Terrestrial Free-Space Optical Communications Network Testbed: INNOVA

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***Abstract*— It is rather important to research on the influence of terrestrial weather conditions for free-space laser communications. The site diversity is one of the solutions, where several ground stations are used. The National Institute of Information and Communications Technology (NICT) is developing a terrestrial free-space optical communications network for future airborne and satellite-based optical communications testbed called IN-orbit and Networked Optical Ground Stations Experimental Verification Advanced Testbed (INNOVA). Several optical ground stations and environmental monitoring stations around Japan will be presented.**

Keywords- free-space laser communications; satellite communications; optical communications; optical ground station; scintillation; atmospheric turbulence; low Earth orbit; site diversity.

I. INTRODUCTION

Recently, remarkable advances have been made in communications using optical and laser technologies such as optical fiber, bringing us into an era where communications between space-based devices using light waves instead of radio waves is becoming practical. Space-based optical communications is characterized by extremely high carrier frequencies, and communications devices can easily be made smaller, lighter, faster, and higher capacity. Spectrum resources can also be freely developed without restriction due to laws and regulations, so such applications hold higher promise for the future than do radio-based solutions [1]. In particular, in light of the ever-increasing need for transmission of huge amounts of data from earth observation satellites [2], the development of systems for high-speed data transmission between low-orbit satellites and terrestrial sites is considered as the first step in establishing powerful communications systems for the future [3]. However, the influence of terrestrial weather conditions remains as a problem to be solved. One potential solution is site diversity, where several ground stations are used [4]. In such systems that implement a direct, high-speed optical link, communications links for transmission of data from satellites to terrestrial sites must be established even in the presence of clouds and rain, making real-time monitoring and prediction of weather conditions another important technology.

At NICT, we are working on experimental demonstrations of a terrestrial free-space optical communications network that will allow high-speed data transmission in future airborne and satellite-based optical communications projects. Specifically, we are investigating site diversity techniques by which communications failures due to bad weather and the like are handled through channel switches among other sites in the ground station network, to allow for continued data transmission and a network environment that uses fade-resistant communications protocols for spatial transmission. We hope that this work will lead to in-space demonstration testing of optical communications with microsatellites, and that such demonstrations can be performed along with users both domestically and abroad.

This paper is organized as follows. An overview of INNOVA is presented in Section 2. In Section 3, the verification of the technology is described, and the terrestrial free-space optical communications network and monitoring stations around Japan for free-space optical communications are introduced. The contributions to standardization are mentioned in Section 4.

II. OVERVIEW OF INNOVA

Figure 1 shows an overview of the terrestrial free-space optical communications network called INNOVA[5], which will be used to verify optical communications technologies for high-speed transmission of data from aerial and satellite-based observation. Specifically, we will investigate site diversity techniques by which communications failures due to bad weather and the like are handled through channel switches among other sites in the ground station network to allow for continued data transmission, as well as a network environment that uses fading-resistant communications protocols for free-space communications. We hope that this will lead to in-space demonstration testing of optical communications with small satellites, and that such demonstrations can be performed with users both domestically and abroad.

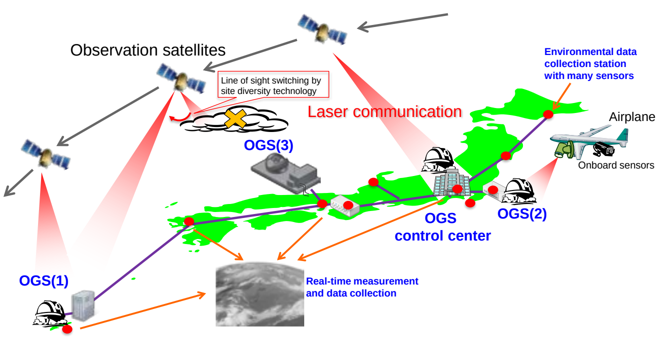


Fig. 1 Overview of INNOVA.

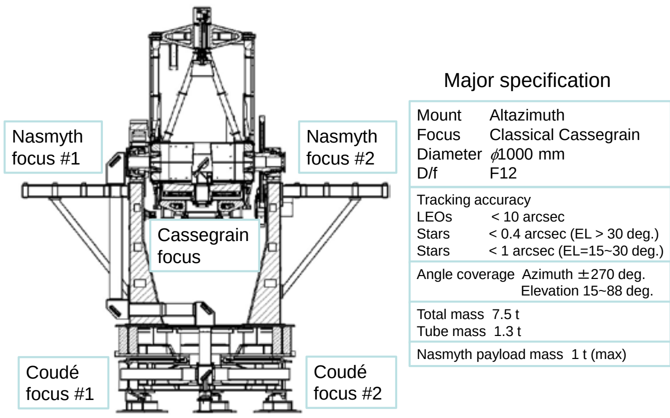


Fig. 2 Specifications of 1-m aperture telescope.

III. Verification of Technologies

A. *Verification of ground station networking technologies for small satellites*

NICT developed a small optical transponder called SOTA for use on microsatellites with mass of around 50 kg [4,6,7], and we are investigating space-based demonstration testing. We plan to use a terrestrial free-space optical communications network with telescopes distributed throughout Japan to verify site diversity techniques. The telescopes used in this test are large, with around 1 m primary mirror apertures (Fig. 2). A notable feature is that these telescopes are linked together to form a wired terrestrial network via multiple free-space optical communications devices, allowing remote control of the ground stations from an optical ground station control center (Figs. 3 and 4). We are also investigating development of a simulator that uses NICT atmospheric models to simulate atmospheric distortions of the laser propagation pathway, thus allowing testing even when the satellites are not in orbit. Insertion into the propagation pathway of large telescopes should allow evaluation of optical signal transmission quality features such as fading resistance [8]. Figure 5 shows an example configuration; the simulator will be installed in each optical ground station.

In the future we hope to work on further experiments alongside universities and other microsatellite users, such as Shinshu University's ShindaiSat project for LED visible light communications [9], and the Hodoyoshi project [10]. We are also investigating the possibility of working with space agencies, for example in cooperative testing of optical ground stations as part of as NASA's future planned demonstrations [11]. Japan could possibly play a role in supporting optical ground stations for international space agencies, should such support be requested.

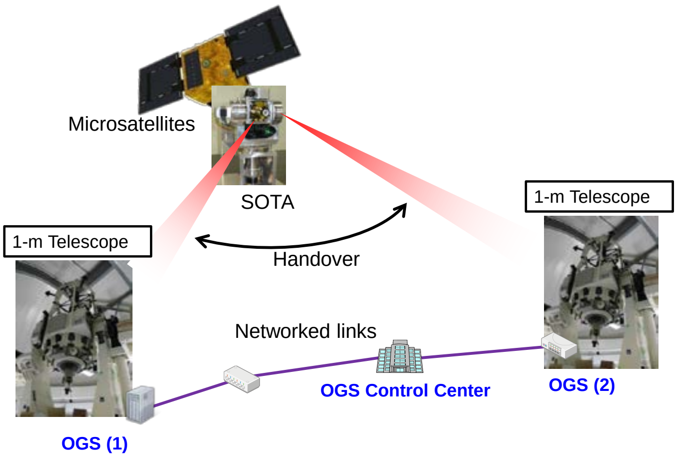


Fig. 3 Image of handover of the optical channel.

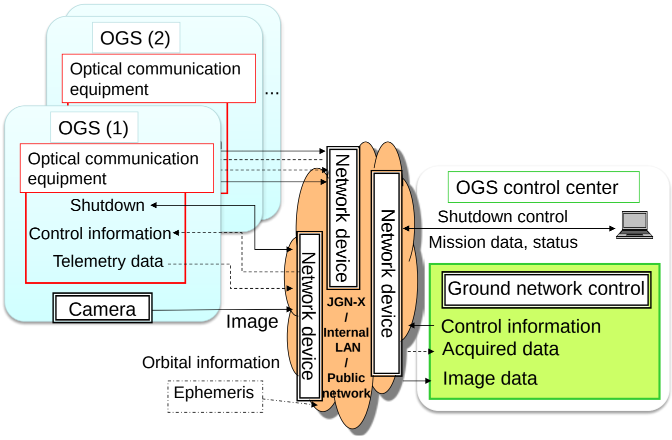


Fig. 4 Example structure of ground station network control.

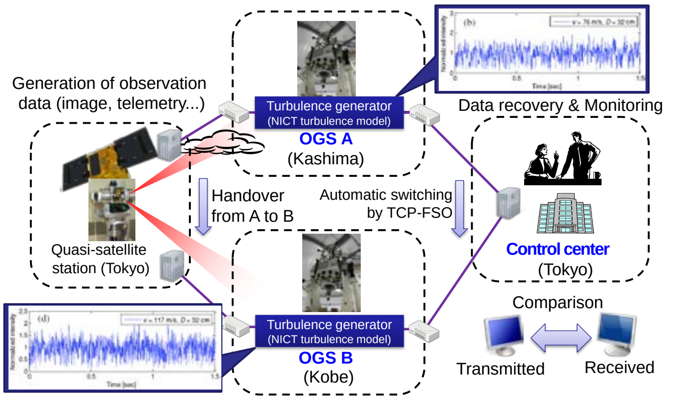
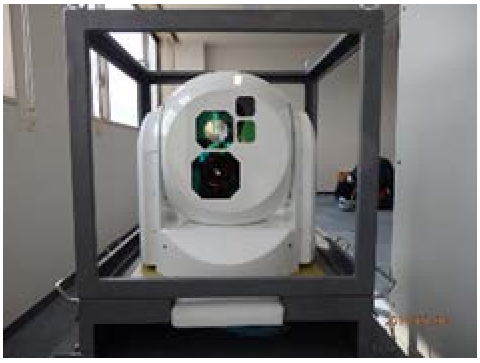


Fig. 5 Example structure of free-space optical communications simulator.

(a) Container

(b) Container when the dome is open



(c) External view of the aircraft laser communication terminal

Fig. 6 Examples of the laser communication systems for aircraft.

B. Technological demonstrations of optical communications with aircraft

In private-sector applications using aircraft-based imaging data, for example measurement-taking after a natural disaster, data acquisition is time-consuming because transfer must occur after the plane has landed. This has created a strong demand for methods of data transfer directly to the ground. To meet such demands, we are investigating small-scale free-space optical communications equipment with primary mirrors of approximately 10 cm aperture, making them applicable to optical communications with aircraft. This device is characterized by being a free-space optical communications device installed in a container and capable of demonstrating optical communications with an aircraft (Fig. 6). Optical communications experiments involving data transfer rates of around 40 Gbps are possible, and we are investigating the use of adaptive optics. We hope to team up with user organizations that require aircraft-based high-speed communications to perform demonstration experiments with them.

C. Verification of data collection and site selection optimization for site diversity

We are investigating a device for environmental data collection and transmission (Fig. 7) to be used in collecting optical ground station climate data such as cloud cover and utilization rate that will be required for site diversity. We are also investigating the construction of an environment that collects data from sensors installed at approximately 10 appropriate locations throughout Japan as shown in Fig. 8. The initial need is to demonstrate the correlation between weather data and the laser wavelengths used by free-space optical communications devices for collection, storage, and transmission of data from all-sky cameras. In the future, we hope to expand our understanding of how to process such real-time sensor information to select the ground station best suited to free-space optical communications, based on predictions of clear weather zones during satellite visibility periods, in conjunction with smart grids and other sensor systems.

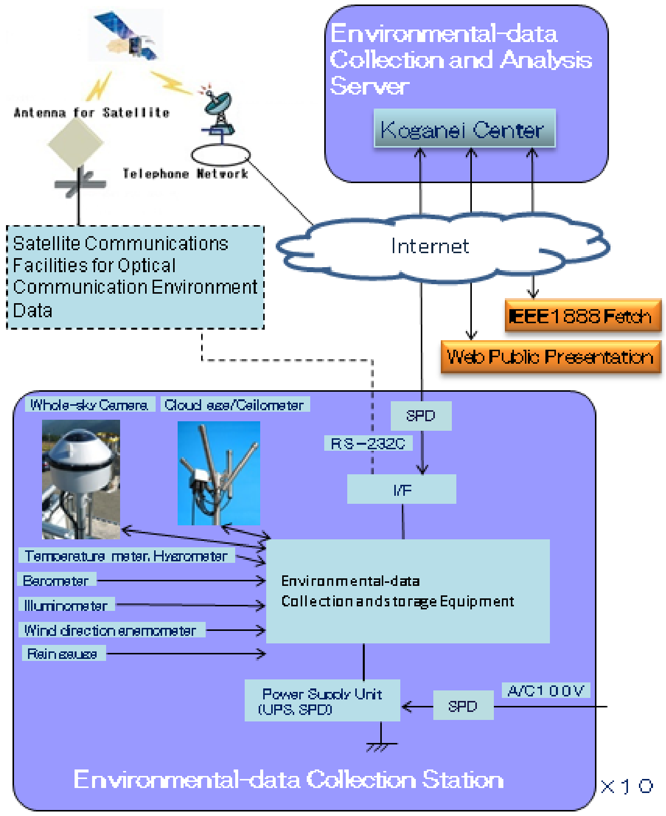


Fig. 7 Example structure of device for optical communications environmental data collection and transmission.

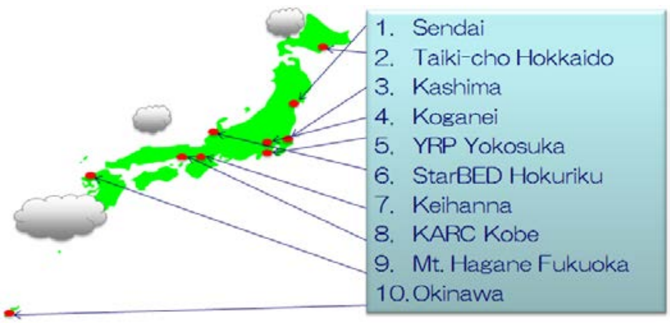


Fig. 8 Installed locations of the sensor stations throughout Japan.

D. Verification of free-space quantum communications with photon-counting technologies

NICT has the capability to fabricate a superconducting single-photon detector (SSPD) in house. A photon-counting communication system that uses an SSPD is being developed. Pulse position modulation (PPM) is being considered as a method to achieve very high sensitivity customized to SSPD. Photon-counting technologies, adapted to free-space laser communications, will be verified and future research collaboration with domestic and international partners is expected, which contributes to the deep space communications. An unmanned aerial vehicle (UAV) will be used for the verification of the laser communication terminals that have photon-counting technologies as shown in Fig. 9.

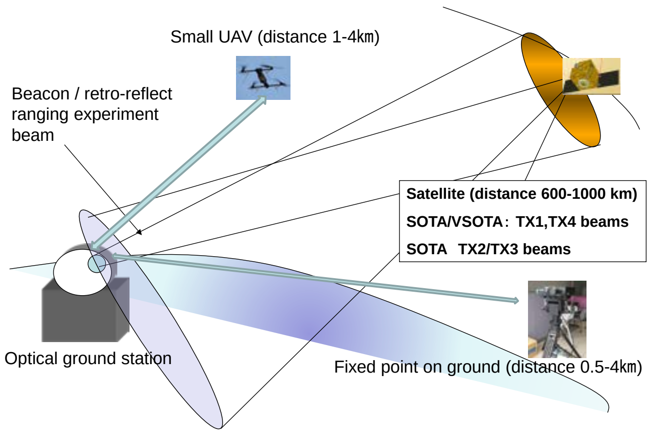


Fig. 9 Configuration example of free-space quantum communication experiments with photon counting.

IV. Contributions to Standardization

The technological demonstration of the optical ground station network introduced in this paper is an unprecedented task, and one that we believe will become a core presence in the field of free-space optical communications. It is now possible to perform the world's first technological demonstration of site diversity technologies. Currently, the Consultative Committee for Space Data Systems (CCSDS) is working toward the standardization of optical communications in space, regarding issues such as link budgets, atmospheric models, handovers as well as concepts of operations, optical communications for low and high signal photon fluxes, and real-time weather and atmospheric characterization data. NICT is now in charge of assembling a green book on real-time weather and atmospheric characterization data as one of the space agencies contributing in the CCSDS meeting. We hope that the technological demonstrations introduced in this paper will contribute to the standardization of such technical issues.

V. CONCLUSIONS

We introduced the terrestrial free-space optical communications network facility: INNOVA. These technologies will make possible high-speed transfer of data from satellites and aircraft performing observations and other tasks. The use of site diversity technologies and multiple optical ground stations should allow continuous data transmission even after interruption of communications, for example due to poor weather, by handing over communications channels. Use of a network environment employing a communications protocol that is fading-resistant in free-space transmission will lead to the provision of stable communications. We hope that this work will lead to in-space technology demonstrations of optical communications with microsatellites, and increased cooperation between users both domestically and abroad.

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