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FEATURE

Special Issue for Space ICT

Interview

Innovative Space Communications Technology Seamlessly Connecting Land, Sea, Air, and Space

What is this movement towards a new era of space-based ICT?

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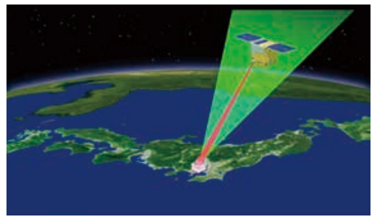


Cover photo
Portable optical ground station completed in February 2020
The station has a 35 cm telescope installed, which is used for the optical antenna module. Satellite-terrestrial optical communications are sensitive to atmospheric conditions, so this station was developed for the purpose of realizing optical communications by selecting a location with favorable conditions.
This research and development was carried out for the "Research and Development of Quantum Cryptography Technologies in Satellite Communication (JPJ007462)" which is part of the Ministry of Internal Affairs and Communications' "Research and Development Project of Priority ICT Technology (JPMI00316)."

Upper left figure
By using the world's first optical communication device (SOTA) mounted on a 50 kg class microsatellite, the experiment directed a laser beam to the NICT optical ground station in Koganei, Tokyo and succeeded in transmitting, via optical communication, images taken by the satellite's camera.

President of the National Institute of Information and Communications Technology
TOKUDA Hideyuki, Ph.D.

Happy New Year!

We pray for those who passed due to COVID-19, and we deeply respect the medical personnel working to treat the infected and seriously ill. We offer our condolences to those who passed in disasters such as the torrential rains in Japan in July 2020, we give our deepest sympathies to those affected by disasters, and we pray for a quick recovery of the affected areas.

Last year, COVID-19 spread globally and caused an unprecedented crisis. In Japan, a state of emergency was issued in April last year and non-essential outgoing was refrained. Even though ICT became indispensable for remote working, online learning, and telemedicine, many issues became apparent, such as delays in society's digitalization. To respond to this "new normal," people seek social and economic activities that avoid the "Three Cs," and we must promote society's digital transformation by developing advanced ICT infrastructure ensuring cyber security and providing non-contact, remote, and highly realistic experiences.

NICT is the sole national research institute in Japan that specializes in ICT. Our mission is to address social issues and create new values through the advancement of ICT. To achieve our mission, we are doing research and development on the world's most advanced technologies and are promoting technology transfer and social implementation of our R&D outcomes through collaboration and open innovation projects with organizations in Japan and overseas. Looking to a post-COVID-19 society, an open symposium was held onlline last June to discuss the "What is your new normal and the Shape of Society in the Post-COVID-19 Era." To realize such society, we also discussed and demonstrated our next generation ICT such as high-strength deep ultraviolet devices, AI chatbots/multimodal voice dialogue systems, simultaneous interpretation systems, Beyond 5G / 6G and cybersecurity.

Under NICT's fourth medium- to long-term plan, there was steady progress in five focusing R&D area: sensing fundamentals, integrated ICT, data utilization and analytics platforms, cyber security, and frontier research. We created excellent, world-leading technologies in space-time standards technologies, high-capacity transmission using new types of multicore optical fibers, Beyond 5G / 6G, brain-inspired information processing and communications, quantum ICT, and bio-ICT, etc. We accelerated the development of security personnel through practical cyber exercises such as CYDER, Cybercolosseo, and SecHack365.We also started NQC (NICT Quantum Camp) to develop "quantum native" human resources and IDI (Innovation Design Initiative) to support the president's thinktank functions and open innovations.

The Ministry of Internal Affairs and Communications also announced the "Global Communication Plan 2025," and R&D of simultaneous interpretation AI has begun, aiming for the Expo 2025 Osaka. Furthermore, both in Japan and overseas, we are promoting joint research and demonstration projects with research institutions, corporations, universities, and local governments. We also promote activities for companies to test and verify the various advanced technologies with NICT testbed facilities and international standardization activities at the ITU, IEEE, IETF, etc.

NICT has three management motto "COC": Collaboration, Open and innovative mind, and Challenging spirit. We promote non-linear R&D that can accelerate open innovation with various stakeholders in contrast to traditional liner R&D model.

We will start a new medium- to long-term plan from April this year and will continue to fulfill our social responsibilities. We appreciate your continued support and cooperation.

Lastly, I wish all of you a wonderful year in 2021.

Interview

Innovative Space Communications Technology Seamlessly Connecting Land, Sea, Air, and Space

What is this movement towards a new era of space-based ICT?

Space development is shifting from a national enterprise to the private sector, and this trend has been accelerating in the last decade or so. In the United States, SpaceX has sent astronauts to the ISS with the Falcon 9 rocket and Crew Dragon capsule, and it also has a plan to launch tens of thousands of small satellites and build satellite internet. In this turbulent era of space development, Japan is also beginning to move towards the commercial use of space. The Space ICT Promotion Initiative Forum (SPIF) was established by NICT together with universities and companies to support this trend from the technical side and further accelerate it. We spoke with KADOWAKI Naoto, Vice President of NICT and SPIF, who has been involved in research since the pioneering early days of space communication technology.

KADOWAKI Naoto

Vice President, NICT

Entered CRL (currently NICT) in 1986. He has engaged in satellite communication. After that he became visiting researcher at AUSSAT in Australia, Chief Researcher at Adaptive Communication Laboratory, ATR, Director General of Wireless Communication Institute, NICT. Current position from 2017. Ph.D. (Information Science).

Q: Commercial use of space is becoming more active, so what is the status of private space development in Japan?

KADOWAKI The Space Activities Act was enacted in Japan to promote space development at the private level. It has been enforced since November 2018, and it can be said that the act has raised interest in the commercial use of space. A variety of activities are expected in space, and satellite communications technologies are one of the most important technologies to realize them. NICT has been researching satellite communications technologies for many years and has a vast amount of accumulated technologies and knowledge. I think that we can contribute to Japan's space development by making use of these research results and development capabilities.

However, in order to do so, national research institutes alone are not enough, and outstanding private sector technologies and human resources are also required. Therefore, we established SPIF with the intention of creating a place for free and open discussion of how to proceed with future research and development, based on the field of space communications.

Q: It can be properly said that this is a new era of space, but what kind of technologies do we need to achieve our goals?

■Technologies supporting a new era of space

KADOWAKI Terrestrial wireless networks have entered the 5G era, but, at the moment, 5G is only terrestrial. I would like to use satellite communications and develop 5G in three dimensions.

Construction of a three-dimensional 5G network will expand upward to the sky with drones, airplanes, stratospheric platforms, low earth orbit satellites, and geostationary satellites. In the future, I would also like to consider communications with the Moon and with Mars.

One other thing is IoT[*1], where communication shifts from places with people to data sensing in places without people, for example, on the ocean. Ocean surface temperature, wind direction / velocity, and atmospheric pressure, etc., have a great influence on the weather, and as such are important data, but there is no easy-to-use network on the ocean right now. However, if the ocean is networked by developing more flexible satellite communications technology, then it will be possible to collect data in real time. You can say that it is something like Beyond 5G, which comes after 5G.

Q: Large-capacity optical communication technologies are becoming important, aren't they?

KADOWAKI Optical link can provide a larger communications capacity than radio waves. Additionally, onboard satellite components for optical communications can be made smaller than the ones required for radio communication, so it will be easy to mount them on the increasing numbers of small satellites and microsatellites in the future.

Another major feature of optical communication is its capability to realize quantum cryptographic communications. In quantum cryptographic communications using optical wave, quantum keys must be distributed over an optical network, and at present, terrestrial optical fiber transmission cannot reach very far. However, if satellites and the ground are connected via optical communication, then quantum keys can be delivered across continents. There are already countries overseas that have succeeded in sending quantum keys via satellite by using relatively large satellites, but we are conducting research on sending quantum keys via small satellites.

As for quantum cryptography, NICT has already conducted basic experiments on the feasibility of quantum cryptographic communications by developing SOTA[*2], a small optical communications device for satellites, and mounting it onto a 50 kg class SOCRATES[*3] (developed by Advanced Engineering Services Co., Ltd. and launched by JAXA in 2014) microsatellite.

Additionally, if the satellites are connected to the Internet, then they may be hacked like on terrestrial networks. NICT also has a department that studies quantum cryptography and cybersecurity, so I expect that they will collaborate as a team and promote measures against hacking.

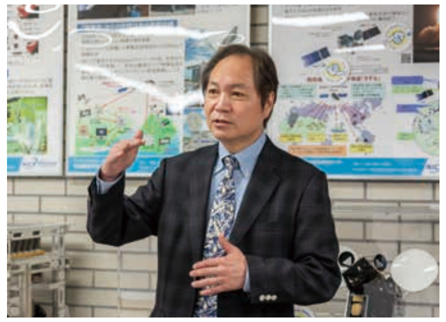
■Implementing a next-generation engineering test satellite

Next, full-scale experiments with ETS-9[*4] are getting closer and closer, aren't they?

KADOWAKI We have started the "ETS-9 Satellite Communications Project" demonstration project to respond to new communications demands in recent years. This is an attempt to demonstrate 10 Gbps class optical satellite communications between a geostationary satellite and the ground, and to develop and demonstrate satellite communication technologies in the so-called Ka-band (20 / 30 GHz) that are more flexible than those using radio waves. It will be the first time in the world to demonstrate 10 Gbps optical communication between a geostationary satellite and the ground.

The radio wave transmission antenna is adopting active phased array antenna technology. With this, we can electronically scan beams via a digitized beam former, and it is an important fundamental technology for realizing large-capacity communication with 100-beam class multi-beams in the future. Additionally, the bandwidth allocated to each beam can be flexibly changed by using digital channelizer technology. These technologies also enable us to dynamically control the beam's direction and bandwidth, increasing radio wave utilization efficiency.

NICT is currently developing an onboard wireless communication device in collaboration with universities and manufacturers, and, if all goes well, ETS-9 will be launched in 2022.



■Wanting participation of youth who will lead the next generation

Q: What is the future outlook for SPIF's activities?

KADOWAKI Technological progress in this field is extremely fast. If something like a large satellite takes five or six years to develop, then it may be equipped with old technology by the time it is launched, and the longer the development time, the higher the cost. Therefore, we have to consider shortening satellite development cycles and reducing costs by using small satellites for in-orbit demonstrations. Furthermore, we are also considering using commercial-off-the-shelf (COTS) components to reduce costs. We consider presenting a new concept of the space development process like this to be one of SPIF's goals.

To that end, we would like to receive a variety of ideas and opinions, including from universities and private companies, and lay out the direction of research and development for Japanese space communication technologies while discussing with them.

We would also like to invite students to participate in SPIF and to make it into a place to talk about space together. I hope that the number of young researchers interested in satellite communications will increase.

*1 IoT: Internet of Things
*2 SOTA: Small Optical TrAnsponder
*3 SOCRATES: Space Optical Communications Research Advanced Technology Satellite
*4 ETS-9: Engineering Test Satellite-9

Research Activities of Space Communications Laboratory in the 4th Medium- to Long-Term Plan

TOYOSHIMA Morio

Director of Space Communications Laboratory, Wireless Networks Research Center

Joined the Communications Research Laboratory, Ministry of Posts and Telecommunications (currently NICT), in 1994. After engaging in ETS-VI laser communication experiments, he was transferred to NASDA (currently JAXA), and after doing research at Vienna University of Technology, he worked on the research and development of onboard satellite communication systems for OICETS, SOTA, and ETS-9. Ph.D. (Engineering).

Frequently launched micro-satellites will change the world of space development. Space development is becoming more familiar to our lives, such as through sophisticated earth observation satellites, satellite communication services by constellation satellites, and a variety of microsatellites. In our laboratory, we have an integrated total view from the Earth's surface to space, and we are advancing research and development of satellite communications technology using light and radio waves to enable communication with anyone, anytime, anywhere, and to realize high-speed, large-capacity, and wide-area usage.

Technology for global optical satellite communication network infrastructure

In response to rising expectations for increased satellite communications capacity and to alleviate pressure on frequency resources, we promoted the development of the HIgh speed Communication with Advanced Laser Instrument (HICALI) onboard a satellite in order to achieve the fastest 10 Gbps class satellite-terrestrial (Figure 1). We are also developing and maintaining an adaptive optics system for the NICT optical ground station for precise tracking and reducing atmospheric fluctuation effects, and will establish basic technology for optical feeder links.

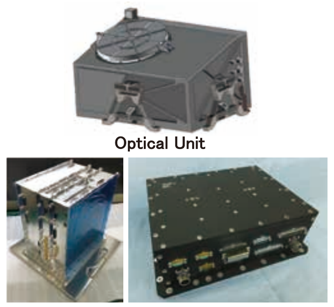


Figure 1 HIgh speed Communication with Advanced Laser Instrument (HICALI), the world's fastest 10 Gbps class transmission equipment onboard the satellite

To improve optical satellite communication quality, we successfully conducted satellite-terrestrial optical communication experiments using a Small Optical TrAnsponder (SOTA) onboard a 50 kg class micro-satellite. Furthermore, we were the first to succeed with a basic quantum communication experiment of transmitting and receiving at the photon-level between the SOTA and an optical ground station, and in July 2017, we published a paper in Nature Photonics (Figure 2). Additionally, we have been collaborating globally with both domestic and overseas companies and research institutions, and promoting satellite-terrestrial optical communication experiments. In April 2020, we succeeded in a bi-directional optical communication experiment between the NICT optical ground station and the optical communication terminal called Small Optical Link for International Space Station (SOLISS) developed by SONY CSL on the International Space Station (ISS) (see p.13 of this issue). In the future, this technology can be used for data transmission from small earth observation satellites and for communication to and within satellite constellations. Furthermore, we have begun research and development of miniaturized optical communication equipment for CubeSat and unmanned aerial vehicles, and we are aiming for 10 Gbps class data transmissions with CubeSats (see pp.10-11 of this issue).

Ensuring global information security is an important social issue, and we are researching and developing satellite quantum cryptography technologies to solve it. In research commissioned by the Ministry of Internal Affairs and Communications, we developed a portable optical ground station vehicle using an 8-ton truck, and conducted evaluation of tracking accuracy, etc. In joint research collaboration, we are developing an optical communication terminal for quantum cryptography (collaboration with the Advanced ICT Research Institute and the Quantum ICT Advanced Development Center). Additionally, a micro-satellite called RISESAT developed by Tohoku University was launched in January 2019. The satellite embarked with a 700-g Very Small Optical TrAnsmitter (VSOTA) developed by NICT and various experiments were conducted. The laser ranging experiments targeting satellites for which accurate orbit and attitude information have not been obtained were successfully conducted, which can contribute to Space Situational Awareness (SSA).

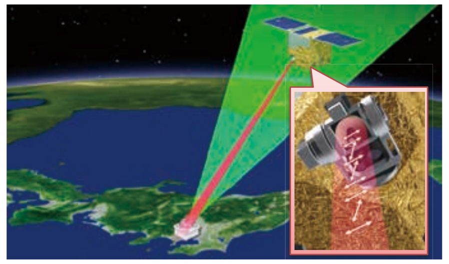


Figure 2 Successful world-first basic experiments in optical communication and quantum cryptography between an optical ground station and a micro-satellite using SOTA

Technology for maritime / space broadband satellite communication network infrastructure

The conceptual designs of a next-generation broadband communication satellite system were created, and contributed to starting the Engineering Test Satellite-9 (ETS-9) project, as a new broadband, flexible, and Ka-band / optical hybrid satellite communication system with 100 Mbps per user (Figure 3). We promoted research and development of the high-throughput satellite communication mission as commissioned research by the Ministry of Internal Affairs and Communications, and conducted research and development of satellite beacon transmission equipment called the Common Communication System (CCS) required for user experiments for satellite tracking. In addition, we completed the development of the satellite fixed multi-beam communication equipment, which is the ETS-9's communications mission. Additionally, the preliminary designs for the satellite operation center for the terrestrial integrated network control and gateway Earth stations (main and sub-stations), and vehicle Earth stations were created. A simulator that comprehensively simulates the frequency / area / RF-optical feeder link switching control functions was developed, and the basic performance evaluation of highly efficient operations control technology was conducted (see pp.8-9 of this issue).

As a basic technology for future flexible on-board payloads, the effectiveness of the system error correction for the onboard digital beam former (DBF) feeder array was confirmed. Full-digital payload technologies onboard micro-satellites are studied, and the research and development of phased array technologies for satellite constellations were conducted. Additionally, a development of low-speed modems for IoT/sensor networks is promoted, which is expected to be new satellite communication use cases.

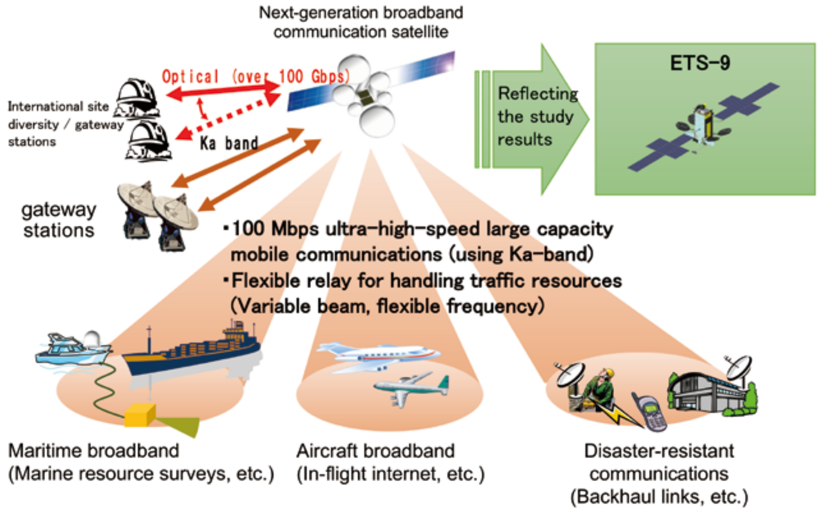


Figure 3 System image of a next-generation broadband communication satellite

Figure 4 WINDS Earth station, set up during the 2016 Kumamoto Earthquake

To provide broadband communication flexibility / agility in areas with congested or disrupted terrestrial communication networks in an emergency, in response to the Kumamoto Earthquake (April 2016) in Kyusyu, in collaboration with NerveNet, etc., the satellite communication link by the Wideband InterNetworking engineering test and Demonstration Satellite (WINDS) was established in Takamori Town to help ensure communications under the event of a disaster (Figure 4, Collaboration with the Resilient ICT Research Center). We also participated in disaster prevention drills, exchanged opinions, and improved the system. With regards to measuring Ka-band propagation characteristics of mobile Earth stations using the WINDS satellite, we measured the blocking effect of trees, etc., while moving the terrestrial on-the-move-vehicle station, and contributed to the standardization document.

To promote satellite communications, we formulated a satellite 5G trial plan with the European Space Agency (ESA) to promote collaboration on the integration of satellites and 5G, and are promoting it as an NICT commissioned research project. We also set up a study group of 19 domestic organizations on the integration of satellites and 5G, conducted studies on use cases, technical issues, etc., and released a white paper. At the "Space ICT Promotion Initiative Forum," established on July 1st, 2020, the 5G / Beyond 5G technology subcommittee plans to continue the discussion on the integration of satellites and 5G from our past studies (see pp.6-7 of this issue).

Future prospects

NICT will promote cutting edge research and development that will become world firsts, centered on space communication technology, and will contribute to standardization activities such as ITU-R, AWG, and CCSDS, etc. Additionally, we will support Space ICT Promotion Initiative Forum's activities promoting the formation of private communities and collaboration between different industries in the private sector, including a variety of companies who are interested in space. We will show the direction for future research and development of Japanese communication and broadcast satellites and demonstration plans, and contribute to strengthening Japan's competitiveness.

Integration of Satellite Communications into 5G / Beyond 5G

MIURA Amane

Senior Researcher, Space Communications Laboratory, Wireless Networks Research Center

Since 1998, he has been with the NICT, formerly Communications Research Laboratory, to engage in the research on satellite communications and antennas. After being transferred to the ATR, he is currently engaging in the research of the communications mission of the Engineering Test Satellite 9 and Beyond-5G space communications. Ph.D. (Information sciences).

The role of satellite communications in 5G / Beyond 5G is attracting attention. The Space Communications Laboratory conducts research and development on integration between Non-Terrestrial Networks (NTN), such as satellite communications, and 5G / Beyond 5G. This paper introduces expectations for satellite 5G / Beyond 5G integration, an image of Beyond 5G-era networks, social issues expected to be solved by satellite 5G / Beyond 5G integration, and prospects for our laboratory's future activities.

Background

Traditionally, satellite communications have provided global services, been less susceptible to natural disasters than terrestrial communications infrastructure, and been used for broadcast services, communication services, and temporary disaster communication. On the other hand, the networks have been constructed independently of terrestrial communication services because large transmission distances cause transmission delays and restricted communication speeds. However, with recent evolutions in satellite communication technology, 5G network technology, and standardization, it is expected that unprecedented services will appear and that conventional services will be significantly improved from integrating NTNs, including satellite communications, and 5G / Beyond 5G.

Expectations for satellite 5G / Beyond 5G integration

There are three possible motivations behind expected integration of satellite communications and 5G / Beyond 5G (Figure 1). First, satellite communication technologies have evolved in recent years. With the advent of High Throughput Satellites (HTS) via geostationary satellites employing large numbers of multi-beams, high-speed and large-capacity can be realized at low costs, and transmission delays can be significantly reduced via the advent of satellite mega-constellations plans with numerous low earth orbit satellites. Terminals have become smaller, consume less power, and have come significantly closer to terrestrial systems. There have been recent moves towards unmanned aircraft, such as the High Altitude Platform Station (HAPS), as communication platforms, and the use of the three-dimensional space (from sky to space) for communications is advancing. Second, efficient 5G integration can be realized by deploying characteristic 5G network technologies in satellite systems, such as software-defined network (SDN) / network function virtualization (NFV), network slicing, and network orchestration, and public-private joint projects in Europe are becoming more active to develop these technologies. Third, in realizing communication services, satellite communications have traditionally been standardized independently of terrestrial mobile communications, but now with 5G, the standardization of NTN, including satellites, is proceeding together with that of terrestrial mobile communications. It is expected that once NTN standardization will progress, plug-and-play features, communications chips, as well as service realization legislation will be developed.

Beyond 5G era networks

Networks in the Beyond 5G era are premised on communication networks in which space and the ground are connected in three dimensions via multiple layers (Figure 2). By seamlessly integrating the ground, sea, sky, and space by linking terrestrial systems, ships, drones, HAPS, and geostationary / non-geostationary satellites, we can realize diverse communication between people and accelerate the resolution of social issues in a constantly changing society. In realizing three-dimensional integrated networks, it is important to have integrated network control technology connecting all elements, technology accommodating diverse communications on geostationary / non-geostationary satellite communications platforms, technology for constructing networks from HAPS / unmanned aircraft, and terminal technology for connecting with all users. Research, development, and demonstrations of these technologies are required.

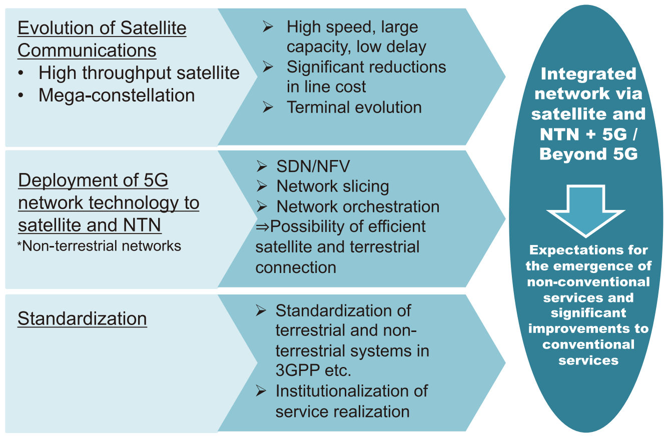


Figure 1　Expectations for satellite 5G / Beyond 5G integration

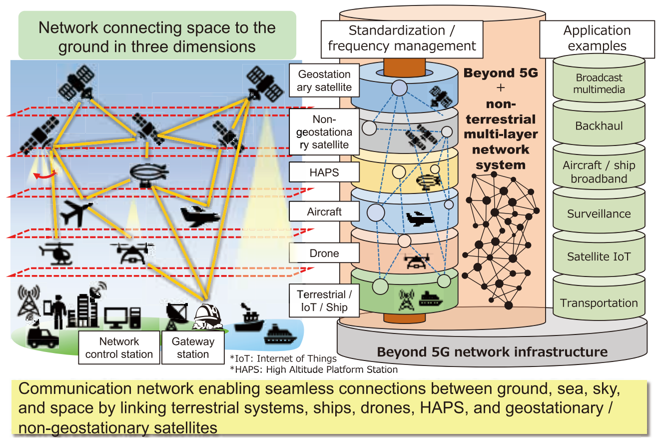


Figure 2　Beyond 5G era network image

Social issues expected to be solved by satellite 5G / Beyond 5G integration

It is expected that a variety of social issues will be solved by realizing a three-dimensional integrated network, with NTN using satellites 5G / Beyond 5G integration as a key (Figure 3). The shortage of communication lines in the ground, sea, air, and space, which will be utilized more actively in the future, will be solved by providing appropriate communications for all mobilities, such as ships, flying cars, drones, (unmanned) aircraft, and space planes. This will realize IoT usages such as MaaS (Mobility as a Service) and seamless logistics, and will expand industrial ICT utilization in marine and non-residential areas. In response to Japan's future issues of aging and population decline, NTN with wide coverage will promote the strengthening and diversification of communications infrastructure in depopulated areas where it is difficult to lay terrestrial communications, and will contribute to promoting smart cities and unmanned operations (autonomous / remote control). For intensifying natural disasters, which have become a serious issue in recent years, 5G technology can realize rapid network switching, and, more than with conventional satellite communications, it will be possible to maintain a seamless communication environment in disaster relief and strengthen terrestrial communication infrastructure such as mobile phone networks. Furthermore, with the new normal from the spread of COVID-19, NTN is expected to provide unmanned operation by taking advantage of NTN's wide coverage, provide appropriate medical services via telemedicine, and local revitalization by providing remote work environments in rural areas.

Future prospects

The Space Communications Laboratory held the "Study Group on the Integration of Satellite Communications and 5G / Beyond 5G" in FY2019, and, with relevant organizations in Japan, we conducted concrete studies on integrating satellite communications and 5G / Beyond 5G and released the report (https://www2.nict.go.jp/wireless/sat5g-scl.html (in Japanese)). We are continuing these activities and will support the "5G / Beyond 5G Integration Technology Subcommittee" through "Space ICT Promotion Initiative Forum" (https://spif.nict.go.jp/ (in Japanese)) activities. With the integration of NTN and 5G / Beyond 5G, including satellite communications, as the key, we will promote activities in this field in Japan towards realization of three-dimensional integrated networks, solving social issues, and creating new services. Additionally, as research and development initiatives, we will promote research and development of core technologies for realizing three-dimensional integrated networks, such as integrated network control technologies, and, in collaboration with Europe, Beyond 5G satellite / terrestrial integration technologies.

In our laboratory, we aim to connect the ground, sea, sky, and space in a seamless three dimensional manner, thereby enabling communications to all areas. Through this, we will continue to work to realize communications that can provide new lifestyles and work styles to ever-changing society.

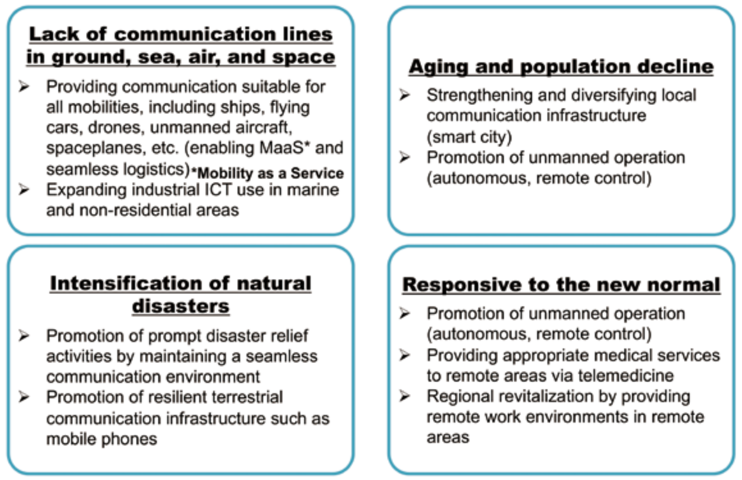


Figure 3　Social issues expected to be solved by satellite 5G / Beyond 5G integration

Optimization of Global Communication Networks to Connect High-throughput and Numerous Satellites

Towards demonstration of Engineering Test Satellite-9 and network control technology

ABE Yuma

Researcher, Space Communications Laboratory, Wireless Networks Research Center

After completing his master course, he joined NICT in 2017 and completed his doctoral course in 2020. He is currently engaged in the Engineering Test Satellite 9 project and research on resource and network management for large-scale satellite communications systems. Ph.D. (Engineering).

Satellite communication systems are expanding in scale due to the rapid increase in satellite numbers, and additionally, communication satellites are becoming more sophisticated. At NICT, we are aiming to realize satellite communication systems that can be operated efficiently, advance research on control models and optimization algorithms for resource allocation and network construction, and are planning to demonstrate a portion of the technologies by using Engineering Test Satellite-9 (ETS-9), scheduled to be launched in FY2022.

Background of satellite communications

Satellite communication between space communication satellites and the ground is mainly used in places where it is not possible to connect to terrestrial communication networks. A familiar example of satellite communication is in-flight internet, where aircraft and ground stations communicate via satellites. Additionally, satellite communication can provide communication links even when many terrestrial networks are unavailable, such as after a disaster. Furthermore, the demand for the Internet of Things (IoT) communications has rapidly increased in recent years, and there is demand for increasing the capacity of satellite communication systems.

Overall plan for ETS-9

In order to make effective use of limited radio resources, at NICT, we are promoting research and development on technologies that increase satellite communication capacity and flexibility, and we are aiming for demonstration with ETS-9, scheduled to launch in FY2022 [1].

Figure 1 shows an overview of the ETS-9 communication missions. ETS-9 is equipped with fixed-beam, variable-beam, and optical feeder link communication missions, with Japan Aerospace Exploration Agency (JAXA) developing the satellite bus system and NICT developing the communication missions. The technologies to be demonstrated on ETS-9 roughly fall into two categories shown below:

Frequency / Area Flexibility Technology

With conventional communication satellites, the communication resources allocated to each region are fixed, so if communication demand suddenly increases at a certain time, such as during a disaster, then many users may not be able to communicate.

Satellite communication flexibility technologies solve this problem. Frequency flexibility technologies are functions that can flexibly change frequency bands, and area flexibility technologies are functions that can flexibly change available communication areas.

By using these technologies and controlling satellite communication missions in response to user requests, it is possible to allocate the required amount of communication resources to the required location, and ETS-9 is equipped with a communication mission to achieve this. It uses frequencies in the 20 to 30 GHz band (Ka band), and the goal is to achieve transmission speeds of 100 Mbps per user.

Figure 2 shows simulation results using the frequency flexibility control algorithm proposed by NICT. This simulation assumes satellite communication services to an aircraft, and it can be seen that communication resource allocations change as the communication requests change over time [2]. By using communication satellites with functionality like this, we believe that the number of people who can communicate will increase more than ever, even after a disaster.

Optical Feeder Link Technology

Optical communication, when compared with communication using radio waves, has characteristics such as large capacity, high confidentiality, and low power consumption. If current radio wave communications can be replaced by optical communications, then we can not only realize larger capacity communication links, but we will also contribute to solving the shortage of radio wave resources.

With ETS-9 we plan to realize a 10 Gbps class communication link between a geostationary orbit and the ground, and we are promoting the development of HIgh speed Communication with Advanced Laser Instrument (HICALI) for that purpose. HICALI has a 15 cm diameter antenna and a 1550 nm (C-band) wavelength laser, which conforms to the international standards discussed by the Consultative Committee for Space Data System (CCSDS) standardization body. We also aim to establish a screening process for space-based usage of optical network devices used on the ground. On the other hand, light is significantly impacted by the atmosphere and clouds, so disturbances to or shielding of the optical signal will lead to deteriorated communication quality even if a large-capacity communication link can be constructed. As such, we are also conducting research on adaptive optics technologies that reduce the effects of atmospheric fluctuations and site diversity technologies that switch between optical ground stations situated in multiple locations.

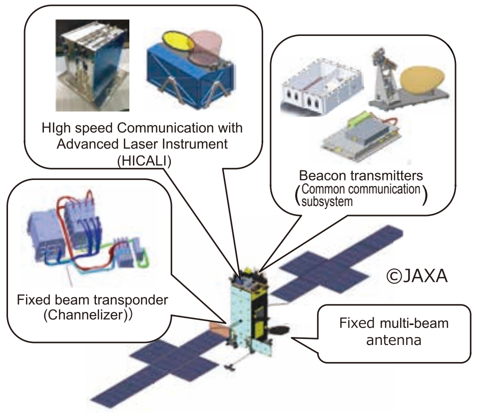


Figure 1 ETS-9 communication missions (main subsystems being developed by NICT)

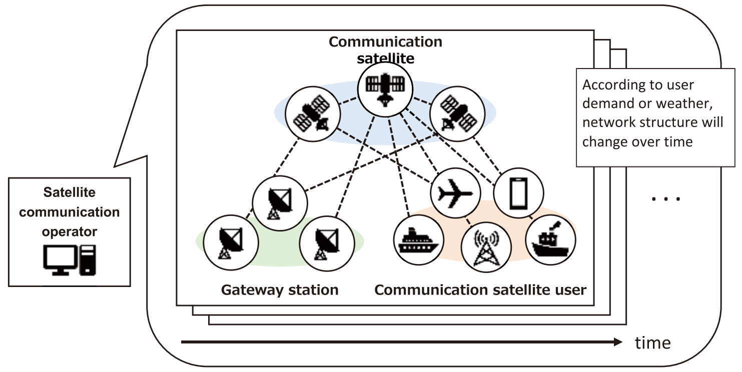
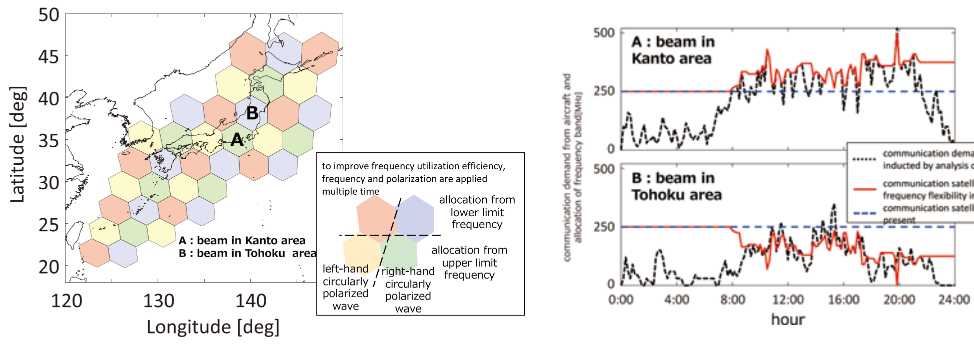


Figure 3 Image of network optimizations for large-scale satellite communication systems



A: Simulation of communication satellite beam placement

B: Simulation results of frequency flexibility function

Figure 2 Simulation results using the frequency flexibility control algorithm

Research on networks connecting very large numbers of communication satellites

There have been satellite constellation systems planned in recent years that can provide a global communication network with large numbers of communication satellites, and it is expected that such large-scale satellite communication systems in the future will have satellites with different orbits, frequencies, sizes, and power, etc. Additionally, it is necessary to optimize the network to always provide a stable communication link according to temporarily varying user numbers and their communication requests, the number of satellites that can be used, and the propagation state of their electromagnetic waves.

The author proposed and developed a model for efficiently operating a large-scale satellite communication system and a control scheme for dynamically optimizing the entire network (Figure 3). With this model, satellites with different orbits and different frequencies can be added to the system in the same framework. Furthermore, it is possible to avoid frequent changes in network structure that are a burden to satellite communication operators.

Based on this model, optimal control schemes, and operational scenarios for large-scale satellite communication systems, the effectiveness of the proposed method was confirmed via simulation, and the author believes that performance can be further improved even if the system expands and the number of satellites gradually increases [3].

Future prospects

In addition to the technologies introduced here, at NICT, we are also conducting research on integrating satellite communications and 5G, and we are considering using ETS-9 as a demonstration testbed. By realizing satellite communication systems that can provide large-capacity and flexible communication links, we believe that user communication requests will be possible anywhere, on aircraft, ships, remote islands, deserts, mountains, and even planets. In order to realize such a world, NICT will continue promoting research on new satellite communication systems and will disseminate the results.

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Ultra-fast Laser Communications Will Open a New World of Possibilities for CubeSats

Alberto Carrasco-Casado

Researcher, Space Communications Laboratory, Wireless Networks Research Center

After completing his Ph.D. in electric, electronic, and automation engineering from Carlos III University of Madrid and Spanish National Research Council in 2015, he joined the Space Communications Laboratory, at NICT. Currently engaged in several projects related to space optical communications, ranging from the development of terrestrial infrastructure, aerial demonstrations using drones and HAPS, to space missions using different kinds of platforms, from CubeSats to large geostationary satellites.

CubeSat microsatellite technology has made great progress in the last decade. The cost of developing small satellites has become reasonable, which has significantly increased the number of users, and this trend is expected to steadily continue in the future. Going forward, CubeSats will play an active role in a variety of scenarios, from short-term missions for university educational purposes to mega constellations that will support communications for millions of people, and it is expected that ultra-large capacity optical-communication technology will open up a new world of possibilities for CubeSats.

CubeSat overview

CubeSats are microsatellites composed of basic units (1U) with 10 × 10 × 10 cm external dimensions. Two basic units are called 2U, three basic units are called 3U, and so on. Approximately 80% of launched CubeSats are between 1U and 3U in size. The modular development of small-satellite technology has made it easier to access space, and over the last few years, more than 1,000 CubeSats have been launched, with this number increasing every year.

CubeSats have reached a high level of technical maturity, and are now ready to be used not only for educational purposes and simple experiments, but also for full-scale missions. However, terrestrial and satellite communication still depends on radio frequency (RF) communication, which has data rates in the "Kbps" class and where spectrum is already congested, so it is difficult to meet the increasing demand for data transmission to the ground. Optical communication, a promising technology to solve this problem, has the potential to improve transmission speeds by several orders of magnitude while keeping the size, mass, and power of onboard optical-communication terminals low.

Role of high-speed optical communication for CubeSats

As mentioned above, the basic technology for communication between CubeSats and the ground is VHF/UHF, and typical transmission speed is around 10 Kbit/s. With large terrestrial antennas, the S-band can reach several Mbit/s and the X-band can reach hundreds of Mbit/s, but with CubeSat size, mass, and power constraints, it is difficult to dramatically improve communication speeds via RF technologies. Furthermore, already congested spectrum is in a difficult position to support the huge number of satellites that will be launched in the coming years. Moreover, space optical communications have a very-high potential, not only to increase communication speeds while reducing size, mass, and power, but also with room for further improvement in the future.

There is a very wide range of applications that can benefit from the increased transmission capacities of CubeSats and small satellites, including communication networks, space observation, Earth monitoring, disaster prevention, deep-space exploration, Internet-of-things device connectivity, basic and applied research, education, etc. There are already plans to use CubeSats in all of these areas, but with the future availability of high-speed communications, it is possible to think of even more new applications. For example, mega constellations can be deployed at a fraction of their current cost, enabling high-speed communications in remote locations and significantly reducing latency. The number of deep-space exploration missions, currently only accessible by space agencies, could also grow significantly due to lower costs. Most importantly, communication speed is currently the most-important bottleneck for CubeSats, so expanding CubeSat capabilities and providing them to the general public may bring completely new applications that no one could have imagined. This is the true value of CubeSats, and optical communications are expected to open up a whole world of new possibilities for them.

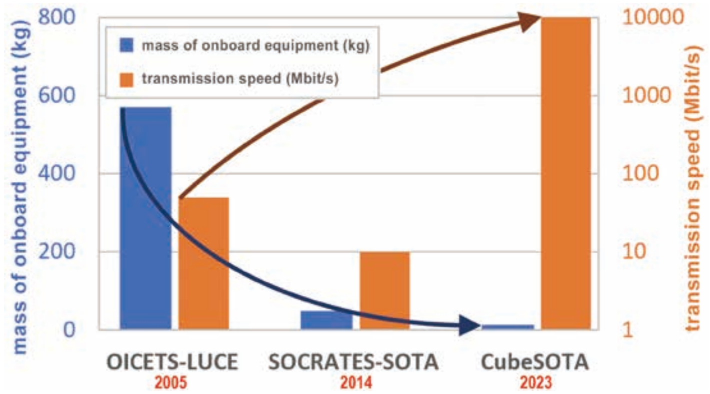

Figure 1 20-year evolution at NICT of transmission speeds and mass of onboard equipment for optical communication with low-earth orbit satellites

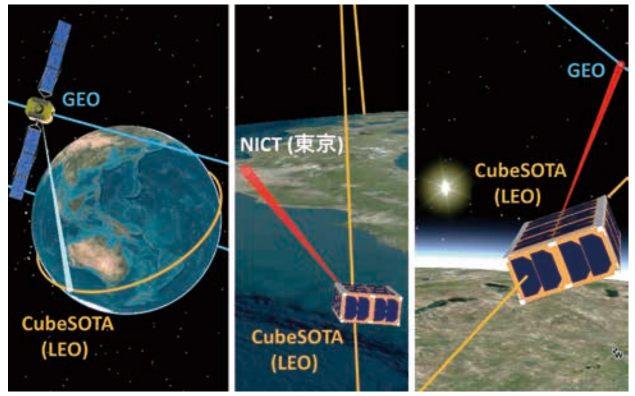

Figure 2 The CubeSOTA mission's demonstration experiment plan: Direct communication with the ground (center) and CubeSat to ground communication via a data relay satellite (left and right)

NICT's advantageous position

NICT has a long history of research and development in the field of optical satellite communications. With regards to only low earth orbit (LEO) satellites, in 2006, NICT succeeded for the first time in the world in demonstrating optical communications between LEO and the ground at 50-Mbit/s using the Optical Inter-orbit Communications Engineering Test Satellite (OICETS), and less than 10 years later, NICT developed the world's first laser-communication terminal for microsatellites called Small Optical TrAnsponder (SOTA), with 5-kg of mass. The SOCRATES satellite, equipped with SOTA, conducted a variety of experiments since 2014, such as 10-Mbit/s optical communication with the ground, and basic quantum-cryptography experiments. Currently, we are aiming to reduce mass and increase communication speeds with a LEO optical-communication terminal called CubeSOTA, designed for the CubeSat platform. As shown in Figure 1, it is expected that communication speeds will be increased by two to three orders of magnitude and that mass will be reduced by more than one order of magnitude.

CubeSats can be put into orbit by launching them on a rocket, or they can be released into space from the International Space Station (ISS). Japan is in an advantageous position because it has its own mechanism to release CubeSats from the ISS's Japanese Experiment Module (JEM) using a robotic arm. The advantages of using the ISS are frequent launch opportunities (approximately 6 times a year), that vibration can be reduced by a dedicated container, and that CubeSats can be checked in advance by an astronaut before their release. The disadvantage though is that the ISS's low orbit (approximately 400 km) limits the satellites to a lifespan of approximately one year, which is sufficient for technical demonstrations.

Current research and development efforts at NICT

Based on the experience miniaturizing SOTA, we are developing an even-more-compact communication terminal for CubeSats, which will demonstrate, in cooperation with the University of Tokyo, multi-gigabit communication using two CubeSOTA satellites (Figure 2). The first one will carry out direct communication with the ground, and for the second one, we are considering a system that can perform intersatellite communication via a data relay satellite in GEO orbit.

Challenges in development include miniaturizing optical amplifiers, telescopes, precision tracking, and modems. As a first step before launching the satellite for the purpose of demonstration and experiments, we are considering the use of high-altitude platform systems (HAPS), that can fly as high as 20 km, well above the clouds just like satellites, but in a less-strict environment. We are also researching to develop portable ground stations that enable experiments in various locations at a low cost, and we are also conducting research and development on ground technologies that can be easily deployed to support high-speed CubeSat communications at a more-affordable cost.

At NICT, we are not only demonstrating the feasibility of high-speed communications for CubeSats, but also aiming to popularize it by miniaturizing optical-communication equipment, with the goal of developing an NICT prototype device based on a design that allows transfer of its technology to the private sector for future commercialization. It is hoped that enabling high-speed communications for microsatellites will promote innovative scientific research and the development of completely new applications.

Experimental Success in Bidirectional Optical Communication Between the International Space Station and an NICT Optical Ground Station Receives the Good Design Award 2020

Space Communications Laboratory, Wireless Networks Research Center MUNEMASA Yasushi

The Development of Space Optical Communication System SOLISS (Small Optical Link for International Space Station), a joint research initiative undertaken by NICT, has received the Good Design Award 2020 from the Japan Institute of Design Promotion, which was jointly awarded to JAXA, Sony CSL, Ricoh, and NICT.

For the SOLISS project, NICT, in collaboration with Sony Computer Science Laboratories, Inc. (Sony CSL), used laser light to demonstrate bidirectional optical (satellite) communications between the International Space Station (ISS) and an NICT optical communication ground station. The features of optical satellite communication are that it can realize much higher speeds and larger capacity communication than satellite communications with radio waves, and NICT has been leading the research and development of optical satellite communication systems since the 1980s. In the field of space communications, research and development led by national-scale institutions has traditionally been the mainstream, but in recent years, there has been active worldwide development led by private companies, with one example being SpaceX's first successful manned flight under NASA's Commercial Crew Development program.

NICT promotes open innovation not only for research and development, but also to widely implement the results in society, and, as part of those activities, NICT and Sony CSL have been jointly conducting research since 2018 towards demonstrating bidirectional optical communication between NICT's optical-communication ground station and SOLISS, which was jointly developed by Sony CSL and JAXA. As a result of providing knowledge based on the developed technologies for NICT-owned satellite-mounted optical communication terminals and by jointly conducting the measurements and experiments necessary for the SOLISS in-orbit demonstration test, on March 11, 2020, we succeeded in establishing a 100 Mbps bidirectional optical communication link between SOLISS and the NICT optical-communication ground station, and then transmitted high-definition (HD) image data via Ethernet. The picture was image data transmitted from SOLISS, mounted on the ISS's external Japanese Experiment Module (JEM) "Kibo" platform, and was received by NICT's optical-communication ground station. This result is also the world's first example of realizing Ethernet communications via an optical-communication device for mounting on small satellites.

The success of this experiment is the result of NICT providing knowledge on the development of optical satellite communication systems and providing technical support related to the experimental operation of optical ground stations, of JAXA supporting the launch of SOLISS and its in-orbit operation aboard the ISS, and of Sony CSL conducting the communication test. By creating such a flexible research and development framework, utilizing the knowledge and facilities of public research and development institutions and combining the outstanding technology and sense of speed from private companies, the experiment was assessed as an example demonstrating, in a short period of time, function and performance not found in conventional space development.

NICT will continue to carry out advanced optical satellite communication technology research and development, and will promote open innovation of space ICT so that it can contribute to strengthening space communications technologies in Japan. Last but not least, we would like to thank all related organizations for their cooperation in this demonstration experiment and in receiving the Good Design Award.

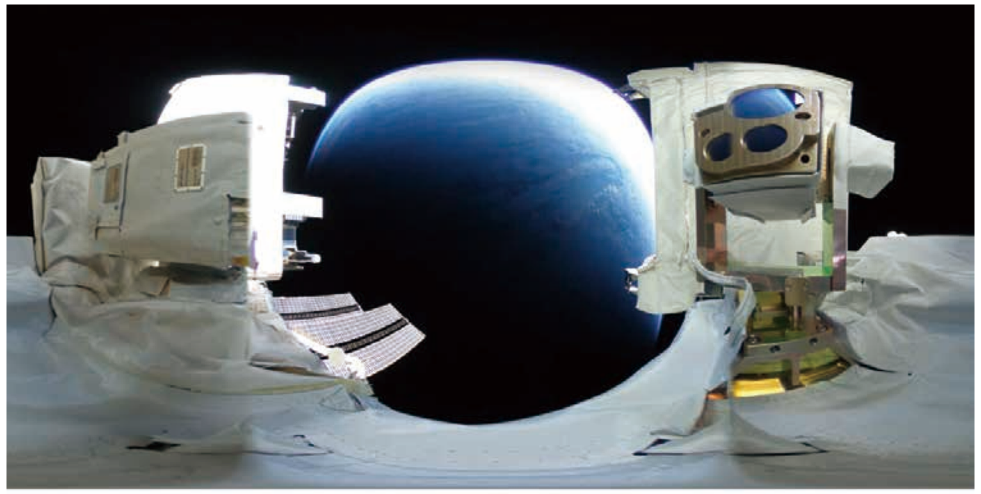

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Photo High-definition (HD) image taken with a 360° field of view monitor camera mounted on SOLISS
Right side: SOLISS optical communication module; Left side: Next-generation high-definition camera (HDTV-EF2)

Low-Profile Active Electronically Steered Array Antenna Enabling Internet Services in Small Aircraft

OKURA Takuya

Researcher, Space Communications Laboratory, Wireless Networks Research Center Ph.D.(Engineering)

Biography

1990 Born in Okayama Prefecture
2012 Graduated from Yokohama National University, Faculty of Engineering with Electrical and Computer Engineering
2013 Completed first two years of doctoral program at Yokohama National University, Graduate School of Engineering in Physics, Electrical and Computer Engineering
2016 Completed doctoral program at Yokohama National University, Graduate School of Engineering in Physics, Electrical and Computer Engineering, and joined Microwave Factory Co., Ltd.
2017 Joined NICT, current position

Awards, etc.

2020 Recipient of the Institute of Electronics, Information and Communication Engineers' 2019 (82nd) Communications Society Young Researcher's Award

Q&As

Q What do you like the most about being a researcher?

A Being able to experience the latest technology is the first step in bringing an "It'd be great if we could do this..." type idea to life. I can also go to a variety of places for academic conferences and experiments (with local gourmet food being one of the pleasures).

Q What are you currently interested in outside of your research?

A Driving.
I signed up for a car sharing program after feeling that COVID-19 made traveling by public transportation a bit scary. At first, it was simply a means of transportation, but the driving itself gradually became fun. Someday, I want to buy a car I love.

Q What advice would you like to pass on to people aspiring to be researchers?

A When I was a student, I was assigned to a laboratory and found it fascinating, thinking, "Research is quite interesting," so I decided to get a Ph.D. and become a researcher. If you feel the charms and allure of research, then I hope you will cherish that feeling and become a researcher.

Recently, the demand for Internet access by people on board large aircraft has been increasing alongside the development of mobile phones. Additionally, according to the future trends in commercial aircraft and the defense / space market that Boeing announced in October 2020 (Boeing Market Outlook, BMO), the number of commercial aircraft is expected to increase from 25,900 to 48,400 over the next 20 years. Furthermore, according to demand forecasts by aircraft model, demand for small / medium-sized aircrafts such as regional aircraft (90 seats or less) and narrow-body aircraft (90 seats or more) is expected to be approximately 35,000 aircraft. It is expected that demand for aircraft satellite communications will significantly increase in order to provide broadband services for both these aircraft as well as for large aircraft. Therefore, effective use of frequencies has become an essential issue to increase the speed and capacity of satellite communication systems, and higher performance aircraft-mounted satellite communication antennas are required.

Generally, it is necessary to increase the antenna's aperture to improve its performance. However, with conventional mechanically driven antennas, the antenna becomes three-dimensionally large, which makes it difficult to mount on small / medium-sized aircraft. Therefore, through research and development of a low-profile active electronically steered array antenna, we aim to contribute to effective frequency utilization by establishing technology to improve antenna performance without compromising aircraft mountability and improving frequency utilization efficiency by more than 30% with multi-value modulation methods.

By the end of the current fiscal year, we plan to actually mount a sub-array antenna, which is part of the array antenna, on an aircraft and evaluate the antenna's performance. If we achieve our targets without any problems, then I believe that this will be the first step towards significantly changing the in-flight internet environment. (This study is conducted under the commissioned research of the "Research and development on narrowband technology using active electronically steered array antenna that can be mounted on small aircrafts" (JPJ000254) by the Ministry of Internal Affairs and Communications, Japan.)

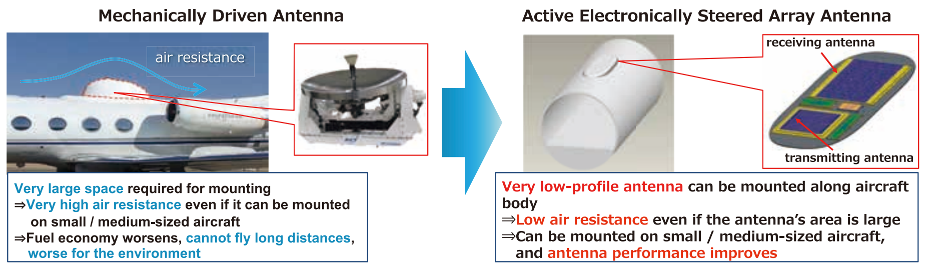

Figure Merits of active electronically steered array antenna

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