R&D for Satellite Communications and Non-terrestrial Networks toward Beyond-5G in Japan

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***Abstract*— At present, discussions on information and communication technologies for Beyond-5G/ 6G are accelerating. In the field of space communications, satellite communications are becoming more advanced and active, and it is expected that an advanced information and communication network will be realized that links the earth and space with satellites. In the Beyond 5G/6G era, spatial network expansion is required, and advanced communication with mobile devices called non-terrestrial networks will become important. This paper describes the efforts and the status of R&D regarding the developments of satellite communications and non-terrestrial networks (NTN) toward Beyond-5G/6G in Japan.**

Keywords—B5G, 6G, NTN, HAPS, HTS, ETS-XI, Lasercom

I. Introduction

In recent years, various platforms such as a broadband stationary satellite with multi-beam and large capacity communication called a High Throughput Satellite (HTS), a mega constellation using a Low Earth Orbit (LEO) satellite group, and a High Altitude Platform Station (HAPS) have appeared around the world, and it is expected to expand from terrestrial communications to a three dimensional (3D) communications network using a Non Terrestrial Networks (NTN) including satellite communications. In Japan, the development of the Engineering Test Satellite No. 9 (ETS-IX) is under way with the aim of launching in fiscal 2023 for the technical demonstration of a next-generation high-throughput satellite communications system [1]. The satellite aims to demonstrate large-capacity mobile communications at a transmission rate of 100 Mbps using the Ka-band, flexible relay technology that responds to traffic fluctuations due to variable beams and frequencies, laser feeder link at a transmission rate of 10 Gbps using laser beams, and linkage with 5G/Beyond-5G (B5G) [2]. On the other hand, laser communication is considered to be one of the important elemental technologies in NTN towards B5G/6G era, so National Institute of Communications Technology (NICT) is conducting R&D on laser terminals and related technologies that can be mounted on various platforms such as drones, microsatellites, and HAPS.

This paper describes some approaches and status of realizing future satellite communications that initiative for B5G/6G and laser communications technologies for NTN.

II. Three Dimensional Seamless Network and Ultra-smart Society in B5G/6G Era

In the B5G/6G era, as shown in Fig. 1, it is expected that a 3D network will be constructed in which various types of elements, such as geostationary satellites, non-geostationary satellites, HAPS, aircraft, drones, ships, and terrestrial terminals, are seamlessly connected in a multi-layered manner. Providing wireless links to a myriad of mobile objects in flight has a problem of exhaustion of radio resources. For this reason, optical communications and terahertz communications are used for communication links. In order to realize such a multi-layer network, it is necessary to develop a network infrastructure that centrally manages these communications.

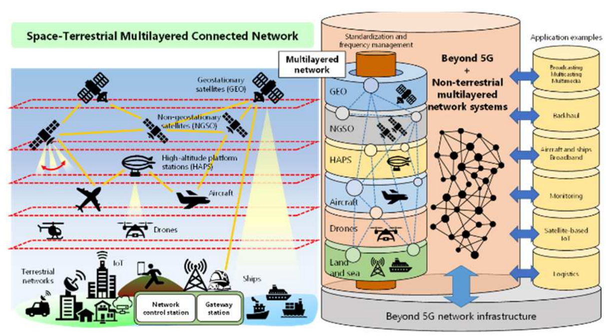


Fig. 1. Conceptual image for network in Beyond 5G/6G

Fig. 2 shows the future image of the ultra-smart society assumed in the B5G/6G era. It is expected that NTN technology will become the mainstream, and as applications of the 3D network, not only conventional broadband communications but also deployment to lunar bases utilizing the features of space utilization, disaster monitoring by satellite IoT on a global scale, and autonomous navigation ships and automatic distribution will be put into practical use. In the B5G/6G era, future telework and telemedicine will be realized using XR (X-Reality) technology achieved by ultra-high-speed wireless communications. Ultra-realistic online games, shopping with avatars, distance education, autonomous flying cars, etc. will be introduced in earnest, and a secure ultra-smart society in which people connect seamlessly and securely and safely will be realized.

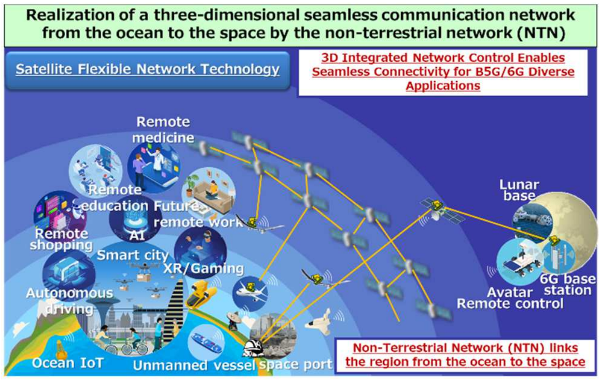


Fig. 2. Concept of Space Comm. R&D for Beyond 5G/6G Network

III. Next Gerenation HTS

The next-generation HTS is required to be more flexible and digital, to have larger capacities, and to be linked with terrestrial 5G/B5G. The conventional HTS has a fixed allocation of communication capacities to each beam of a multi-beam, so that it cannot respond to changes in the required bandwidth and utilization area during the operation period because the communication capacities are insufficient or wasted. Therefore, the key to the next-generation HTS is to make satellite repeaters flexible and digital (channelizer, digital beamformer (DBF), beam hopping, etc.) in order to use communication resources efficiently. The conventional HTS mainly uses the Ka-band, but many applications including the higher-frequency Q/V band are being filed with the ITU. The problem is to increase communication capacities in consideration of the future depletion of radio resources. Therefore, the key to the next-generation HTS is to use laser communications, which can be substantially increased in capacity compared with radio waves, especially for high-capacity links. The use of laser communications, which can be substantially increased in capacity compared with radio waves, is in the R&D stage. With the advent of mega-constellation plans using HTS and LEO satellites, Ultra-high-speed, massive capacities has been realized at low costs. Terminals are also much closer to terrestrial systems than in the past due to drastic miniaturization and low power consumption. Against this background, efforts to link satellite communications with 5G/ B5G are being advanced. In 3GPP, the standardization of NTN including satellite communications is being advanced, and is scheduled to be specified in Release17, which is scheduled to be established in 2022.

In Japan, seamless connections with satellites and HAPS were taken up in the "Expandability" category at the Beyond 5G Promotion Strategies RoundTable Conference held by Ministry of Internal Affairs and Communications (MIC) in 2020. And discussions on the cooperation between satellites and 5G/B5G and NTN are being advanced at some study groups and the Space-ICT Promotion Forum, which was established 2021.

IV. ETS-IX Project

In Japan, the Basic Space Plan (decided by the Cabinet in April 2016) clearly stated the examination and launch of ETS-IX. Technical studies were conducted at the Study Group on the Next Engineering Test Satellite (November 2014 to April 2015, January 2016 to May 2016), and as a result, the development of next-generation satellite bus technology and satellite communication technology was promoted. At present, Ministry of Education, Culture, Sports, Science and Technology (MEXT)/Japan Aerospace Exploration Agency (JAXA) is promoting the development of satellite bus and MIC/NICT is promoting the development of communication mission for the launch in fiscal 2023.

The communication mission of ETS-IX is required to acquire the world's most advanced mission technology that is competitive in the world market from the viewpoint of strengthening the international competitiveness. In consideration of the situation in which capacity enlargement and bit unit cost reduction by HTS are progressing in the satellite communication field and the above-mentioned technical issues, it was concluded that the goal of the demonstration technology in the communication mission of ETS-XI would be to increase the capacity of satellite communication by Ka-band and laser communication, to make satellite communication flexible by channelizer/DBF technology, and to control the integrated operation of the communication system.

Fig. 3. Image of ETS-IX @JAXA

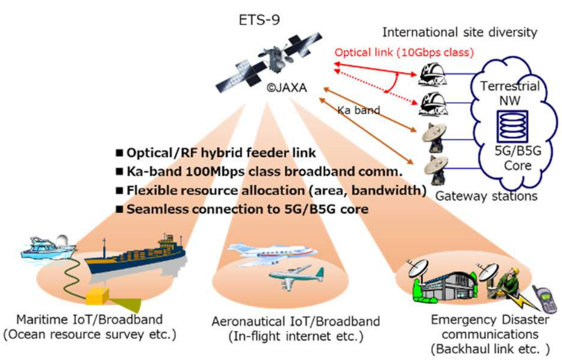


Fig. 4. ETS-IX communication system

The communication system of ETS-IX consists of four communication subsystems mounted on a satellite and a ground segment (Ka-band, laser ground communication system). The communication mission is limited to the demonstration of core technology considering scalability. MIC has developed a wideband channelizer and multi-beam feed section technology [1,2] as a fixed beam communication subsystem and wideband DBF technology as a variable beam communication subsystem. NICT is promoting the development of laser satellite communication technology as an laser feeder link communication subsystem and a common section communication subsystem for beacon transmission. The outline of the communication mission is shown in Fig. 4 and explained below.

A. Fixed beam communication subsystem

The goal is to demonstrate a channelizer, multi-beam feeder, and feeder link that operate in the Ka-band [3]. The goal is to develop a wide-band channelizer technology capable of changing the bandwidth of each port and the number of ports according to future systems. The goal is to develop a 5-beam (feeder link 2-beam) multi-beam feeder that can be mounted in a compact and high-density manner to demonstrate frequency repetition. The goal is to achieve a transmission speed of up to 100 Mbps. The digital channelizer is to develop a low-power consumption algorithm to cope with the increase in the bandwidth and a high-efficiency waste heat technology for high-speed data transmission in a housing. For the multi-beam feeder, a circuit structure for compact integration in order to realize a high-density beam arrangement is integrated. The fixed-beam communication subsystem was completed as a payload on a satellite, and will be installed on the ETS-IX, which is under development separately, for on-orbit demonstration tests.

B. Variable beam communication subsystem

The goal is to demonstrate DBF technology that operates in the Ka-band with a newly developed variable beam technology that can operate at more than 100 MHz / port, can vary the shape of each beam, can form two beams simultaneously, and has a maximum transmission speed of 100 Mbps. For the development of the variable beam communication subsystem, its overall configuration, development of DBF processor, an antenna and RF section will be examined and evaluated [4]. The system was completed as a payload on a satellite, and will be installed on ETS-IX, which is under development separately, and will be used for on-orbit demonstration tests.

C. Laser feeder link communication subsystem

The goal of this project is to develop an laser satellite communication technology to demonstrate the world's highest level of communication capability of up to 10 Gbps between a geostationary orbit and a ground station using laser light. The laser communication system to be mounted on ETS-IX is called HICALI (High Speed Communication with Advanced Laser Instrument) [5]. In order to use high-speed devices developed for ground-based laser communication networks in space, HICALI aims to establish a screening process to ensure environmental resistance and reliability through research commissioned by NICT. In the laser communication experiment between geostationary orbit and the ground using HICALI, NICT plans to confirm the operation of laser communication devices in orbit, confirm the high-speed laser communication function of 10 Gbps transmission rate, obtain propagation data of laser light, experiment on site diversity according to weather conditions, and verify new technologies at laser ground stations including adaptive optics.

V. Laser Communication Systems for NTN

Free-space laser communications have the potential to bring the bandwidth of optical fibers to moving platforms, greatly enhancing their communication capabilities. Therefore, free-space laser communication is expected to play a key role to cope with the demanding bandwidth requirements of B5G/6G networks to support an increasing number of wireless terminals disseminated throughout the world and generating an unprecedented amount of data. For this purpose, practical and versatile lasercom systems will be necessary to be developed and deployed in real scenarios as soon as possible. NICT intends to meet this requirement by developing a series of communication terminals that can fit a variety of platforms and scenarios to fulfill the requirements of different use cases [6]. Fig. 5 shows several of these use cases, where NICT is currently planning to demonstrate and deploy these terminals.

Table 1 shows all the lasercom terminals that are currently being developed by NICT.

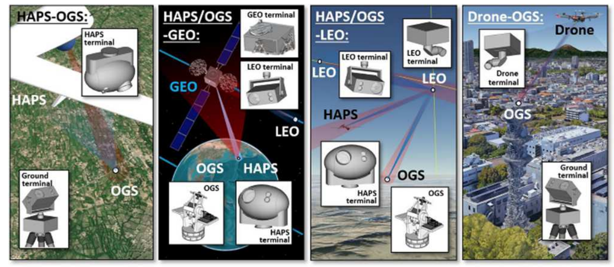
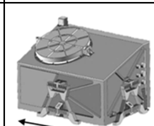


Fig. 5. NICT's lasercom terminals for small platforms

TABLE I. Optical-head assemblies (OHA) of NICT's space laser-communication terminals.

	HICALI terminal	FX terminal	ST terminal
Max-range scenario	GEO-ground (2 ways)	LEO-GEO (1 way), LEO-LEO (2 ways)	LEO-ground (1 way) HAPS-ground (2ways)
Aperture size	15 cm	9 cm	3 cm
Mass (OHA)	~80 kg	~8 kg	~4 kg
Data rate (max)	10 Gbps	10 Gbps (+ future option of 100's Gbps)	
Spectral band	C-band		
Direction select.	Polarization + wavelength	Wavelength (+ polarization compatible)	
Field of regard	360° × ±10°	360° × ±90°	360° × ±90°
CAD image (OHA)	 ~55 cm	 ~20 cm	 ~10 cm

The first one is HICALI, which development was already completed, and it is currently under qualification and test, prior to being integrated and embarked in the GEO satellite ETS-IX. HICALI was designed specifically for a very well-defined and fixed scenario, i.e., bidirectional 10-Gbit/s links between ground and GEO orbit. The other two terminals are called Full Transceiver (FX) and Simple Transmitter (ST). Unlike HICALI, these terminals were not designed for a specific scenario or platform, but with the goal to make them as versatile as possible. The maximum distance range defined in the table refers to the worst-case scenarios in which the terminals can work, but they are designed to adapt their operation to support other use cases, e.g., with significantly shorter distances as well. The FX terminal (Fig. 6, right), as its name indicates, was designed to meet the requirements of high-speed bidirectional communications at long distances. Bidirectional communications can be supported up to several thousands of kilometers in a LEO-LEO scenario such as LEO constellations. The key component of the FX terminal, which enables it for high-speed bidirectional long-range communications, is the 9-cm miniaturized telescope that allows collimating a very-narrow beam to cover long distances with small geometrical losses, as well as providing enough receiving gain to close the link at high speed. The ST terminal (Fig. 6, left) is a further-miniaturized version of the FX terminal with a compact gimbal design and a smaller aperture, although enough to collimate a laser beam to support LEO-ground downlinks, which was the original concept for this terminal. In the ST terminal, the smaller aperture allows to significantly miniaturize the gimbal at the cost of the smaller receiving gain, which sacrifices the highspeed bidirectional operation at distances such as LEO ground. Depending on the scenario and platform, the basic configuration is established by selecting one type or the other, FX or ST. Then, the modem can be selected between a 10-Gbit/s type and a 100's-Gbit/s type, to further refine the requirements of the scenario.

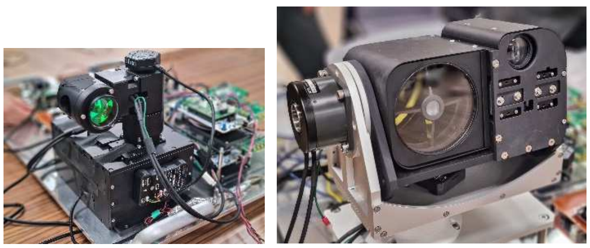


Fig. 6. Early prototypes of ST terminal (left) and FX terminal (right) for preliminary validation and tests.

VI. CONLCUSIONS

In the B5G/6G era, a large number of mobile objects will move and fly not only on land and in the sky, but also on the ocean and in space. This paper described the three dimensional seamless network technology that will be required mainly for NTN in the safe and secure ultra-smart society of the B5G/6G era. This paper also described the research and development of the next generation satellite communications system technology for aiming verification by using the ETS-IX and introduced the current efforts in NICT towards the development of a new series of miniaturized lasercom terminals with the goal of meeting the requirements of many different scenarios and platforms.

ACKNOWLEDGMENT

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