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NICT NEWS

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FEATURE

Optical Satellite Communication toward the Future of Ultra High-speed Wireless Communications

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National Institute of Information and Communications Technology

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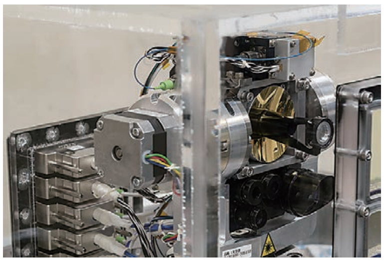


Cover photo
Optical telescope with 1 m primary mirror. It receives data by collecting light from satellites. This was the main telescope used in experiments with the Small Optical TrAnsponder (SOTA). This optical telescope has three focal planes, a Cassegrain, a Nasmyth, and a coudé.
The photo in the upper left of this page shows SOTA mounted in a 50 kg-class micro-satellite. In a world-leading effort, this was developed to conduct basic research on technology for 1.5-micron band optical communication between low-earth-orbit satellite and the ground and to test satellite-mounted equipment in a space environment. Recent basic experiments in quantum communication have also been successful, as published in Nature Photonics. The telescope has a diameter of approximately 5 cm, and the mass of SOTA is approximately 6 kg.

INTERVIEW

New Possibilities Demonstrated by Micro-satellites

Morio TOYOSHIMA
Director
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, Morio TOYOSHIMA was transferred to NASDA (currently JAXA), and after doing research at Vienna University of Technology, worked on the research and development of onboard laser communication equipment for OICETS, SOTA, and HICALI, was involved in satellite laser communication and quantum key distribution (QKD) experiments. Ph. D (Engineering).

High precision Earth observation satellites are being launched, one after another. These are micro-satellites of many types, used for research, education, and commercial purposes. As the development of space becomes more familiar in our daily lives, it is bringing a range of new conveniences. The Space Communications Laboratory, Wireless Networks Research Center, conducts R&D, focusing on optical (laser) satellite communications, in hopes of making breakthroughs in satellite communications data transmission technology. We spoke to Laboratory Director, Dr. Morio TOYOSHIMA, about this research.

"Mega-constellations" advancing in many countries

—To begin with, can you tell us about current trends in space communications technology?

TOYOSHIMA: Many countries have been working actively on mega-constellation projects* in recent years. This development of space itself holds potential for innovation, and several of these projects are considering use of optical satellite communications.

A recent trend particularly in optical satellite communications is the planned implementation of optical data relay satellite systems in the United States, Europe, and Japan. NASA's Lunar Laser Communication Demonstration (LLCD) at the Goddard Space Flight Center (GSFC) successfully established 622 Mbps optical communication links between the moon and the earth using a satellite launched in September 2013. And in April 2019, NASA's Laser Communication Relay Demonstration (LCRD) project plans to launch an optical data relay satellite system into geostationary orbits. In Europe, the European Space Agency (ESA) operates an optical data relay service on geostationary satellites called the European Data Relay System (EDRS), and the Copernicus Earth observation project has launched five low-earth orbit (LEO) Sentinel satellites that initiate optical communications for data transmission. In Japan, the Japan Aerospace Exploration Agency (JAXA) is also planning the Japanese Data Relay System (JDRS) using an optical data relay satellite.

—How is research organized and what are the main research themes in the Space Communications Laboratory?

TOYOSHIMA: The laboratory has two locations, our headquarters in Koganei and the Kashima Space Technology Center, with approximately 50 members conducting research and development, including researchers, students, and supporting staff. Our two main research themes are radio satellite communications and optical satellite communications. Our objectives are to establish satellite communications using these to develop communication networks that can be used at sea and in space, and be useful in mobile situations and for disaster prevention and mitigation.

In several countries, recently so-called High-Throughput Satellite (HTS) services are being started using Ka band communications satellites with capacity exceeding 100 Gbps. However, HTS services are limited by the communications capacity of gateways called feeder links, connecting the earth station and the satellite, that bundle user lines with terrestrial communications, and technology to expand the feeder link communications capacity is highly sought after. Our laboratory is conducting R&D on genuine multi-gigabit optical satellite communications technology to resolve this issue and establish infrastructure technologies for 10 Gbps-class optical communications to resolve demand for high-capacity next generation communications.

Extra success achieved by the SOTA project

—Is the Small Optical TrAnsponder (SOTA) project completed at the end of last year part of these efforts?

* Groups of many small satellites or unmanned aircraft are linked and cooperate to achieve a specific objective. As with constellations of stars and orbital positions, groups of satellites in particular are called satellite constellations. There are many projects, largely promoted by Google (USA) and Facebook (USA), being executed by companies including Space-X (USA), Oneweb (USA), O3b (UK), Leosat (USA), and Kaskilo (formerly eightyLEO, Germany).

INTERVIEW

New Possibilities Demonstrated by Micro-satellites

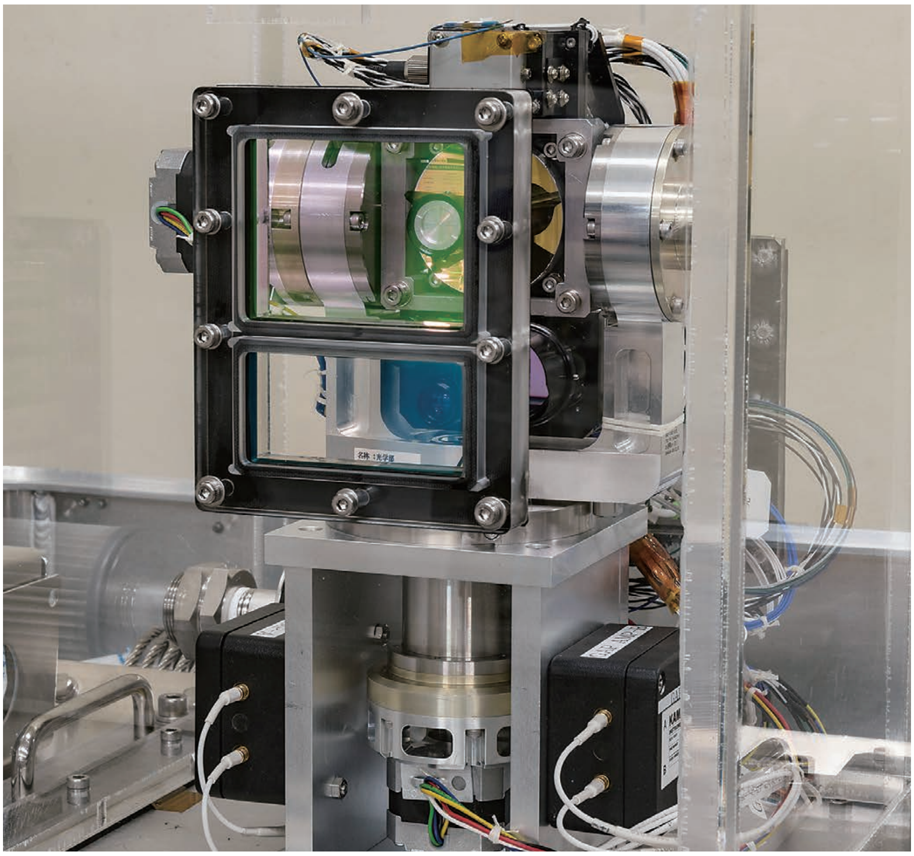
TOYOSHIMA: The goal of the SOTA project was to expand optical satellite communications technology for very small satellites, developing 6 kg-class ultra-compact optical communications equipment (Small Optical TrAnsponder, SOTA), and to demonstrate it mounted on the 50 kg-class Space Optical Communications Research Advanced Technology Satellite (SOCRATES). It was done in collaboration with private enterprise.

The project started in 2009, and after the preliminary design review and the critical design review, a flight model was built. The SOCRATES satellite carrying SOTA was launched into low-earth orbit in May 2014. In the demonstration, images taken by an onboard camera mounted on the 50-kg class micro-satellite were transmitted via optical communications for the first time, using 1.5-micron laser light with original error correcting codes implemented in SOTA. The low-earth orbit made it accessible from various countries during its orbit, therefore international collaboration tests using SOTA were also conducted, involving international space agencies such as CNES in France, DLR in Germany, CSA in Canada, and the ESA in Europe. In particular, we conducted successful adaptive optics (AO) experiments using SOTA with the CNES optical ground station.

In optical satellite communications experiments, telescope operation and communication tests were done mainly by Expert Maki AKIOKA, Senior Researcher Yoshisada KOYAMA, Researcher Yasushi MUNEMASA, and Researcher Hideki TAKENAKA. International collaborative experiments were planned and performed by Researcher Dimitar KOLEV, and polarized light measurement experiments were done by Researcher Alberto CARRASCO-CASADO, and Researcher Hideki TAKENAKA.

These experiments ended with the termination of operation of the SOCRATES satellite in November 2016.

During the operation of the satellite over a period of two years, tests in optical communications, and basic experiments in quantum key distribution (jointly with the Advanced ICT Research Institute) were conducted, along with international collaboration experiments. This work yielded more success than expected.



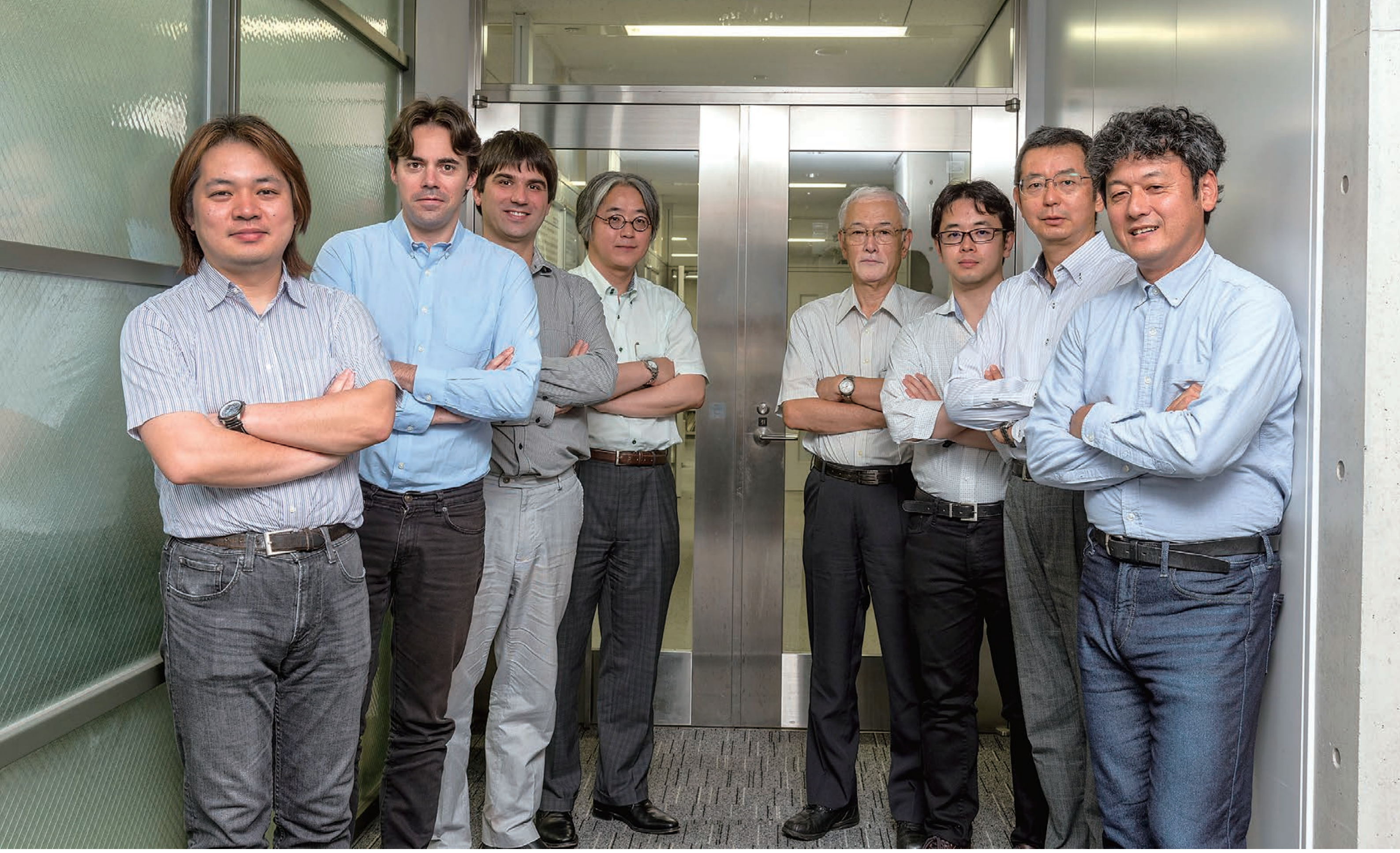
SOTA installed in a micro-satellite. Telescope diameter is approximately 5 cm, and the mass is approximately 6 kg.

— Can you tell us about some of the difficulties and innovations encountered in the SOTA project?

TOYOSHIMA: Earlier successes used satellites as large as several hundred kilograms, so at the outset of the project, no one believed that it would be possible to incorporate laser communications on a 50 kg-class small satellite.

With small satellites, many functions must be crammed into a small package. Tracking and maintaining communication with a small satellite is extremely difficult because the laser beam used for communication is so narrow and the low mass and resultant low inertial moment make it difficult to stabilize. No one had done such a test and there was no past data, so there was an element of trial-and-error in the design work.

We also had issues with materials. In space, thermally-resistant materials are an important factor. Any deformation can result in inability to communicate properly. In space, metals prone to deformation with temperature change can become almost flabby, but materials that do not deform in the harsh environment of space are extremely expensive. Considering practical implementation in the future, it was essential to complete the mission at a "reasonable" cost. As such, aluminum alloys that are easily available at low cost were used for all structural materi-



SOTA Project team
From the left: Yasushi MUNEMASA, Alberto CARRASCO-CASADO, Dimitar KOLEV (mainly satellite testing), Morio TOYOSHIMA, Yoshisada KOYAMA, Hideki TAKENAKA (mainly satellite instrumentation development), Kenji SUZUKI (site diversity, see P6-7), and Toshihiro KUBO-OKA (satellite orbit determination, see P10-11). Also Hiroo KUNIMORI (earth station development, see P4-5), and Tetsuharu FUSE (satellite orbit determination, see P8-9).

als in the SOTA project. These are susceptible to thermal deformation, but the problem was solved by using athermal structural design, which includes deformation in computations, compensating for deformation in the design.

Future development of optical satellite communication

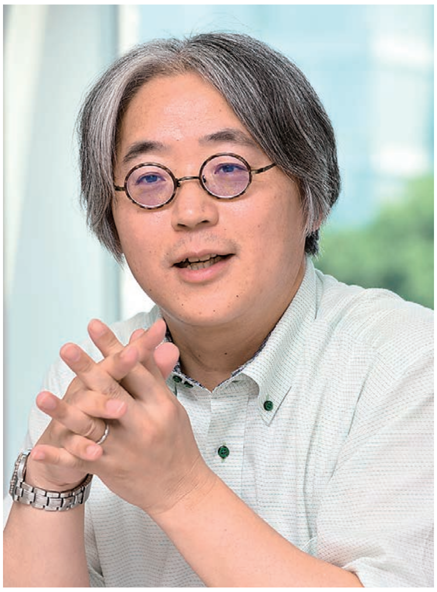
—— Can you tell us more about projects currently in progress and planned for the future?

TOYOSHIMA: In elemental technology research, R&D is needed on optical communication AO technologies for an optical feeder link technology. We are also conducting research on debris using large aperture telescopes and on determining orbits precisely by use of optical measurements. In the site diversity study, we are researching collection of environmental weather data for the weather forecast of optical communications. In the future, our HIgh speed Communication with Advanced Laser Instruments (HICALI) project will be developing a 10 Gbps-class satellite optical transceiver to be mounted on the ETS-IX satellite scheduled for launch in 2021, when we hope to demonstrate our optical feeder link basic technology.

——What are the prospects for development of optical satellite communication? What can users hope to see, and what impact might it have on society?

TOYOSHIMA: We expect use of optical satellite communication to progress further in Asia, America, and Europe, mainly in use of optical data relay satellites mainly for the inter-satellite laser communications.

With the success of the SOTA project, plans for mega-constellations and applications of optical communication systems are becoming increasingly active. For example, by connecting many very-small satellites by high-capacity optical communications, a cloud-type supercomputer could be built in space, opening up future possibilities such as systems that are robust in situations like disasters. We expect development to accelerate in these areas in countries around the world in the future, and we will continue to focus efforts on implementing optical satellite communications technologies and building business models.



A Deep-space Optical Communication and Ranging Application

Single photon detector and receiver for observation of space debris

Hiroo KUNIMORI
Senior Researcher
Space Communications Laboratory
Wireless Networks Research Center

After graduating from university, Hiroo KUNIMORI joined the Ministry of Posts and Telecommunications Radio Research Laboratory (currently NICT) in 1981. Engaged in research on space-time measurement, telecommunication standardization, satellite laser ranging, and optical space communication.

Perhaps everyone has seen artificial satellites as they fly slowly like shooting stars across the evening sky. The NICT Space Communications Laboratory conducts research on networks connecting space with the ground, communicating with artificial satellites using radio waves and light, and conducts development and testing of detection technologies in collaboration with institutes within and outside of Japan. This article introduces some elemental optical technologies used for very-long-distance communication and ranging in deep space.

Background

It is now 60 years since humans launched the first artificial satellite, Sputnik, in 1957, and there are now approximately 1,000 satellites, mostly in near-earth orbits, operating in the fields such as communications, weather, and global positioning. The brightest artificial object is the International Space Station (ISS) at an altitude of approximately 400 km, construction of which began in the 1980s. The radius of the Earth is approximately 6,400 km, so this is only 6% to 7%; a distance just skimming the surface when looking at the Earth as a whole. Most satellites orbit the Earth at low orbits like this, under 1,000 km. On the other hand, geostationary satellites orbit at 36,000 km above the equator. Beyond that is Earth's only natural satellite, the moon, at 380,000 km, or approximately ten times the distance of geostationary satellites. Beyond that is so-called deep space, studied by Hayabusa and other well-known spacecraft, and the closest planet, Venus, which is 42 million km at its nearest; 100 times farther than the moon. "Deep space" does not have a unique definition, but the International Telecommunication Union uses it to refer to the region beyond two million km, for the purposes of radio use. For communication with deep space, high-output transmitters and highly-sensitive receivers (large antennas, low noise) are needed to detect the electromagnetic energy as it attenuates in inverse proportion to the square of the distance.

From another perspective, there are now some 1,000 satellites operating compared to only one 60 years ago. Along with them, a well-known problem is the approximately 20,000 known pieces of space debris of a 10 cm or greater (rocket parts, decommissioned satellites, and fragments) and hundreds of thousands if smaller unknown objects are included. Ordinary laser radar is developed for space communication applications with satellites equipped with retroreflective mirrors, but when light strikes space debris, it is scattered. For this reason, high-power lasers and highly sensitive

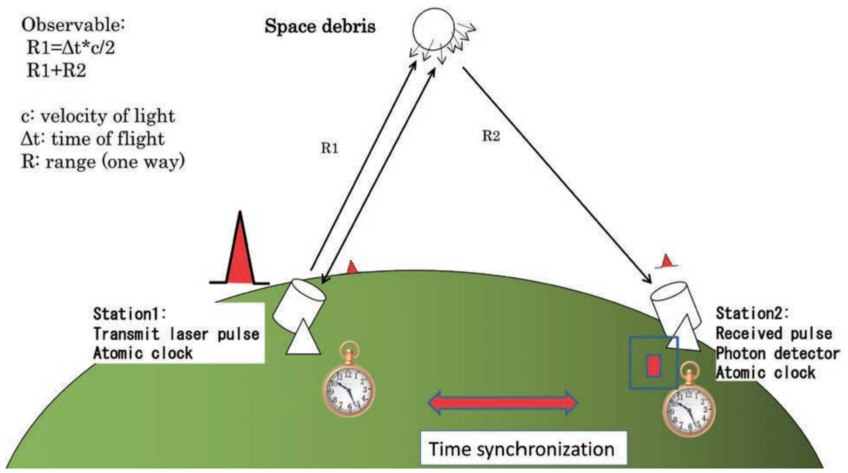


Figure 1 Highly-sensitive retroreflector communication test and satellite laser ranging (test concept)

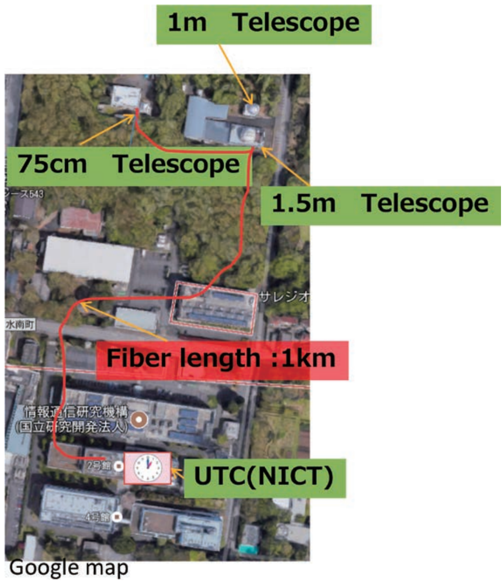


Figure 2 Locations of 1 m class telescopes at NICT Koganei station


Figure 3 1.5 m telescope satellite laser ranging

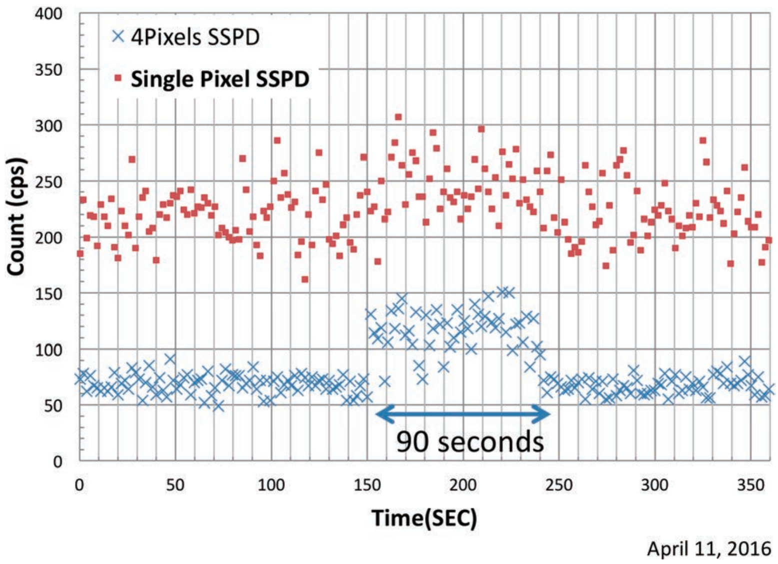


Figure 4 SOTA downlink signal received photon counts by SSPD

receivers are needed to identify space debris. An overview of our experiments is shown in Figure 1.

Optical ground stations

NICT operates several 1 m class telescopes as optical ground stations at NICT Headquarters (in Koganei) as shown in Figure 2. We have used 1.5 m and 75 cm telescopes to build a space debris observation system. A photograph of the satellite laser ranger using the 1.5 m telescope is shown in Figure 3. To transmit light pulses accurately toward moving satellites, it includes control equipment for the telescope gimbal with tracking accuracy of arcsecond precision, a high-output pulse laser (for nanosecond detection, 1 nano is 1 part in 1 billion), a pico-second laser (1 pico is 1 part in 1 trillion), a pulse position modulation (PPM) transceiver, and a single-photon detector.

The frequency used as a basis for measuring distance accurately (10 MHz) is obtained by optical fiber from UTC (NICT), which is maintained by NICT (Figure 2, a red line).

Establishing highly-sensitive links

NICT is promoting international collaboration tests in this field. The Space Environment Research Center (SERC) was established in Australia in 2014 as a joint government and private enterprise association to research the observation, prediction, and elimination of space debris. NICT used its laser ranging technology to establish an optical link with Japan's Hayabusa 2 satellite, which is currently travelling toward the asteroid belt, during its Earth swing-by in 2015, in a joint experiment with JAXA, the National Astronomical Observatory of Japan, and the Chiba Institute of Technology. In this experiment, the SERC system established an uplink over approximately six million km (JAXA Web: http://www.hayabusa2.jaxa.jp/topics/20151225_02_e/).

We are also operating ultra-sensitive detectors (superconducting nanowire single photon detectors (SSPD)) developed by NICT's Advanced ICT Research Institute in the 1.5 m optical ground station, and conducting research to detect the extremely weak retroreflected optical communication signals.

We have successfully received photon level signals from the SOTA low-earth-orbit satellite. The photon count from the SOTA satellite is shown in Figure 4. Of the two types of SSPD, we were only able to get a signal using the 4-pixel array SSPD. The communication and measurement system at the ground station is currently being upgraded to check the performance of the 4-pixel SSPD.

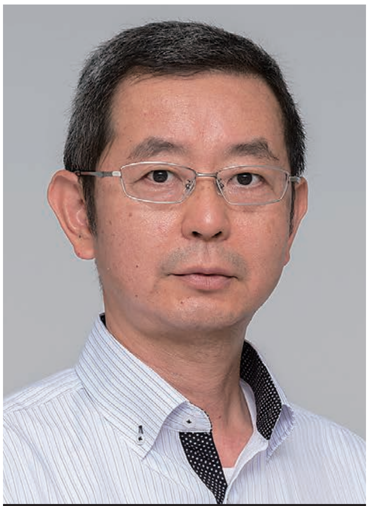
Future prospects

In order to increase the reception sensitivity of optical communications equipment on the next-phase engineering test satellite, which Japan is promoting for applications in ultra-sensitive communications methods, we are engaged in joint research with institutions in Australia, including SERC and the University of Western Australia as introduced in this article. We are sharing information on adaptive optics (AO) technology, which is able to compensate for atmospheric turbulence, an issue affecting both space debris observations and optical space communications.

Based on this, NICT is creating specifications for a system to measure atmospheric turbulence above NICT stations and developing other basic technologies for Japan's future space exploration missions, solving issues with deep space communication while gathering user requirements in deep-space investigation.

Environmental-data Collection System for Satellite-to-Ground Optical Communications

Verification of the Site Diversity Effect



Kenji SUZUKI
Senior Researcher
Space Communications Laboratory
Wireless Networks Research Center

Kenji SUZUKI joined the Ministry of Posts and Telecommunications Radio Research Laboratory (currently NICT) in 1983. Since then, he has engaged in research on satellite control technology, mobile satellite communication, the Multimedia Virtual Laboratory, development of JEM/ICS, research using small satellites, and research on optical and RF signal multi-feeder links. He received the Satellite Communications Research Awards in 2011, 2014, 2015, and 2016 from the Technical Committee on Satellite Communications of the IEICE.

It is expected that broadband satellite communication systems will use higher frequency radio waves (e.g. millimeter waves) or optical lasers for the feeder link from the geostationary data relay satellite to the ground station and for a direct downlink from the earth-observation satellite. However, millimeter waves and optical lasers are both susceptible to attenuation by rain and clouds, which can interfere with communications.

For optical satellite to ground communication, if site diversity is constructed among two or more ground stations connected with a terrestrial network (Figure 1), it can be assumed that a link should be establishable with one of the ground stations. Research on weather relevant to optical satellite communication, such as the extent of clear sky regions, includes analysis of digital weather instrument data from the "Himawari" weather satellite, AMeDAS, and other sources of the Japan Meteorological Agency. However, there has been no verification of the site diversity effect taking actual satellite orbits into account through on-site long-term acquisition, storage, and analysis of data such as the statistical distribution of clear sky regions, cloudage and cloud height. We therefore aim to establish the site diversity technique by statistically analyzing environmental data accumulated over a long period of time.

Environmental-data collection system

The Japanese map in Figure 2 shows the ten environmental-data collection station locations. This shows "Real-time environmental-data" in a browser page. We exhibit at-a-glance real time environmental-data experimentally. In this case, four out of ten stations are judged to be capable of optical communication. An example of a field installation of an environmental-data collection station is shown in Figure 3. It has a whole-sky camera and cloudage/ceilometer for measuring the amount and height of clouds, and various other weather sensors. The environmental data acquired by each environmental-data collection station are sent to the server at the center station via the network, stored in the database, statistically processed and analyzed.

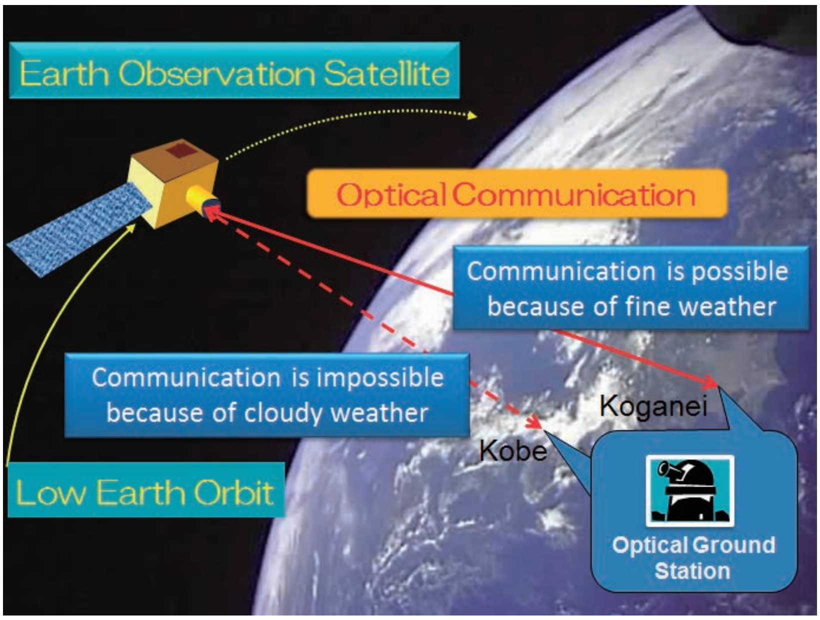


Figure 1　Site diversity image

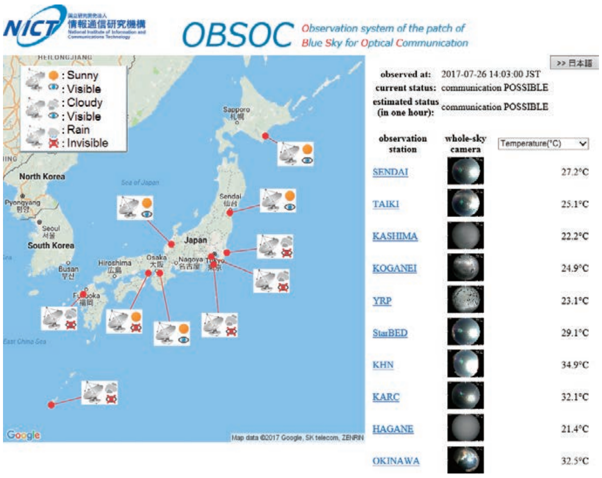


Figure 2 Real-time environmental-data display (http://sstg.nict.go.jp/OBSOC/?lang=e)

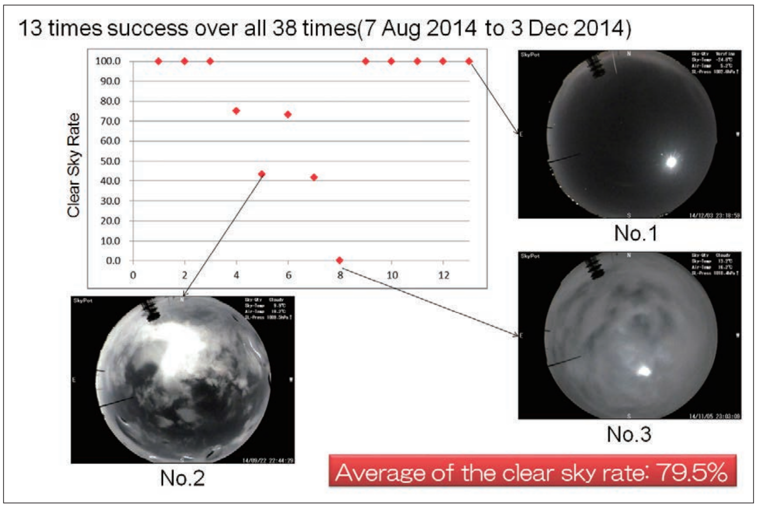


Figure 4 Clear sky judgment during a SOTA experiment —Success—

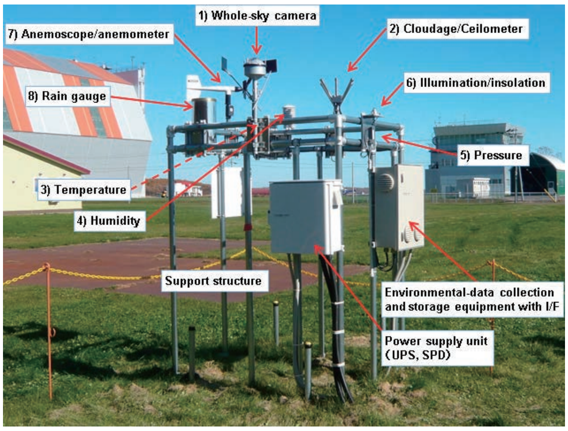


Figure 3 Environmental-data collection station (Taiki-cho Hokkaido)

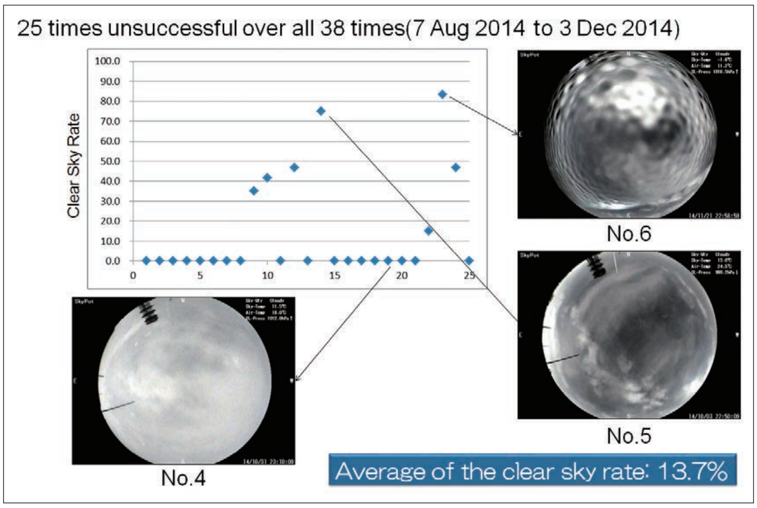


Figure 5 Clear sky judgment during a SOTA experiment —Unsuccessful—

Clear-sky rate analysis using environmental-data

Annual clear-sky rate (June 1, 2014 to May 31, 2015) from ten environmental-data collection stations, yielded good results of 56.8% in Kobe, 56.4% in Koganei, and 54.4% in Kashima, which were better than expected, and 45.3% in Hokuriku and 47.2% in Okinawa were not too bad. Hagane mountain in Kyushu was as low as 35.3%.

We compared the clear-sky rate calculated from environmental-data with whether the experiment using the SOTA* on the SOCRATES LEO small satellite was successful, or failed due to rain or cloudiness, during the period from August to December in 2014. The SOTA experiment was conducted 38 times. Figure 4 shows the clear-sky rates for 13 times that the optical beacons were received successfully from the satellite. For these cases, the average clear-sky rate was 79.5%. Whole-sky camera image No. 1 shows mostly clear sky. Image No. 2 has a clear-sky rate of 40%, with sparse clouds and some clear areas. The experiment was successful at times in this case. Image No. 3 shows thin cloud cover over the whole sky and the clear-sky rate was 0%, but the laser was able to penetrate it and the experiment was successful in some cases. For the 25 times that the SOTA experiment failed, the average clear-sky rate was 13.7% (Figure 5). In most cases, the whole sky was cloudy as in image No. 4, but there were also cases as shown in image No. 5, when the clear-sky rate was 75%, but the experiment failed due to thin clouds that prevented the laser from penetrating, and image No. 6, when the experiment failed due to being cloudy just after a rainfall, in spite of that having a clear-sky rate was 83.3%. Although there were variations as described above, the results showed the validity of the clear-sky rate.

Future plan —Validation of site diversity effect—

We plan to verify the correlation between the laser wavelengths used in free-space optical communication and environmental-data, to collect, store, and analyze environmental-data covering a period of at least three years to confirm the effectiveness of the site-diversity effect. (e.g. How many ground stations must be used in Japan to improve the site diversity effect?) As future satellite operation, to predict an optical ground station capable of optical satellite communication using environmental-data at time the satellite is passing and to consider algorithms for selecting the optimal ground stations.

＊ SOTA (Small Optical TrAnsponder)

Optical Observation System for Satellites Using Optical Telescopes

Supporting safe satellite operation and satellite communication experiment

Tetsuharu FUSE
Senior Researcher
Space Communications Laboratory
Wireless Networks Research Center

Completed his doctoral course in 1999. After working at the National Astronomical Observatory of Japan in Hawaii, Tetsuharu FUSE joined NICT in 2010. Engaged in R&D on optical communications equipment for the next-generation engineering test satellite and satellite optical ground station systems, based on orbital dynamics and optical observation technologies. Also a guest associate professor at the University of Electro-Communications. Ph.D. (Science).

The ability to understand the correct positions and precise orbits of artificial satellites is a fundamental technology for safe satellite operation and for satellite communication experiments.

We have attached ultra-sensitive cameras to optical telescopes at NICT Headquarters (Koganei City, Tokyo) as well as to those at the Kashima Space Technology Center (hereinafter, Kashima Center), Wireless Networks Research Center, and after photographing artificial satellites together with the background stars, we measure the position of the satellite from the image data, developing technology that determines the motion of the satellite in an Earth orbit. The know-how gained will also be useful in future development of satellite optical ground stations.

Background

Since the 1990s, Kashima Center has been conducting optical observations of satellites using two wide-field 35 cm optical telescopes (Figure 1). When installed, the telescope system was specialized for geostationary satellites, which do not appear to move when viewed from the ground, so it was not capable of observing satellites in low-Earth-orbit (LEO), which appear to move very quickly. This telescope system was damaged in the Great East Japan Earthquake that occurred in March 2011, so in 2011 the telescope mounts were replaced along with other improvements such as CCD cameras and a refurbished control system capable of capturing LEO satellites in addition to geostationary satellites, so it can now make observations of all satellites.

Figure 1 Two domes on the roof of the research main building

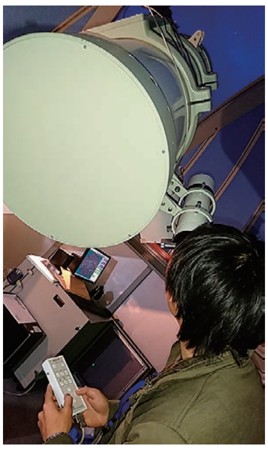


Figure 2 Preparing for observations

Photographing geostationary satellites

The ultra-sensitive CCD camera in the new observation system has a control system that uses a GPS-synchronized rubidium-clock frequency generator and the camera shutter speed is designed to measure capture timing with 30 microsecond accuracy. Using this camera combined with the wide-field telescopes, the field of view is six times of the full moon, or 1.6 degrees horizontally and 1.1 degrees vertically can be captured at once (Figure 2).

For geostationary satellites, the telescope is aimed at the satellite and held still to capture the image. In this state, the fixed stars appear to move due to the rotation of the Earth, and appear as lines with length that is dependent on the exposure time. Conversely, geostationary satellites move with the same angular speed as the Earth's rotation, as their name implies, so they are stationary with respect to the ground stars and appear as points in the image.

Figure 3 is an image taken with the telescope aimed toward Kizuna (Wideband InterNetworking engineering test and Demonstration Satellite; WINDS), showing Kizuna in the lower-right of the image. The other point image appearing in the upper-left was identified as CHINASAT 5A (China) after measuring its position relative to the background fixed stars and consulting a database.

Each satellite operator knows the positions of their satellites from radio measurements, but must rely on information from other countries to know the state of neighboring other satellites and space debris (rocket bodies, decommissioned satellites, etc.). Our observation system has been recognized as useful for the safe operation of satellites in geostationary orbit, which is quite congested, and for protecting satellites from approaching or colliding with space debris.

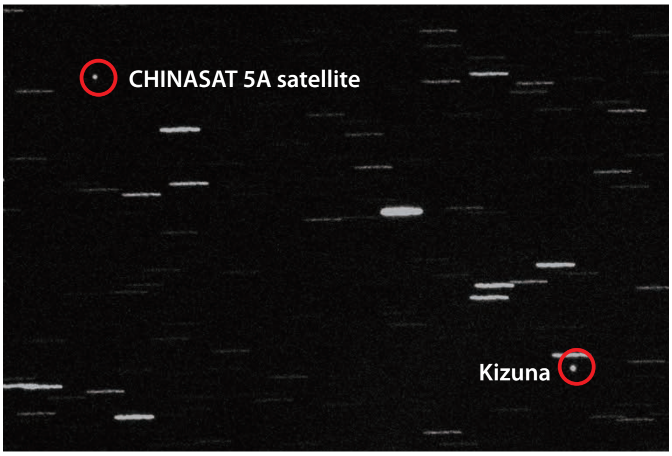


Figure 3　Kizuna (lower right) and CHINASAT 5A (upper left) satellites

Figure 4　Fast moving ISS

Figure 5　Portable 25 cm telescope

Figure 6　Portable telescope observation system not using any special devices. (Using a smartphone to photograph the screen of the PC to record the experimental process.)

Photographing low-Earth-orbit satellites

When the telescope is in sidereal tracking mode to follow the motion of the fixed stars, these stars appear as points. For example, aiming the telescope where the International Space Station (ISS) is predicted to be in the night sky, based on information provided by JAXA, and taking a photograph while tracking the fixed stars produces an image like that in Figure 4. The publicly available information is not highly accurate, but with the wide field of view of this system, the satellites generally fall within the field of view even when position information is not accurate. The system is able to provide orbit data of higher precision than the location data provided. It has received attention from satellite and rocket developers and operators, and we have had many visitors come to see the system.

NICT Headquarters' portable system

The Kashima Center telescope system cannot be moved, but we plan to use the 25 cm telescope mounted with the 1.5 m telescope at NICT Headquarters, together with a digital SLR camera as a portable observation system in the future. We are modifying the SLR camera, including removing the internal infrared filter, which will enable us to photograph satellites that do optical communication using infrared light.

Figure 6 is a photograph of using the portable telescope for trial observations of the SOCRATES microsatellite communicating optically with the 1 m aperture telescope at NICT Headquarters. The camera can be controlled remotely from a notebook PC in the control room. The SOCRATES satellite is in a high-speed low-Earth orbit, so we captured the communication light emitted by the satellite while having the 1.5 m telescope track the fixed stars and using it as a mount.

In the future, we intend to switch to a camera with higher time precision, to create a highly anticipated portable system capable of capturing satellite orbits with high precision.

Future prospects

The satellite observation technology that we have accumulated is broadly applicable, beyond our current activities in safe satellite operation and supporting satellite communication experiments. This know-how can be applied directly to Space Situational Awareness (SSA) systems, which urgently need consolidation throughout the world. It is also useful for knowing the state of the orbits of satellites to be launched in the future, and there are plans to use it as an observation technology for developing satellite optical ground stations for optical communications.

Development of "HICALI"

Ultra-high-speed optical satellite communication between a geosynchronous satellite and the ground

Toshihiro KUBO-OKA
Research Manager
Space Communications Laboratory
Wireless Networks Research Center

After completing graduate school, Toshihiro KUBO-OKA worked as a special researcher for the Japan Science and Technology Agency (assigned to the Ocean Research Laboratory, Hydrographic Department, Maritime Safety Agency) and then joined the Communications Research Laboratory (currently NICT) in 2000. He has been engaged in research on artificial satellite optical observation and orbit determination, and also on optical satellite communications since 2015. Ph.D. (Science).

The Space Communications Laboratory is developing communications devices to be installed on the next engineering test satellite scheduled to be launched into geosynchronous orbit in 2021. This satellite will feature a hybrid communications system using two types of electromagnetic waves: Ka-band radio and laser light. This article introduces the objectives for optical satellite communications and the state of development of devices to be used on the next-phase engineering test satellite.

Satellite communication using light

NICT has been conducting research on optical satellite communications using lasers since the 1980s. The Kiku 6 satellite launched in 1994 achieved the first ever bidirectional optical communication between an artificial satellite and the ground, and Kirari (OICETS), launched in 2005, conducted the first ever laser communication tests (at transmission rates of 10 Mbps) between the ground and a low-earth-orbit satellite (Figure 1). The Space Optical Communications Research Advanced Technology Satellite (SOCRATES), launched in 2014, was a 50 kg-class micro-satellite carrying the Small Optical TrAnsponder (SOTA), which was used mainly to conduct communication tests with ground stations of NICT Headquarters (Koganei City, Tokyo) and also those in Okinawa and Kashima. This was the first time optical satellite communications tests that were done between a microsatellite and a ground station.

Based on these experiments, the next-phase engineering test satellite to be launched in 2021 will demonstrate an ultra-high-speed optical communications system capable of the highest level optical data transmission, with 10 Gbps speeds on both uplink and downlink between ground-stations and geosynchronous orbit 36,000 km above the equator. It will also establish basic technologies for optical feeder links. The optical communications equipment on this next-phase engineering test satellite is called High Speed Communication with Advanced Laser Instrument (HICALI) (Figure 2).

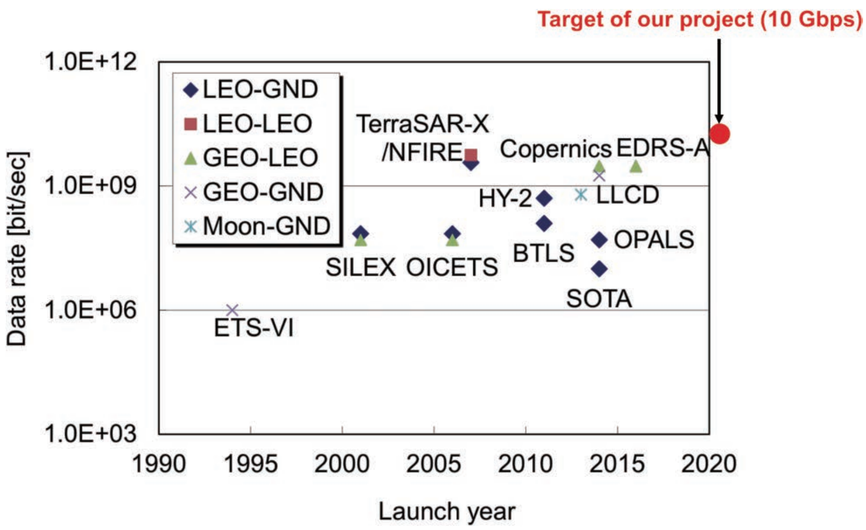


Figure 1　Increasing transmission speeds in optical satellite communications

On-board equipment

HICALI is composed of optical components that process transmitted and received signals, data converters for connecting with radio communications devices, a telescope for transmitting and receiving laser light, and coarse and fine pointing mechanisms to aim it at the target on the ground. Current plans specify use of infrared laser light of wavelength 1.5 µm for HICALI. This wavelength region is widely used for terrestrial optical fiber, so high-speed devices, equipment, and formats used in terrestrial optical communications networks can also be used for space optical communications. However, devices that can be used for 10 Gbps-class ultra-high-speed optical communications have not yet been developed or tested in space. As such, devices used on earth will be used, but they must be made to operate over long periods of time without failing under radiation and other harsh conditions in space. We plan to establish a screening process to ensure the environmental tolerance and reliability in space, of the primary optical communication devices, and to use devices that can be guaranteed to be reliable. A multiple wavelength laser will be used so that Wavelength Division Multiplexing (WDM), which is used for high-speed communication on terrestrial optical fiber, can also be demonstrat-

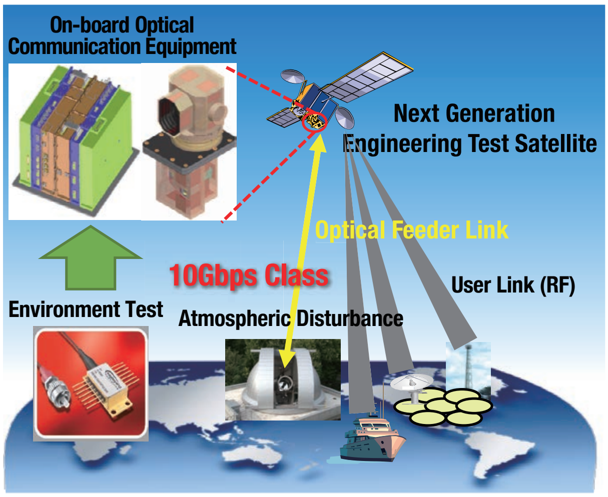


Figure 2 Overview of optical satellite communication testing in the next-generation engineering test satellite project

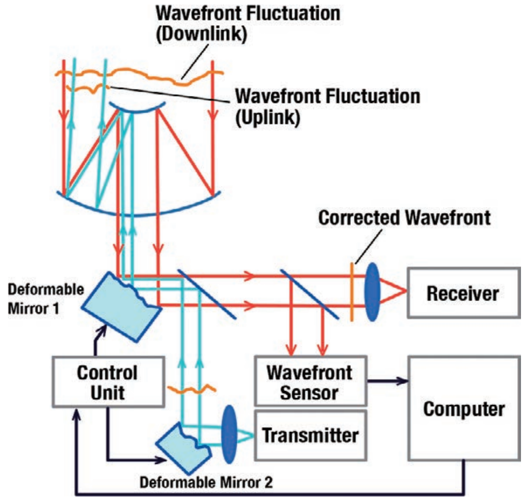


Figure 3 Adaptive optics (AO) system for uplink/downlink bidirectional optical signals

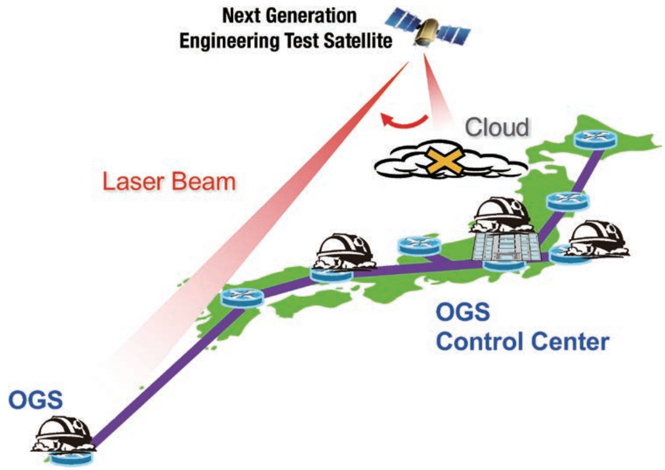


Figure 4 Overview of site diversity for optical communication between satellite and ground stations

ed for communication between satellite and the ground.

Technical issues with the Earth station

Optical satellite communication between geosynchronous satellites and the ground are susceptible to the intermittent effects of weather, when clouds in the direction of the satellite obstruct the light and stop communication. In astronomy, the effects of variation in the atmosphere are reduced using adaptive optics (AO) technology, in which distortions in the images of a star are measured with a wavefront sensor such as a Shack-Hartmann sensor,*1 and variable mirrors are adjusted to compensate for the distortion. However, optical satellite communication also requires compensation for aberration*2 due to the motion of the satellite, so AO systems used for astronomy cannot be used as-is. We are currently developing an AO system to correct light aberration that can be used for optical communication (Figure 3). Also, in contrast with astronomy, which requires compensation for atmospheric effects on light from space, optical satellite communication is bi-directional, so atmospheric effects on the uplink, emitted from the ground toward the satellite, must also be reduced. For the latter, we have proposed a wavefront compensation method that performs sensing at the receiver aperture, which is larger than the wavefront transmission aperture, and estimates the wavefront on a different propagation path (patent application submitted in January 2017).

On another front, we also plan to demonstrate a site diversity scheme to avoid the effects of clouds (See P6-7 in this issue), which uses equipment including all-sky cameras and nephometers installed in ten locations throughout Japan to gather environmental data. These data are used to predict which areas are clear and can be used for optical communications, and ground stations at these locations are used for optical communication, which is aimed at demonstrating site diversity (Figure 4).

Future developments

The optical feeder link to be tested on HICALI has potential in the future to replace radio feeder links, which are reaching bandwidth limits as communication volumes increase. Currently, the Consultative Committee for Space Data Systems (CCSDS), which works on standardization in the space data systems field, is holding discussions on standard formats for space data communication and conversion within satellites, between satellites and ground stations, and between deep space and ground stations. This study group is discussing laser wavelengths, communication methods, encoding technologies, and other aspects.

Development of HICALI will be used for standard technologies and to advance proposals in the standardization discussion, keeping in mind the goal of developing systems that will be used widely in the future.

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*1 Shack-Hartmann sensor
A device with a micro-lens array placed in front of a device capable of high-speed image capture. Used for high-speed measurement of the shape and intensity distribution of a light wavefront.

*2 Aberration (of light)
A phenomenon whereby light direction appears to shift when the observer is moving relative to the object from which the light emanated.

Live Electrooptic Imaging (LEI) Camera

— Real-time visual comprehension of invisible electromagnetic waves —

Radio waves and electromagnetic fields are everywhere around us, but invisible to human eyes. Equipment named Live Electrooptic Imaging (LEI) camera was invented in NICT, by which electric field distribution and its dynamical behaviors in the GHz range are visualized as video images in real time. Intuitional understanding is thus available by the LEI camera technique regarding the behaviors of radio waves emitted from an antenna as well as electric signals propagating around in an electric circuit.

■ Technical overview and application fields

An exterior of the first LEI camera setup is shown in Figure 1a. The black part in the front contains the down-facing observation window having an electrooptic (EO) crystal plate. Figure 1b indicates a schematic of its electrical and optical configurations together with a visualization example: radio waves emitted from a commercially available Bluetooth module. Here, the EO effect providing an ultra-fast feature, where the local refractive index of the EO crystal plate is modified by the electric field of the emitted radio waves, is combined with a high-speed CMOS image sensor providing an ultra-parallel feature.

Figure 2 shows stroboscopic image series thus taken for the radio waves, indicating clearly that the emission originates from a limited portion of a chip antenna (Figure 1c) mounted on the module (the corresponding video is available at http://lei-camera.nict.go.jp/). The detailed radio wave behavior is thus apparently indicated. The latest LEI camera technique is applicable to radio waves and electromagnetic fields up to 100 GHz, which is higher than frequencies of automobile millimeter-wave radar, and its spatial resolution has reached the micron range (See https://www.nature.com/articles/s41598-017-08442-8 for details).

Conventional techniques visualizing invisibles around us such as microscopes, telescopes, and infrared cameras have led to tremendous ranges of applications, and, therefore, the LEI evolution for the invisible high-frequency electric fields seems likely in the similar sense. Its uses and applications will be numerous, spanning all fields that handle electricity, and may include new fields not yet even conceivable.

■ Quest for uses, applications, and collaboration partners

Some currently assumed uses and applications of the LEI technique include operation analysis of prototype electronic circuit boards, test IC chips, and prototype antennas, diagnosis of electronic device faults, and anti-noise measures in high-frequency circuits. Visual observation based on real-time videos for those is so effective and efficient that it should provide the benefit of significantly reducing work time.

For further information, please contact our office at ippo@ml.nict.go.jp as shown below.

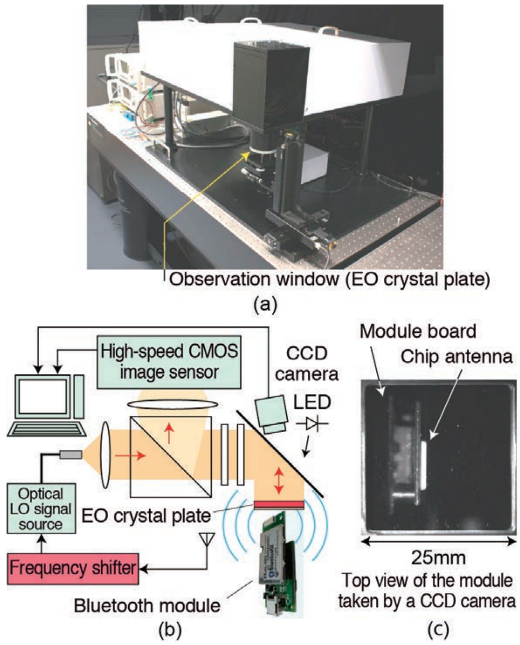

Figure 1 Exterior of the first live electrooptic imaging camera (a), its electrical and optical configurations (b), a mounted chip antenna (c)

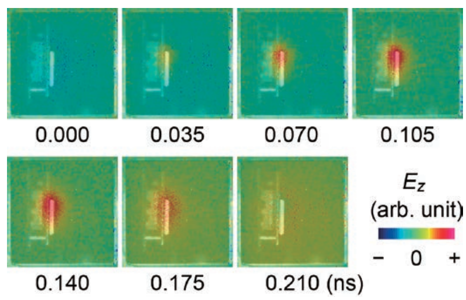

Figure 2 Stroboscopic expression of visualized radio-wave emission superimposed on the optical image (Figure 1c)

<Patent information>

Publication No.: Patent Pub 2017-156248

Name of invention: Electric field imaging equipment

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Awards

The IPSJ Best Paper Award was established in 1970 to commemorate ten years since the inauguration of the Information Processing Society of Japan. It is awarded to authors with particularly excellent published journal papers (among 591 papers published in FY2016).

Information Processing Society of Japan

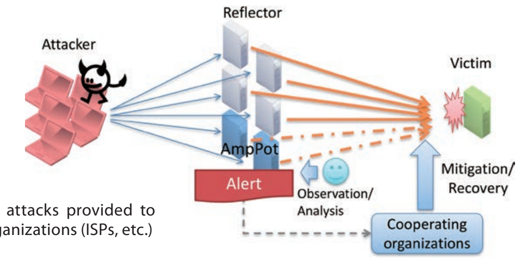
IPSJ Best Paper Award (2016)

"DRDoS Attack Alert System for Early Incident Response"

Overview

In joint research with Yokohama National University and Saarland University in Germany, the NICT Cybersecurity Research Institute has developed the AmpPot system to quickly detect and observe distributed reflection denial of service (DRDoS) attacks, which abuse DNS, NTP, and other servers on the Internet to amplify traffic, and with this system has proposed a DRDoS attack alert system for early response and verified its effectiveness.

The paper reporting these research results, "DRDoS Attack Alert System for Early Incident Response," was awarded the IPSJ Best Paper Award for 2016.



Alerts of DRDoS attacks provided to collaborating organizations (ISPs, etc.)

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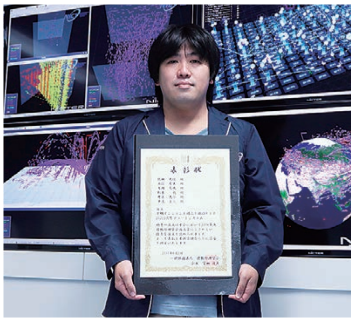


Researcher Daisuke MAKITA, lead author

Comment from the Recipients

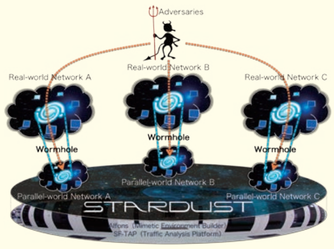
This paper proposes a system that gives notification when a type of DoS attack called a DRDoS attack occurs, and describes how it was shown to be effective through actually building and operating the system. We are very proud to receive such an honor from the IPSJ for this paper. We would also like to offer sincere thanks to those who supported us in receiving this award.

data

- Date: June 2, 2017
- Description: In recognition of "DRDoS Attack Alert System for Early Incident Response" as an excellent paper worthy of the IPSJ Best Paper Award (2016).
- Co-recipient: Tomomi NISHIZOE (NTT Communications Corporation), Katsunari YOSHIOKA (Associate Professor, Graduate School of Environment and Information Sciences, Yokohama National University / Institute of Advanced Sciences, Yokohama National University), Tsutomu MATSUMOTO (Professor, Graduate School of Environment and Information Sciences, Yokohama National University / Institute of Advanced Sciences, Yokohama National University)

Development of the “STARDUST” Cyber-attack Enticement Platform

By carefully imitating the organization of a government or enterprise in a "parallel network" to attract attackers, and then stealthily observing the attack behavior over long periods of time, STARDUST provides real-time understanding of detailed behavior of attackers after they have penetrated an organization, which has conventionally been difficult to collect.



■STARDUST steals the show at Interop Tokyo 2017

In cyberattacks targeting government or enterprise organizations, malware is often introduced by email attachment or other means, but handling them has been limited to analyzing the malware after the damage is done, which only yielded information regarding the initial intrusion.

As a countermeasure for targeted attacks, the NICT Cybersecurity Research Institute has developed a cyberattack enticement platform called STARDUST, which carefully imitates the organization of a government or enterprise in a "parallel network" to attract attackers, and then observes (stealthily) the attack behavior over long periods of time such that the attacker cannot sense the observation. This can provide real-time understanding of detailed attack behavior after the organization has been penetrated, which has conventionally been difficult to collect. The parallel network can be built in several hours, and includes various servers holding data that imitates an organization's information resources as well as several hundred operating PCs, so the system behaves much like a real organization. A dynamic exhibit was operated at Interop Tokyo 2017, with multiple media showing STARDUST in operation.

STARDUST is a research platform that produces its own real data set, so development is ongoing to improve aspects, such as its stealthiness in observing attackers, while it is also being used in efforts to establish technology for identifying attackers and sources of attacks in collaboration with industry and security organizations.

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