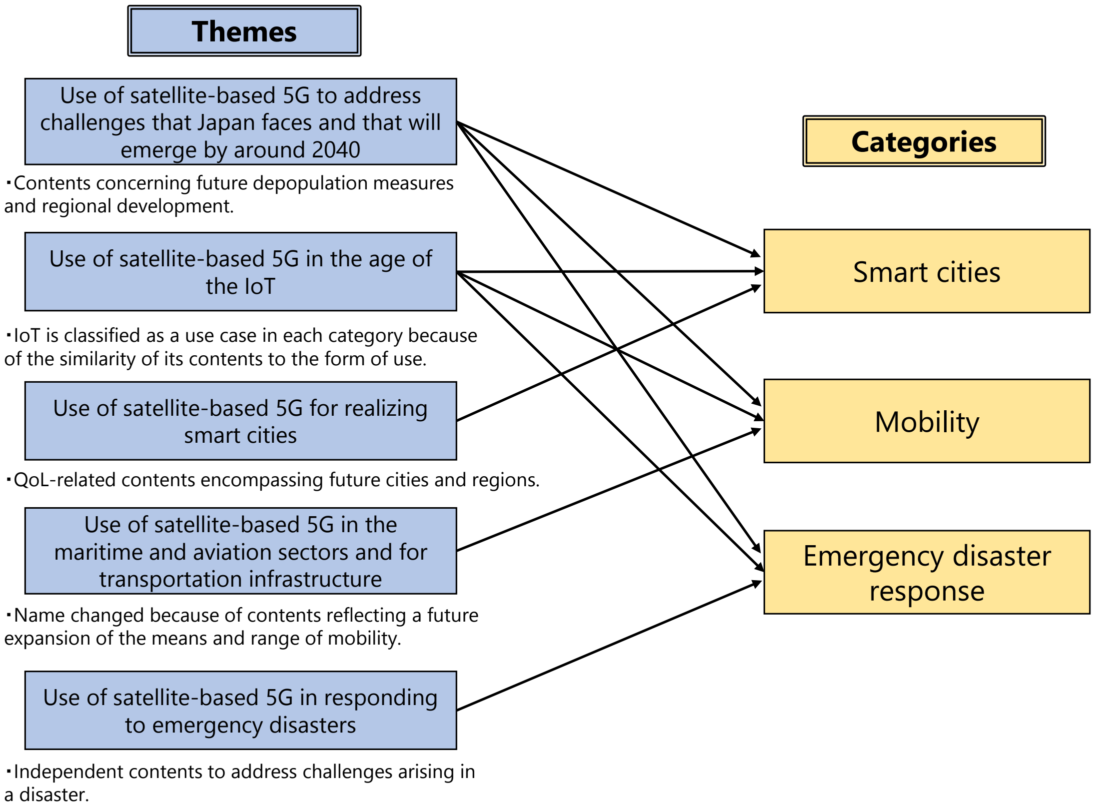


Figure 3-4: Reclassifying use case themes

Table 3-1: Summary of use cases

Category	Use cases
A: Smart cities	・Various types of data communication services based on the use of satellite terminals installed at traffic lights on roads and 5G terminal base stations. ・High-speed communication links that can be simultaneously used by a large number of people at tourist sites. ・Providing 5G service to hotels and other such establishments. ・Providing information for tourists through the monitoring of the natural environment. ・Urban planning that combines LEO satellite images, positioning information, and communications. ・Broadcasting alternatives based on the use of satellite multicasting. ・Autonomous driving (effective in rural areas where the population is shrinking). ・While the population will shrink in the future, there will still be people, which means that the expansion of areas receiving 5G coverage is important; remote medicine will also be required. ・Autonomous robots. ・Using satellites for local 5G (such as on construction sites). ・Support for foreign workers (such as translation services where 5G coverage is not available in areas where the population is declining). ・Using satellites for temporary base stations. ・Large-scale agriculture. ・Using satellites as a maintenance-free option for base stations. ・Backup option for remote islands.
B: Mobility	・Collecting monitoring data obtained by various types of equipment on board ships (including engine system and measurement systems). ・Expanding 5G services to the sky (space) with satellites and HAPS. ・High-speed, higher-capacity, and lower-cost aircraft communications. ・Flying cars. ・Seamless management of logistics in logistics systems at sea and on land, and IoT utilization. ・Autonomous driving. ・Beyond line-of-sight drone operations by satellite.
C: Emergency disaster response	・Landslides, dam monitoring, and more. ・Collecting and providing information for predicting natural disasters using sensors installed in a distributed pattern. ・Backhauling with LEO satellites and HAPS in the event of a disaster. ・Connecting D2D smartphone relays to satellites (current smartphones connect directly). ・Observing disaster conditions with the IoT (terrestrial systems cannot be used). ・Always available earth observations (disaster prediction, disaster observation).

4. Investigating initiatives concerning the integration of satellites and 5G

In this chapter, the benefits of the integration of satellites and 5G for users, technologies for the integration of satellites and 5G as required for realization, the validity of and evaluation items assessed in domestic trials, and the results of investigations into technologies to be confirmed are indicated with respect to use cases in each category based on discussions related to use cases as mentioned in the preceding chapter.

4.1. Effectiveness of the integration of satellites and 5G

We studied a conceptual diagram of systems involved in the integration of satellites and 5G in order to realize use cases in each category, and investigated effectiveness in the event that the integration of satellites and 5G is adopted and the technical issues that are relevant for this realization. The results of our investigation are presented below:

Category A: Smart cities

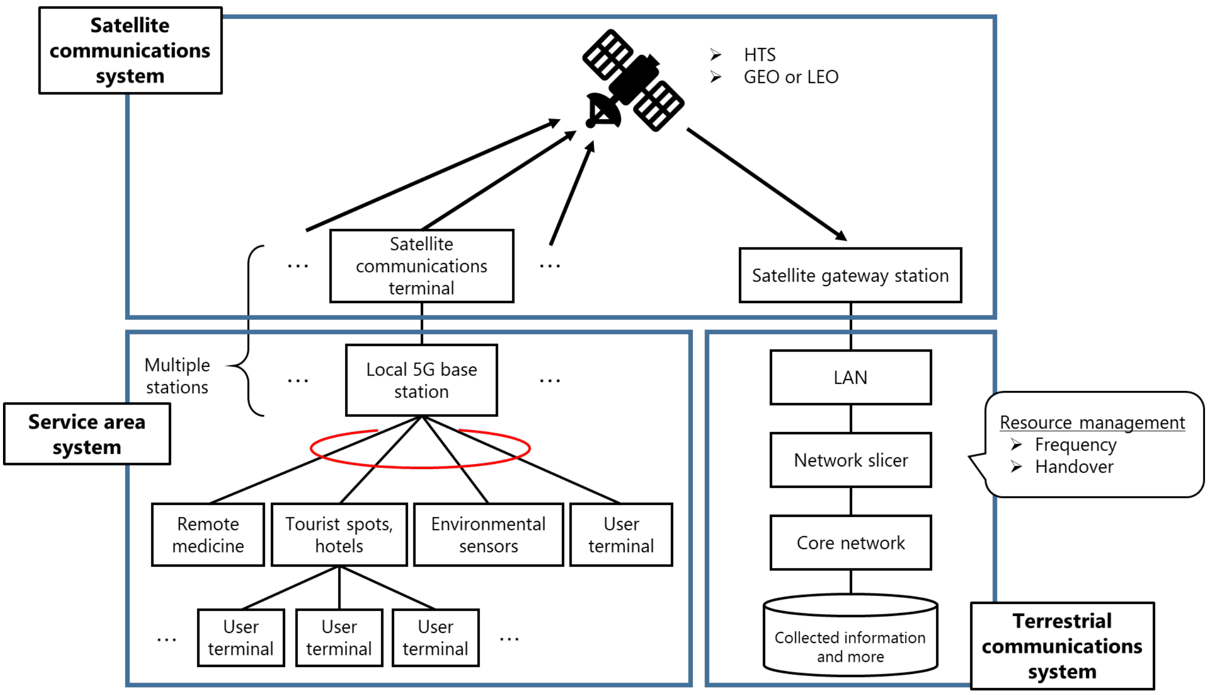


Figure 4-1: Conceptual diagram of systems involved in smart cities

- Conceptual diagram of systems: Figure 4-1
- Investigating system concepts

・Backhaul uses.

・Where there are no alternative means other than satellites.

・Hypothesizing that the unit price of satellite communications will go down (and that systems based on the use of large numbers of satellites will also emerge).

・Softwarization of networks (networks will be built even with general-purpose components by non-communication carriers).
・Slicing technology permits the use of multiple satellites (GEO, LEO) according to the application.
● Investigating use case benefits (summary)
・Creating spot areas in rural areas and other locations lacking a terrestrial network.
・Ad-hoc network construction in response to demand.
・The maritime use of satellites (unmanned ships, remote islands, uninhabited islands) is effective.
・Unmanned convenience stores (video, sensor data).
・Use with IoT: Monitoring birds and animals with sensors and cameras, accident measures.
・Lower latency in entertainment and financial applications.
・Greater efficiency through MEC processing of satellite image data.
・Remote medicine, operating heavy machinery on a remote basis, agricultural automation.
・Eliminating public and private network congestion through the use of slicing and effectively transmitting aircraft passenger links and aircraft management links.
● Technical issues
・The 5G core needs to be a protocol that takes latency into account.
・For use cases that require low latency, a connection to LEO is essential and latency parameters for different slices also need to be adjusted.
・Handover control between a satellite system and a terrestrial system is required.
・The interface between satellite terminals and 5G base stations needs to be considered.
・Priority control at the application level is required.
・Using Q/V bands and other high frequencies.
● Effectiveness of adopting satellite-based 5G technologies

Providing 5G services to areas where terrestrial systems have not been adequately developed, such as remote islands, mountainous areas, and national parks.
● Concerns
・Whether it is acceptable to use general-purpose options for terminals and modems and whether there are any new research and development elements.
・Whether it is possible to configure parameters applicable to a local 5G base station from a network slicer.

Category B: Mobility

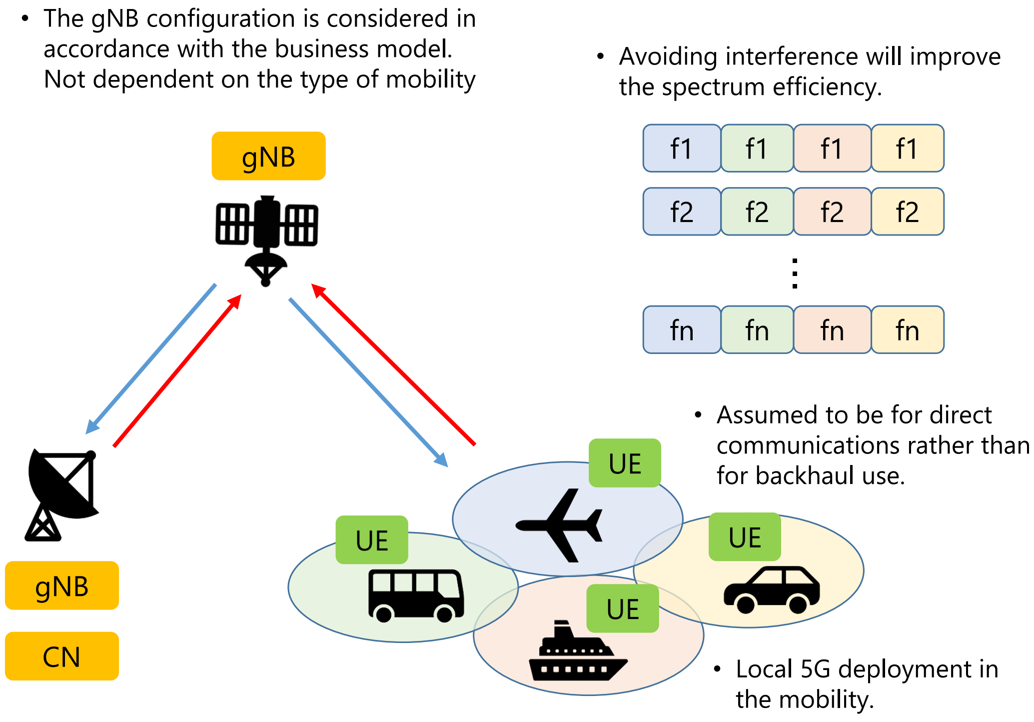


Figure 4-2: Conceptual diagram of systems involved in mobility

● Conceptual diagram of systems: Figure 4-2

● Investigating use case benefits

・Wireless repeaters enable the conversion of in-flight user communications and satellite communications.

・Centralized management of communications (benefit of having network operators).

・Accommodating high-capacity video data and power-saving IoT (load management) with slicing.

・Allocating satellite beams to aircraft through higher satellite capacity and beamforming technology.

・LEO satellites are more advantageous than GEO satellites in terms of spatial separation.

・Beam/satellite switching is possible with handover technology.

・Some applications allow for satellite delays.

● Effectiveness through the adoption of satellite-based 5G technologies

(a) QoS

・Setting the priority levels for services with network slicing.

・Whether it is possible to share high-value-added, secure communications and general services.

(b) Interference avoidance

・Whether it is possible to avoid interference between beams and between beams and terrestrial cells using 5G technology.

・Whether it is possible to help small antennas, for which side lobe suppression is difficult to achieve, avoid interference and whether it is possible to efficiently use the 28 GHz band.

・Whether interference-avoidance technology for communicating with terminals in the context of large numbers of base stations in 5G can be applied to the integration of satellites and 5G.

(c) Efficient use of LEO/MEO systems

・Whether satellite-based 5G technologies can be used for the management of resources for an entire LEO satellite network.

・Network control methods need to be investigated.

● Technical issues and concerns

・Adjacent satellites and adjacent beams will be visible since antennas mounted on mobility systems are small in size, and off-axis radiation increases.

・Realization of three-dimensional frequency management and seamless movements.

・Total management of terrestrial and satellite systems.

・Narrowing of beam and power saving achieved for earth station antennas.

・Using the Q/V band and other high frequencies.

・Upgrading multi-beam technology.

・Applying massive MIMO technology.

Category C: Emergency disaster response

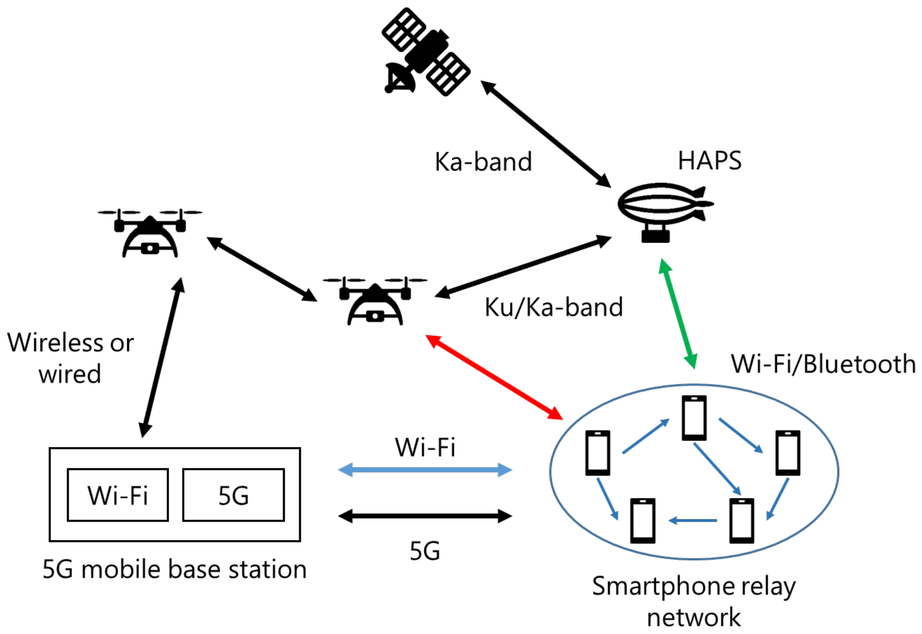


Figure 4-3: Conceptual diagram of systems involved in emergency disasters

● Conceptual diagram of systems: Figure 4-3

● System objectives

・Means of communications can be flexibly selected according to the state of the disaster area in the event of a disaster.

・Ensuring the minimal necessary communications with smartphones that are normally used.

● Investigating use case benefits

・Disaster victims and relief organizations for end-user disaster relief and monitoring by local governments.
・Service providers and telecommunications carriers.

(a) Benefits in terms of disaster relief

・Management for discovering victims (detection confirmation, rescue means, transmission, and other matters).
・Safety confirmation through the use of smartphones.
・Collecting information with drones (aerial photograph, data mule).
・High-definition video (such as 4K) is transmitted through D2D.
・Rapidly transmitting video information from the sky above to emergency headquarters in order to verify the state of a disaster-affected area.

(b) Methods by which networks are realized in terms of disaster relief

・Networks that can be set up quickly; for example, local 5G (means of communications based on the use of helicopters, HAPS, and other options).
・Using ad hoc networks (using satellite-based 5G).

(c) Benefits in terms of monitoring

・Transmitting video, audio, and data.
・IoT (using sensing devices).

(d) Methods by which networks are realized in terms of monitoring

・Network slicing for each application (satellites, terrestrial systems).

● Issues (overall)

・Investigating conditions and issues concerning frequency selection on each path (Figure 4-4, Table 4-1).
・Interference avoidance with terrestrial 5G.
・Network management in 5G cores; seamlessly connecting heterogeneous networks and multiple links.
・Optimal distribution of service areas upon taking coverage provided by smartphone relays, drones, HAPS, and satellites into account.
・Optimal placement of and function sharing among gNB and edge nodes.

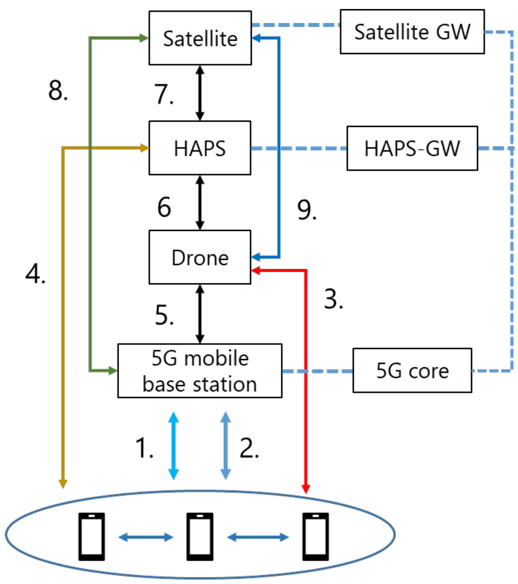


Figure 4-4: Communication paths

Table 4-1: Issues related to each path

Path	Opposite station		Proposed frequency	Issues
1.	Smartphones	Mobile base station	Wi-Fi	・For smartphone relay links, there are empirical testings conducted by KOZO KEIKAKU ENGINEERING and NTT DOCOMO.
2.	Smartphones	Mobile base station	5G	・Frequency selection. ・Mobile base stations need to be portable, small, and lightweight to enable them to be easily installed in the field.
3.	Smartphones	Drone	5G	・Selection of frequencies that can be supported with the omnidirectional antenna of a smartphone. ・The ability of a drone to load(weight and power).
4.	Smartphones	HAPS	5G	・Can the omnidirectional antennas of smartphones with the C-band spectrum or lower frequencies establish the UE-HAPS link ? ・Can 28 GHz massive MIMO technology be accommodated on the HAPS side?
5.	Mobile base station	Drone	5G	・Frequency selection. ・Ensuring coverage and link capacity through wired connections.
6.	Drone	HAPS	Ku/Ka	・Frequency selection. ・Are gNB functions included in HAPS?
7.	HAPS	Satellite	Ka	・Satellite tracking function for HAPS.
8.	Mobile base station	Satellite	Ka	
9.	Drone	Satellite	Ka	・Frequency selection (trade-off for which weight and power are taken into account in accordance with the link design).

The Study Group discussed effectiveness through the integration of satellites and 5G and the technologies and issues to be addressed for realization after making assumptions as to who the target end users and service providers would be in each category. Investigative results are presented in Tables 4-2, 4-3, and 4-4.

Table 4-2: End users, service providers, effectiveness, and method of realization (Category A: Smart cities)

End user (service)	Service provider	Effectiveness (benefits)	Method of realization (technologies, issues)
・Events, temporary use (enable network construction on a temporary basis) ・Marathons, festivals, etc. ・Dam construction ・Meter reading ・Monitoring systems (rural) ・Landslide monitoring ・Forestry and agriculture ・Remote robotic control ・Autonomous driving ・Smart grid	・Government offices ・Security companies ・Local governments ・Carriers ・JA (agricultural cooperatives), fishery cooperatives	・Control a larger number of terminals (compared to existing) and collect data from a large number of terminals at the same time ・Select delay tolerance data using MEC ・Seamless handover between terrestrial and satellite systems ・High fish-finding accuracy ・Farming	・Efficiently use links by compression for each application ・Discard unnecessary data with MEC/AI on the terminal side ・Technology to seamlessly switch between terrestrial and satellite systems ・Communications protocols: 5G version of DVB or other existing protocols is required ・Definition of satellite-based 5G (delay, speed of communications, error rate) ・What to do about systemization ・Leveling the quality of user links; quality of service ・Terrestrial station control protocol ・Can switching delay be reduced with 5G?
・Remote healthcare (remote surgeries, video transmission)	・Hospitals	・High capacity, low latency	・Can the low latency of terrestrial 5G be maintained even when communicating via satellites? ・Systemization and statutory revisions are required

Table 4-3: End users, service providers, effectiveness, and method of realization (Category B: Mobility)

End user (service)	Service provider	Effectiveness (benefits)	Method of realization (technologies, issues)
・Airlines ・Shipping companies ・Passengers ・Aircraft manufacturers ・Shipbuilders ・Logistics	・Service providers ・Shipping companies ・Airlines ・Manufacturers	・Operation control ・Internet connectivity ・Airframe monitoring ・Environmental monitoring (temperature, humidity, other meteorological data) ・Container location information	・Satellite capacity ✓ MIMO ✓ Beamforming (spatial separation) ・Handover technology ・Thinking of objects and individuals as a single user ・Network slicing ✓ mMTC (large number of connections) ✓ eMBB (high capacity) ・Earth station ✓ Terminating type ✓ Wireless repeater type (ships, aircraft)
・UAV		・Beyond line-of-sight communications	・Using HAPS ・Realizing low latency
・Space agencies		・Networks in space	・Relay satellites

Table 4-4: End users, service providers, effectiveness, and method of realization (Category C: Emergency disaster response)

End user (service)	Service provider	Effectiveness (benefits)	Method of realization (technologies, issues)
・Disaster victims ・Rescue organizations (disaster relief) ・Local governments (monitoring)	・Telecommunications carriers ・Telecommunications carriers	・Management for the discovery of disaster victims ・Confirming safety through the use of smartphones ・Collecting information using drones (aerial photography, data mule) ・Transmitting video (4K) through D2D ・Transmitting video information from the sky above to emergency headquarters to verify the state of a disaster-affected area. ・Video, calls, data, IoT, sensing devices	・Networks that can be set up quickly; for example, local 5G (helicopters, HAPS) ・Using ad hoc networks (using satellite-based 5G) ・Slicing for each app (satellites, terrestrial systems)

An outline of investigative results is presented below.

・Smart cities

Use cases were investigated on the premise that spots are created in rural areas and other places where terrestrial networks are lacking. End users (services) included utilization at events; metering; health monitoring, agriculture, forestry, and fisheries; smart grids; and remote healthcare. Service providers included government offices, local governments, and carriers. For effectiveness, improvements in the number of simultaneous connections beyond what can be obtained with 4G are expected through simultaneous terminal control and data collection. By selecting the data necessary by MEC on the terminal side, transmission efficiency is expected to increase. If terrestrial and satellite systems can be seamlessly connected according to the 3GPP protocol, we can also expect to see switching times shrink.

・Mobility

Shipping companies, airlines, passengers, and logistics were identified as end users. Service providers conceivably consist of communications service providers, shipping companies, airlines, and manufacturers. Operation control, Internet connectivity, airframe monitoring, environmental monitoring (temperature, humidity, and other meteorological data), and the management of container location information can be listed under effectiveness. Environmental monitoring (temperature, humidity, and other meteorological data) can also be deployed for other uses (for example, environmental monitoring can also be used for route selection if meteorological information can be obtained from ships). In these cases, each object and individual can be thought of as a user (terminal), the global movement of which necessitates service continuity and network slicing (large numbers of simultaneous connections, high speeds, and high capacities). Earth stations for ships and aircraft conceivably consist of wireless repeater-type stations and terminating-type stations.

・Emergency disaster response

Use cases were investigated upon being broadly divided into two main types: disaster relief and monitoring. End users for disaster relief consisted of victims and rescue organizations while those for monitoring included local governments. Service providers comprised telecommunications carriers. Listed for effectiveness were usage to manage the discovery of victims, confirm safety through the use of smartphones (through a network combining D2D, drones, HAPS, and satellites), enable the high-capacity transmission of 4K video through D2D, and transmit video information from the sky above to emergency headquarters to verify the state of a disaster-affected area. Under methods of realization, it was noted that networks that could be set up quickly were essential. For example, the connection of local 5G to helicopters and HAPS was conceivable, as was the use of ad hoc networks based on the use of satellite-based 5G. Content in terms of monitoring included video, calls, data, and data from IoT sensing devices. It was thought that network slices could be configured for each app as a method of realization. In this context, there will be a need to control the speed of communications and delays upon taking networks for both satellite and terrestrial systems into account.

Also noted was the use of low-latency HAPS as relays for beyond line-of-sight communications with UAVs, the use of satellites for backhauling purposes, and the use of networks in space by space agencies.

4.2. Investigating domestic trials

In order to verify the effectiveness of use cases investigated in the preceding section, demonstrations and evaluations through trials will be required. Thus, we discussed the effectiveness of trials, evaluation items, and technologies to be checked for each use case that was investigated. As stated in 2.3.2, however, trials and demonstrations based on the use of test beds had already been conducted in Europe. For this reason, the Study Group proceeded with investigations by also taking differences between overseas needs and domestic needs into account.

First, a questionnaire survey on trial proposals for the three categories investigated to date was administered to the members of the Study Group. Expected use cases for which trials, evaluation items to be checked, and technologies related to satellite-based 5G were surveyed. The results of this questionnaire survey are laid out in Tables 4-5 through 4-7 (number of valid responses: 8 institutions). In Category A (smart cities), expectations were shown to be great with respect to unmanned systems, monitoring (video and data), and local 5G/backhauling (where satellites are used as a local 5G backhaul). The results indicated that expectations were great with respect to mobile eMBB, the IoT, drone systems, logistics systems, and backhauls (satellites and HAPS) in Category B (mobility) and with respect to backhauls (satellites and HAPS), smartphone integration, and monitoring (video and data) in Category C (emergency disaster response).

Table 4-5: Expected use cases for trials (Category A: Smart cities)

Item	Number of responses	Contents	Keyword	Keyword features
A-1	1	Various types of data communication services based on the use of satellite terminals installed at traffic lights on roads and 5G terminal base stations		
A-2	1	High-speed communication links that can be simultaneously used by a large number of people at tourist sites		Local 5G Backhaul
A-3	1	Providing 5G service to hotels and other such establishments	Local 5G, backhaul	
A-4	2	Providing information for tourists through the monitoring of the natural environment	Monitoring (video, data)	Monitoring (video, data)
A-5	1	Urban planning that combines LEO satellite images, positioning information, and communications	LEO	
A-6	1	Broadcasting alternatives based on the use of satellite multicasting	Multicasting, broadcasting	
A-7	0	Autonomous driving (effective in rural areas where the population is shrinking)		Unmanned system
A-8	1	Remote medicine (remote surgeries and video transmission; expanding 5G areas is necessary even in places where the population is in decline)	Remote medicine, backhaul	

A-9	1	Autonomous robots, remote robot control	Monitoring, unmanned system	
A-10	4	Satellite use for local 5G (such as on construction sites)	Local 5G, backhaul	
A-11	0	Support for foreign workers (such as translation services where 5G coverage is not available in areas where the population is declining)		
A-12	1	Satellite use for temporary base stations (marathons, fairs, and other events; dam construction)	Backhaul	
A-13	3	Large-scale agriculture, forestry	Monitoring, unmanned system	
A-14	0	Using satellites as a maintenance-free option for base stations		
A-15	3	Backup option for remote islands	Backhaul	
A-16	1	Monitoring system (such as monitoring for unmanned convenience stores)	Monitoring (video, data)	
A-17	1	Horse industry		

Table 4-6: Expected use cases for trials (Category B: Mobility)

Item	Number of responses	Contents	Keyword	Keyword features
B-1	4	Collecting monitoring data obtained by various types of equipment on board ships (including engine system and measurement systems)	Mobile eMBB, IoT	Mobile eMBB, IoT Backhaul (satellites, HAPS) Logistics system Unmanned system
B-2	4	Transmitting information related to operation control for ships		
B-3	4	High-speed, higher-capacity, lower-cost ship communications (such as with respect to Internet connection)		
B-4	3	Collecting monitoring data obtained by various types of equipment on board aircraft (including engine system and measurement systems)		
B-5	3	Transmitting information related to operation control for aircraft		
B-6	3	High-speed, higher-capacity, lower-cost aircraft communications (such as with respect to Internet connections)		
B-7	2	Expanding 5G service to the sky (space) with satellites and HAPS	Backhaul (satellites, HAPS)	
B-8	1	Flying cars	Mobile eMBB, IoT	
B-9	3	Seamless management of logistics in logistics systems at sea and on land and IoT utilization (such as with respect to containers)	Logistics system, IoT	
B-10	1	Autonomous driving	Unmanned system	
B-11	2	Beyond line-of-sight drone operations by satellites		
B-12	2	On-site monitoring in terms of meteorological and climate observations (video, data)	Monitoring (video, data)	

Table 4-7: Expected use cases for trials (Category C: Emergency disaster response)

Item	Number of responses	Contents	Keyword	Keyword features
C-1	4	Landslides, dam monitoring, and more	Monitoring (video, data)	
C-2	3	Collecting and providing information for predicting natural disasters using sensors installed in a distributed pattern		
C-3	4	Backhauling with LEO satellites and HAPS in the event of a disaster	Backhaul (satellites, HAPS)	Monitoring (video, data)
C-4	4	Connecting D2D smartphone relays to satellites (current smartphones connect directly)	Smartphone integration	
C-5	3	Observing disaster conditions with the IoT (terrestrial systems cannot be used)		Backhaul (satellites, HAPS)
C-6	2	Always available earth observations (disaster prediction, disaster observation)	Monitoring (video, data)	
C-7	4	Observing disaster conditions from the sky (with drones)		Smartphone integration
C-8	2	Confirming safety with smartphones in the event of a disaster	Smartphone integration	
C-9	2	Utilizing satellites to find disaster victims	Monitoring (video, data)	

In addition, an outline of opinions on expected use cases for trials as obtained from institutions via means other than the questionnaire survey is as follows:

- Relaying with traffic lights and providing services to users in cars and trains.
- Local 5G and network slicing.
- Smartphone relay network in the event of a disaster.
- In-flight network connection and smartphone relay networks.
- 5G backhaul and seamless connection switching with terrestrial systems.
- Local 5G backhaul, IoT in the context of logistics systems, LEO and HAPS.
- Backhaul.
- Backhaul, large volume of terminal connections by the IoT.
- Unmanned monitoring systems, forestry and large-scale agriculture.
- Network slicing of aircraft airframe control communications and data transmission communications.
- ICT in the countryside and other local areas (such as for remote medicine and online payments), autonomous driving.
- Backhaul and the provision of communications for mobility.
- Local 5G, mobility communications, IoT monitoring, LEO-based remote operations, dairy farming, and other examples of large-scale agriculture.
- Collecting information related to operation control for ships, providing communication services within mobility systems, and sediment sensing using IoT.
- Use cases with high private-sector demands and disaster monitoring.
- Local 5G.

A survey on evaluation items to be ideally checked through trials and technologies required for this purpose was also conducted by questionnaire. The results of this questionnaire are shown in Table 4-8. As indicated in this table, characteristic items for the integration of satellites and 5G are enumerated for each category.

・There is a high level of interest in the extent to which seamless connections can be secured by switching between terrestrial and satellite systems.

・There is also a high level of interest in the effects of network slicing. In particular, the effectiveness and feasibility of multiple network slices were listed as items subject to evaluation.

・There is a high level of interest in the extent to which QoS can be improved through network orchestration.

Table 4-8: Expected use cases and technologies for trials

<table>
<tr><th>Use case</th><th>Evaluation item response</th><th>Evaluation item (response summary)</th><th>Response summary concerning key technologies required for the integration of satellites and 5G</th></tr>
<tr><td>Smart cities</td><td>・Transmission characteristics (information speed, BER characteristics)
・Simultaneous connectivity
・Latency
・Simultaneous use of multiple slices
・Switching between terrestrial and satellite systems
・QoS (upper layer quality)
・feasibility of link establishment
・Quality of video transmission
・Percentage of national land covered by satellites</td><td rowspan="3">・Transmission characteristics (information speed, BER characteristics)
・Simultaneous connectivity
・Latency
・Simultaneous use of multiple slices
・Switching between terrestrial and satellite systems
・QoS (upper layer quality)
・Link establishability
・Quality of video transmission
・Video transmission quality (including drones)
・Percentage of national land covered by satellites</td><td rowspan="3">・Optimal control by network slicing/NFV
・Simultaneous operations of multiple slices
・Access control
・Integrated operations of satellites/terrestrial systems (orchestration)
・Interference avoidance
・Local 5G
・5G IoT
・Connecting with LEO
・User terminals, low power consumption
・Video transmission
・Remote control
・Real-time control (low latency)
・Utilizing the Q/V band (high frequencies)
・High-capacity transmission
・Upgrading multi-beams</td></tr>
<tr><td>Mobility</td><td>・Transmission characteristics (information speed, BER characteristics)
・Simultaneous connectivity
・Latency
・Simultaneous use of multiple slices
・QoS (upper layer quality)</td></tr>
<tr><td>Emergency disaster response</td><td>・Transmission characteristics (information speed, BER characteristics)
・Simultaneous connectivity
・Latency
・Simultaneous use of multiple slices
・QoS (upper layer quality)
・Call-loss ratio
・Video transmission quality (including drones)</td></tr>
</table>

5. Investigating standardization as it applies to the integration of satellites and 5G

5.1. State of standardization concerning the integration of satellites and 5G as promoted by the 3GPP

An investigation into standardization concerning the integration of satellites and 5G as promoted by the 3GPP began in March 2017 for non-terrestrial networks (NTN) and has been carried out for TSG RAN and TSG SA within the framework of investigations carried out by the 3GPP as shown in Figure 5-1. This investigation has thus far yielded documents as indicated in Table 5-1. Plans for NTN-related releases as formulated by the 3GPP are outlined in Figure 5-2. Specifications for the integration of satellites and 5G are contained in a plan to be completed for Release 17, which is scheduled for release in 2022.

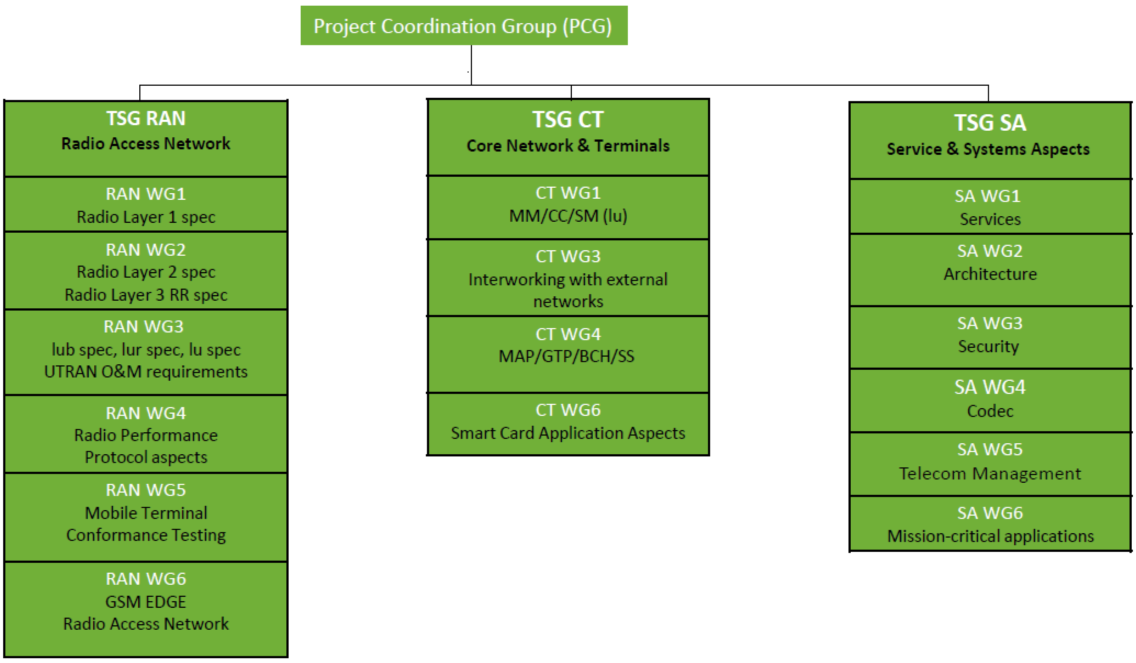


Figure 5-1: Framework of investigations by the 3GPP[10]

Table 5-1: Documents related to the integration of satellites and 5G maintained by the 3GPP

Item	Standard	Contents
3GPP Activities in TSG RAN	TR 38.913	Study on Scenarios and Requirements for Next Generation Access Technologies
	TR 38.811	Study on New Radio (NR) to support non-terrestrial networks
	TR 38.821	Solutions for NR to support non-terrestrial networks (NTN)
3GPP Activities in TSG SA	TS 22.261	Service requirements for the 5G system
	TR 22.822	Study on using Satellite Access in 5G
	TR 23.737	Study on architecture aspects for using satellite access in 5G
	TR 28.808	Study on management and orchestration aspects with integrated satellite components in a 5G network

TSG RAN：Technical Specification Group Radio Access Network

TSG SA：Technical Specification Group Service and System Aspects

TR：Technical Report、TS：Technical Specification

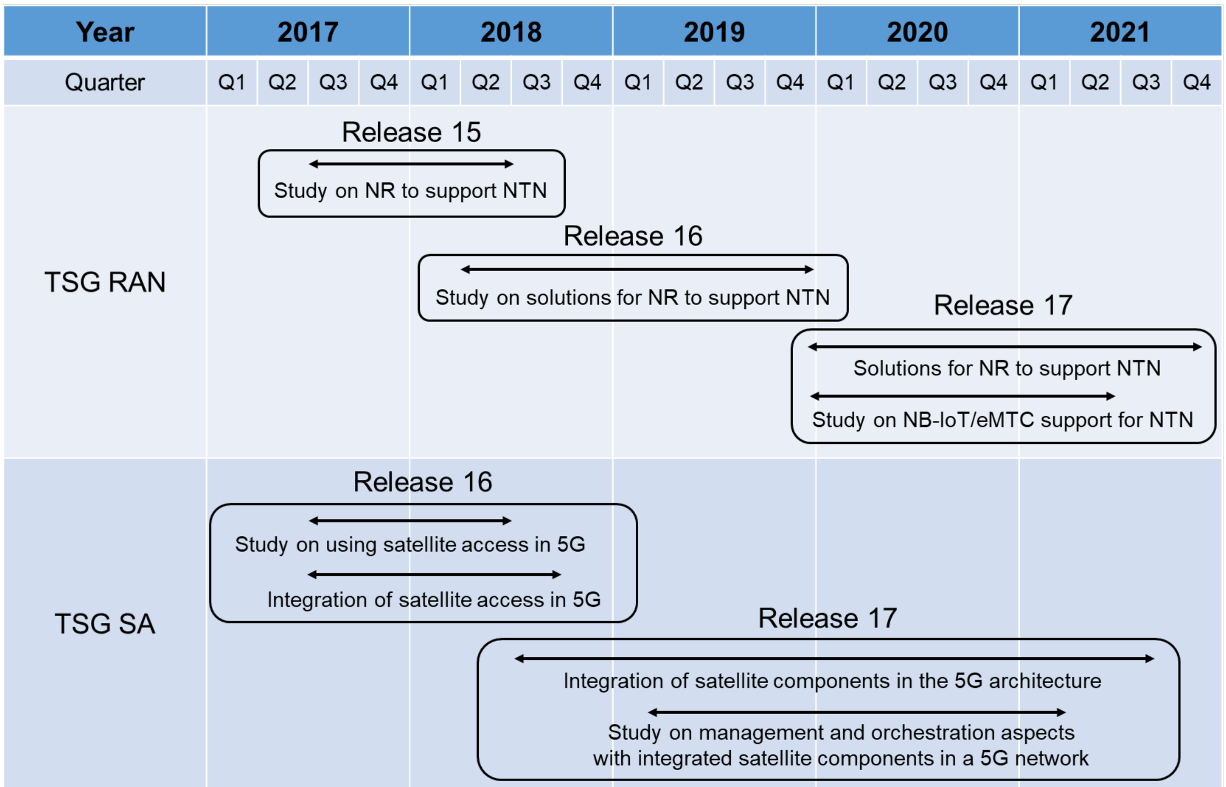


Figure 5-2: Release plans related to the integration of satellites and 5G in the 3GPP (produced based on [11])

Technical items to be considered for non-terrestrial networks (NTN) in discussions related to 5G NR specifications as held by the 3GPP are presented in Table 5-2.[12]

Table 5-2: Impact in terms of changes to 5G NR specifications that need to be taken into account in NTNs (areas subject to technical investigations)[9]

NTN attribute	Impact	Affected specifications	Technical orientation
Altitude: High	Transmission delay: Large	HARQ	Feedback
		Adaptive control at the physical layer (MCS, power, etc.)	Changing the method of adaptive control
		Waiting time at the upper layer	Revising the timer value
Movement of base	Cell pattern fluctuations	Handover, paging	Revising sequences

station (in the case of LEO)	Fluctuations in transmission delay	Timing advance	Revising sequences and frequency values
	Doppler fluctuations	Initial synchronization	Appropriately selecting parameters (sub-carrier interval)
		Time density of DMRS	Appropriately selecting parameters (density)
Cell: Wide area	Difference in transmission delay values in cells: Large	Random access Timing advance	Doppler compensation Delay compensation
Propagation loss: Large	Nonlinear distortions in transponders	PAPR	PAPR suppression technology

Excerpted from 3GPP document TR 38.811

5.2. Investigating in connection with standardization

In accordance with the trend towards standardization as discussed in the preceding section, the Study Group investigated items for which standardization was believed to be needed as the use of satellite communications in conjunction with 5G undergoes future growth in Japan. Items for which it is believed that standardization will be needed in each category are indicated in Table 5-3. These items have been broadly divided into items related to standardization for the integration of satellites and 5G by the 3GPP and items to be standardized in the field of applications.

Table 5-3: Proposed standardization items related to the integration of satellites and 5G

Category	Proposed standardization item	Classification
Smart cities	・Quantitative definition of satellite-based 5G (such as in terms of speed in Mbps, delay in ms, and number of connections)	Satellite-based 5G standardization
	・Provisions governing quality of communications and satellite quality for each application	Satellite-based 5G standardization
	・Communication protocols on a layer-by-layer basis (satellite-based 5G version corresponding to DVB-S2X)	Satellite-based 5G standardization
	・Protocol for ascertaining user state (user terminal), protocol by which the foregoing is controlled (base station)	Satellite-based 5G standardization
	・Seamless switching between satellites and terrestrial systems; network slicing method	Satellite-based 5G standardization
	・Reducing equipment and development costs by standardizing satellite-based 5G chips	Satellite-based 5G standardization
	・Developing laws for remote medicine	Application standardization
Mobility	・What kind of network slicing architecture should be built (divided according to what standard)? (Examples: Divide according to the form of use by the network provider, such as mMTC or eMBB. Divide according to the effectiveness and benefits of each use case.)	Satellite-based 5G standardization
	・How to sort out issues, such as the interference caused by placing base stations in the air and installing repeaters in moving bodies (such as aircraft) (from the standpoint of developing the law rather than standardization).	Application standardization
Emergency disaster response	・Scheduling in terms of data transmission	Satellite-based 5G standardization
	・Standardization as concerns roaming procedures	Satellite-based 5G standardization
	・Standardization of and adoption of an API (application programming interface) for data required in the event of a disaster	Application standardization
	・Power saving for IoT sensor systems (such as for EIRP, frame configuration, and intermittent transmission and reception)	Application standardization
	・Detailed information pertaining to disaster information (specific items concerning victim location information and detailed requirements with respect to the contents thereof)	Application standardization

An outline of the results of investigations for each category is presented below.

- Smart cities
  Even as investigations are being conducted by the 3GPP, there is a question as to whether a definition of satellite-based 5G (such as in terms of delay, speed, and error rate) is also necessary in Japan. Moreover, standard specifications governing communication methods (such as with respect to frame configuration), parameter provisions governing seamless connections, and provisions governing service quality to ensure the quality of end-to-end communications on a per-user basis shall be stipulated. Ascertainment of the state of user terminals and the management of networks based on this information will also be required. For remote medicine, whether low latency for terrestrial 5G can be maintained with satellites is an issue. It is conceivable that systemization and statutory revisions will be required.

- Mobility
  Standardization is required for different types of use cases, such as operation control and Internet connectivity. Given considerations with respect to frequency sharing and radio interference, statutory revisions will be needed if repeaters are to be installed in moving bodies.

- Emergency disaster response
  Standardization required for disaster response include the unification of data required in the event of a disaster, scheduling in data transmission, standardization of roaming, provision of IoT sensor power, and provision of detailed information on disaster information. Satellite-based 5G integration is also effective in collecting large amounts of data using mMTC.

Some items corresponding to standardization as concerns the integration of satellites and 5G as described above are also included in the contents currently being promoted for non-terrestrial network systems in Release 17 through the 3GPP. In the future, it will be necessary to focus on 3GPP trends, as well as the study contents that are effective for domestic use. In addition to the standardization of the aforementioned communication protocols, discussions concerning standardization required to use satellite frequencies with 5G technology will also be required. For example, if you will be using 5G standards for aircraft communications based on the use of the Ku and Ka bands, you will need to request frequencies by entering background technology into ITU-R SG5. If you will be using 5G with a different application, an entry into ITU-R SG4 will need to be made.

6. The concept of communication networks expected in Beyond 5G

In investigating future communication networks including satellite communications in light of the effectiveness of the integration of satellites and 5G as discussed by the Study Group and the required technologies involved, it is conceivable that communications networks in Beyond 5G will be premised on a network that is connected from space to the ground on a multilayered basis. A conceptual diagram of this system is presented in Figure 6-1 (In this report, the network to be realized by around 2040 as a successor to 5G is defined as Beyond 5G). Research and development work with a view to realizing this network will need to be undertaken.

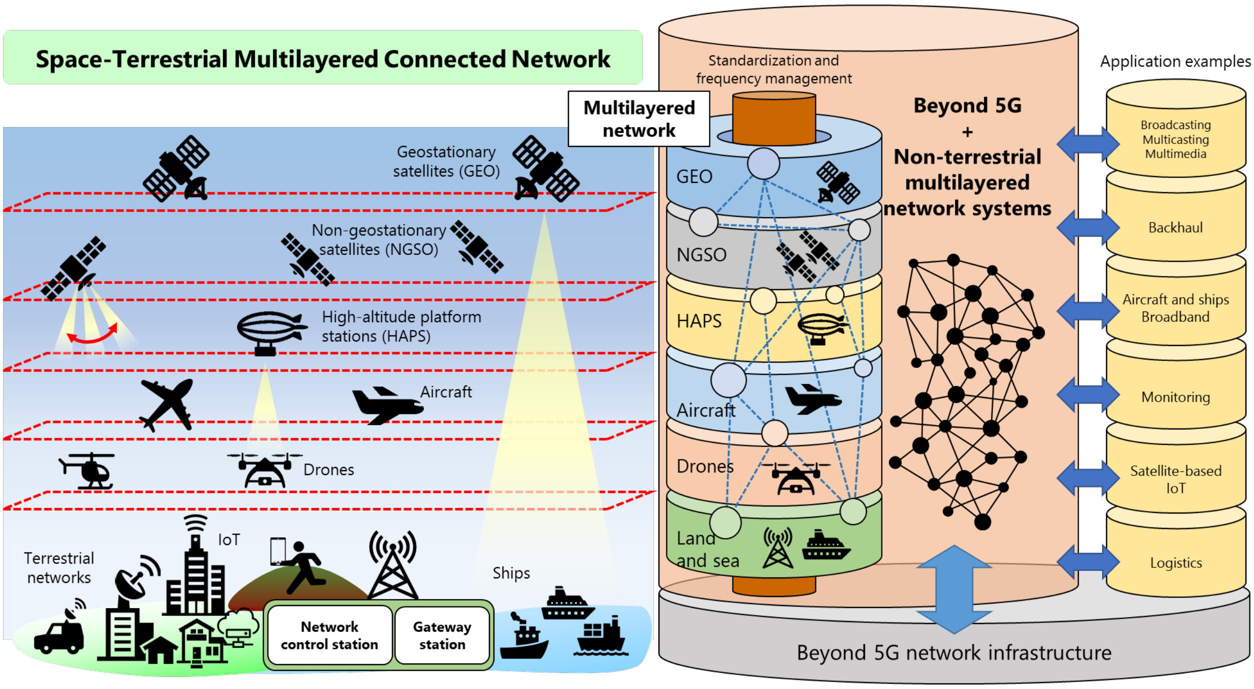


Figure 6-1: Concept of communication networks in Beyond 5G

7. Conclusion

Conferences of the Study Group were held for the purpose of specifically investigating the effective use cases made possible by the integration of satellite communications and 5G, the required technical issues and methods of realization, evaluations and demonstrations, and standardization with a focus on the roles of satellite communications in 5G and in light of activities being carried out through European projects and the state of progress being made for standardization by the 3GPP. Key results are summarized below:

- The integration of satellites and 5G aims to expand terrestrial 5G technology to encompass non-terrestrial networks inclusive of satellite communications. Key technologies for this purpose consist of SDN/NFV, network slicing, network management, edge computing, and other network technologies in the context of 5G. Activities related to the integration of satellites and 5G have been preceded by various projects, including SAT5G and SATis5 in Europe, and standardization through the 3GPP is progressing.

- Three motivations that speak to the necessity of adopting the integration of satellites and 5G can be considered. First, there is the evolution of satellite communications in recent years. The emergence of HTS and mega-constellation plans based on groups of LEO satellites will accommodate higher speeds and higher capacities at low cost, while terminals that are significantly miniaturized and can operate at lower power consumption levels are getting much closer to terrestrial systems than before. Second, there is the possibility of being able to efficiently realize the integration of satellites and 5G through the deployment of network technologies characterizing 5G technology in satellite systems. Third, while the architecture for conventional satellite communications had been built independently of terrestrial systems, standardization has been promoted for non-terrestrial systems, inclusive of satellites, for the first time with 5G by the 3GPP. This is expected to lead to progress in terms of the promotion of plug-and-play features and development of ASICs as non-terrestrial systems undergo standardization. Against this backdrop, we can expect to see unprecedented use cases and groundbreaking improvements to conventional use cases generated through the integration of satellites and 5G.

- In investigating effective use cases in Japan, an investigation based on social conditions, such as domestic demographics during the 5G/Beyond 5G era (2020-2040), is important for establishing context. A conceptual investigation of systems that are effective for use case categories consisting of smart cities, mobility, and emergency disaster response, as well as the effectiveness of technologies necessary for the foregoing, was checked.

    - Smart cities: Use cases are premised on the creation of spots in rural areas and other places where terrestrial networks are lacking. End users (services) included utilization at events; metering; health monitoring; agriculture, forestry, and fisheries; smart grids; and remote healthcare. Service providers included government offices, local governments, and carriers. For the effectiveness of the use of satellite-based 5G, improvements in the number of simultaneous connections beyond what can be obtained with 4G are expected through simultaneous control and data collection.

We expect to see more effects in terms of the collection of large amounts of data with IoT than in terms of high-speed communications. By selecting data necessary by MEC on the terminal side, transmission efficiency is expected to increase. If terrestrial and satellite systems can be seamlessly connected according to the 3GPP protocol, we can also expect to see switching times shrink.

- Mobility: End users consisted of shipping companies, airlines, passengers, and logistics. Service providers consisted of communications service providers, shipping companies, airlines, and manufacturers. Operation control, Internet connectivity, airframe monitoring, environmental monitoring, and the management of container location information are included under the effectiveness of the use of satellite-based 5G. In these cases, each object and individual can be thought of as a user (terminal), the global movement of which necessitates service continuity and network slicing (large numbers of simultaneous connections, high speeds, and large capacities). Earth stations for ships and aircraft conceivably consist of wireless repeater-type stations and terminating-type stations. The use of low-latency HAPS as relay points for beyond line-of-sight communications with UAVs, the use of satellites as backhaul components, and the use of networks in space are also possible.

- Emergency disaster response: Use cases can be broadly divided into two main types: disaster relief and monitoring. End users for disaster relief consisted of victims and rescue organizations while those for monitoring included local governments. Service providers comprised telecommunications carriers. Listed for effectiveness were usage to manage the discovery of victims, confirm safety through the use of smartphones (through a network combining D2D, drones, HAPS, and satellites), enable the high-capacity transmission of 4K video through D2D, and transmit video information from the sky above to emergency headquarters to verify the state of a disaster-affected area. Under the methods of realization, it was noted that networks that could be set up quickly were essential. For example, the connection of local 5G to helicopters and HAPS was conceivable, as was the use of ad hoc networks based on the use of satellite-based 5G. Content in terms of monitoring included video, calls, data, and data from IoT sensing devices. It was thought that network slices could be configured for each app as a method of realization. In this context, there will be a need to control the speed of communications and delays upon taking networks for both satellite and terrestrial systems into account.

- For trials in Japan, the effectiveness of trials can be expected, especially in connection with unmanned systems, monitoring (video and data), mobile eMBB, IoT, logistics systems, local 5G and backhaul, and smartphone integration.

- With respect to standardization, the integration of satellites and 5G is being studied primarily in the discussion of non-terrestrial networks through the 3GPP, and specifications are slated for completion with Release 17. Items for which standardization is conceivably necessary are broadly divided into items related to the standardization of the integration of satellites and 5G through the 3GPP and items to be standardized in the field of applications. In addition to focusing on 3GPP trends in the future, we will need to investigate content that is effective for domestic use. As well as the standardization of communication protocols, discussions concerning the standardization required to use satellite frequencies with 5G technology will also be required.

- Future communication networks including satellite communications were investigated in light of the effectiveness of the integration of satellites and 5G as discussed by the Study Group and the required technologies involved. It is conceivable that communications networks in Beyond 5G, defined as a network to be realized by around 2040 as a successor to 5G, will be premised on a network that is connected from space to the ground on a multilayered basis. Research and development work with a view to realizing this communication network will need to be undertaken.

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In holding conferences of the Study Group, we invited a wide range of organizations related to the integration of satellites and 5G, including domestic satellite operators, terrestrial mobile carriers, satellite-related manufacturers, universities, survey and research institutes, and standardization bodies, to participate and were able to promote the effective exchange of opinions in a way that would lead to future initiatives. At the same time, community formation was spurred in a way that was effective for promoting initiatives for the integration of satellites and 5G in Japan. NICT wishes to express the appreciation to all of the members and observers who participated in this process.

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Appendix: List of Members and Observers

Internal Member: National Institute of Information and Communications Technology (NICT)

External Members: SKY Perfect JSAT Corporation, Nippon Telegraph and Telephone Corporation (NTT), NTT DOCOMO, INC., KDDI CORPORATION, SoftBank Corp., Panasonic Corporation, Mitsubishi Electric Corporation, NEC Corporation, NEC Space Technologies, Ltd., Japan Radio Co., Ltd. (JRC), Japan Aerospace Exploration Agency (JAXA), The University of Tokyo, Waseda University, Tohoku University, Mitsubishi Research Institute, Inc. (MRI), KOZO KEIKAKU ENGINEERING Inc., Rakuten Mobile, Inc.

Observers: Association of Radio Industries and Businesses (ARIB), Ministry of Internal Affairs and Communications (MIC)