

Conceptual Design of NICT's Optical Ground Station System for a Japanese LEO Satellites Constellation Project, LAIDEN

Yasushi Munemasa^{*a}, Kenta Sakabe^a, Hideki Takami^a, Alberto Carrasco-Casado^a, Takayuki Usami^a, Jun-ichi Nakazono^a, Koichi Shiratama^a, Dimitor R. Kolev^a, Hideaki Suganuma^a, Yoshihiko Saito^a, Toshihiro Kubo-oka^a, and Hiroyuki Tsuji^a

^a Wireless Networks Research Center, National Institute of Information and Communications Technology (NICT), 4-2-1, Nukui-kitamachi, Koganei-city, TOKYO, 184-8795, Japan

ABSTRACT

The National Institute of Information and Communications Technology (NICT) in Japan has over 40 years of experience in R&D of laser communications with missions such as ETS-VI (Engineering Test Satellite VI), OICETS (Optical Inter-orbit Communications Engineering Test Satellite), SOCRATES/SOTA, JAXA's LUCAS (Laser Utilizing Communication System) project, "HICALI" (High speed Communication with Advanced Laser Instrument) on ETS-9 (Engineering Test Satellite 9) project and so on. Through these projects, we have been R&D of "site diversity" idea for extend the time of available laser communication between space (satellite) with the OGS in temperate monsoon climate zones such as East Asia area and Japan, whose weather are fluctuated. To increasing the reliability of the network, we were constructing multiple OGS sites in Japan with LEO satellites correlation for laser communications.

From 2023, we involved in a Japanese LEO satellites constellation project, LAIDEN project, which is the national project managed by NEDO (New Energy and Industrial Technology Development Organization) for Japanese LEO Optical Communication Network System development and demonstration, which called as K-program (Key and Advanced Technology R&D through Cross Community Collaboration Program).

In this paper, we describe result of conceptual design of NICT's optical ground station system for the LEO Satellites Constellation Project.

Keywords: Optical Ground Station, LEO satellites constellation, site diversity, LAIDEN

1. INTRODUCTION

Recently, satellite broadband communication services between the satellites and the terrestrial networks using RF (Radio Frequency) band are emerging all over the world, some requiring capacities are increasing rapidly year by year. However, with the radio bandwidth resources becoming exhausted, high-speed optical communications can be used instead to achieve ultra-broadband communications. Therefore, in the inter-satellites of the LEO satellites constellation networks, the laser communication system with very low interference among the other systems are becoming popular instead of the communication by RF networks. However, the communication capacity of the satellite networks and the TN (Terrestrial Network), such as a feeder link system are still the communication by RF, which is becoming a large obstacle to realize the NTN (Non-Terrestrial Network) systems, such as the Beyond 5G or 6G networks aims [1].

The National Institute of Information and Communications Technology (NICT) in Japan has over 40 years of experience in R&D of laser communications with missions such as ETS-VI (Engineering Test Satellite VI), OICETS (Optical Inter-orbit Communications Engineering Test Satellite), SOCRATES/SOTA, JAXA's LUCAS (Laser Utilizing Communication System) project, "HICALI" (High speed Communication with Advanced Laser Instrument) on ETS-9 (Engineering Test Satellite 9) project and so on. Through these projects, we have been R&D of "site diversity" idea for extending the time of available laser communication between space (satellite) with the OGS in temperate monsoon climate zones such as East Asia area and Japan, whose weather are fluctuated. To increasing the reliability of the network, we were constructing multiple OGS sites in Japan with LEO satellites correlation for laser communications.

^{*}y.munemasa@nict.go.jp; phone +81-42-327-6497; fax +81-42-327-6825; www2.nict.go.jp/wireless/en/

From 2023, we involved in a Japanese LEO satellites constellation project called LAIDEN (LASer Inter-satellite DEMonstration Network), of which founded by Japanese government the national project managed by NEDO (New Energy and Industrial Technology Development Organization) for “Japanese Inter-satellite LEO Optical Communication Network System development and demonstration” called as K-program (Key and Advanced Technology R&D through Cross Community Collaboration Program).

In this paper, we describe result of conceptual design of NICT’s optical ground station system for the LEO Satellites Constellation Project.

2. LAIDEN PROJECT

Background of LAIDEN project

In the industry segment of LEO satellite constellation using with laser communication system, a lot of development or demonstration projects are planned in Europe and the U.S., and a lot of new manufacturers have been increasingly established. Thus, a major trend is changed from conventional technology-driven research and development to the concept of a national satellite laser communication network and the technological development of compact, high-performance, low-cost laser communication equipment to accommodate this network. It is highly significant for Japan to demonstrate satellite laser communication network technology as an essential key-technology for building a space communications infrastructure.

As mentioned, Japanese own communication infrastructure on space is an essential, and it is important to have the ability to build it by itself. Furthermore, the importance of space communications infrastructure is increasing as national economic and/or security activities are expanding into space and the skies worldwide. The purpose of this research and development is to establish satellite optical communications network technology to build a global-scale satellite optical communication network system. In addition, satellite laser communications network technology is an important component of communications infrastructure such as satellite constellations and non-terrestrial networks in Beyond 5G or 6G era. The goal is not to merely develop elemental technologies, but to provide the services to security users and commercial market.

Then, national economic security reasons, Japanese government funded for “Japanese Inter-satellite LEO Optical Communication Network System development and demonstration project”. Space Compass which is a joint venture between NTT, Inc. and Sky Perfect JSAT Corporation, leads this project as a project leader and have established a project formation with NICT, AXELSPACE Corporation and NEC Corporation. [2]

Plan of LAIDEN project

The LAIDEN project’s ambitious goal is to develop key technologies for the optical network consisting of demo LEO satellites which plan to be launched in early 2028 and 2029, Optical/RF Ground stations, Space Compass’s GEO satellites, for which the service launch is planned in 2028, and centralized network Orchestrator and to conduct in-orbit demonstrations with multi-layer optical network.

At the first phase, the project completed the design of the demonstration system considering the potential customer needs, After that, the project is ongoing to design, develop, manufacture pre-demo satellites equipped with optical communication terminals (OCTs), and will be launched in by the end of FY2027. The main purpose of these two pre-demo satellites is to perform the in-orbit test for optical communication links between LEO satellites inner-plane, and LEO satellite and the optical ground station. A simple network architecture of planned demonstration in the project is shown in Fig. 1. [2]

The key elemental technologies of the project are as follows;

- i. Multi-vender OCTs for small size satellites
- ii. Optical communication router for the optical communication networks
- iii. Control system for optical communication equipment
- iv. Small size satellites that can equip inter-satellite optical communication systems
- v. Network operation and control system

- vi. Network Orchestrations for managing multi-vendor LEO constellations, Ground station network and GEO satellites
- vii. Ground stations (Optical and RF), Optical site-diversity, and Optical-RF diversity, Adaptive optics function
- viii. Optical communication network emulator to support the demonstration with the partial of the constellation

At LAIDEN project, we mainly will develop and installation optical site-diversity system and Adaptive Optics (AO) system for up and down link laser communication system (part vii) in NICT's Optical ground station (OGS) and demonstrate communication between the OGS and the pre-demo and demo satellites.

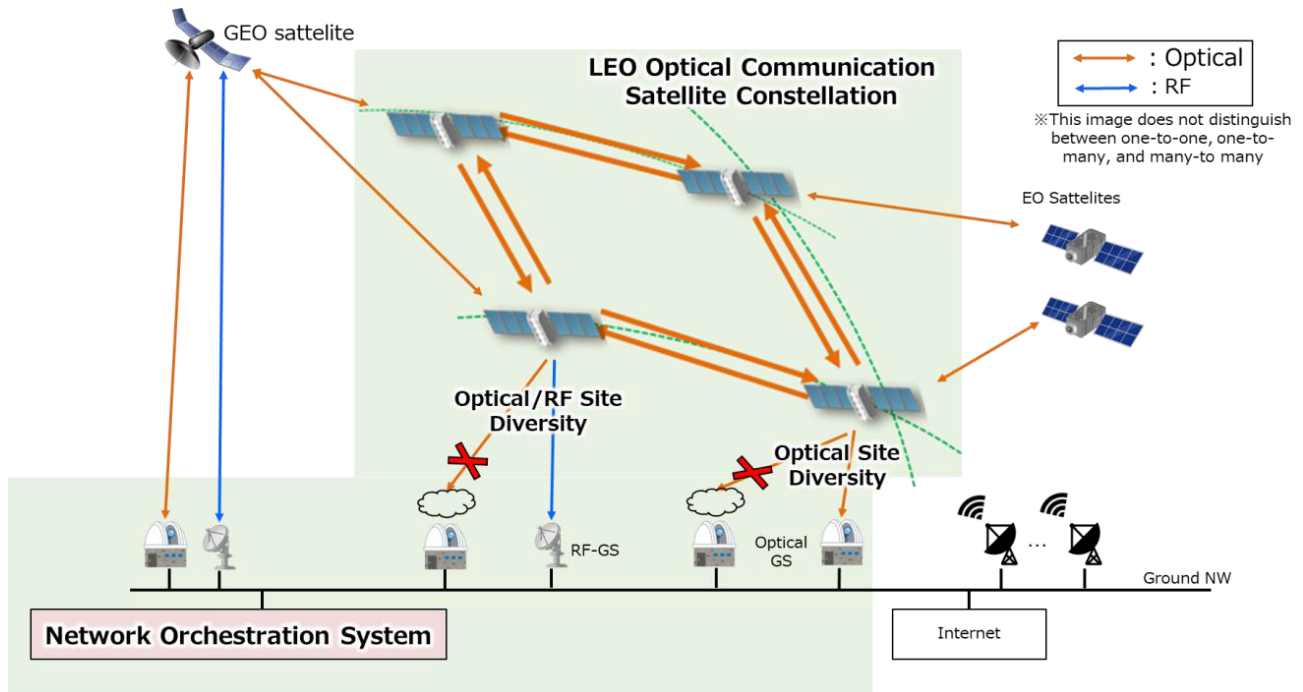


Figure 1. A simple network architecture of planned demonstration in the project [2]

3. NICT'S OPTICAL GROUND STATION

Satellite laser communication is an indispensable technology for the coming high-speed, large-capacity communications. However, there are some issues unique to optical communications. The laser beam for communications is easily affected by the atmospheric conditions between the satellite and the ground.

Cloudy conditions make optical communication between the satellite and the ground impossible. In such a case, it is necessary to communicate between the ground and the satellite in a cloudless area. In this case, multiple OGSs can be deployed, and the site-diversity method can be used to automatically select a location with better conditions for communication [3]. Furthermore, if there are portable or mobile OGSs, it is possible to move to a location with better conditions and establish communication with the satellite. To demonstrate such as site-diversity system, in addition to the OGSs which were installed in Okinawa, Kashima (Ibaraki prefecture) and Koganei (Tokyo Metropolitan, NICT Headquarter) in 2014, we have newly installed small OGSs in Kobe, Kashima, and Koganei in 2024. We also developed a new mobile OGS for the purpose of actively moving to locations with better conditions. We have named these new testbeds HICALI-GATE and have begun to consider making it available to a wide variety of users. Currently NICT OGS Network is shown in Fig.2.

As it is now certain that the human activity area in space will extend to the Moon in recent years, the 2-meter telescope is a testbed for demonstrating optical communications between the Moon and Earth [4].

Atmospheric effects are not only by clouds; atmospheric density fluctuations caused by spatially atmospheric temperature and wind variations also affect the quality of transmitted beam. Although the wavefront of the transmitted

beam is aligned when it is emitted from the satellite, the wavefront is distorted when it passes through atmospheric density fluctuations that make it impossible for the telescope at the OGS to efficiently receive the transmitted light. For this reason, we also installed instruments at each station to compensate for this effect. Those instruments are not included in the testbed, but they could be used under certain conditions.

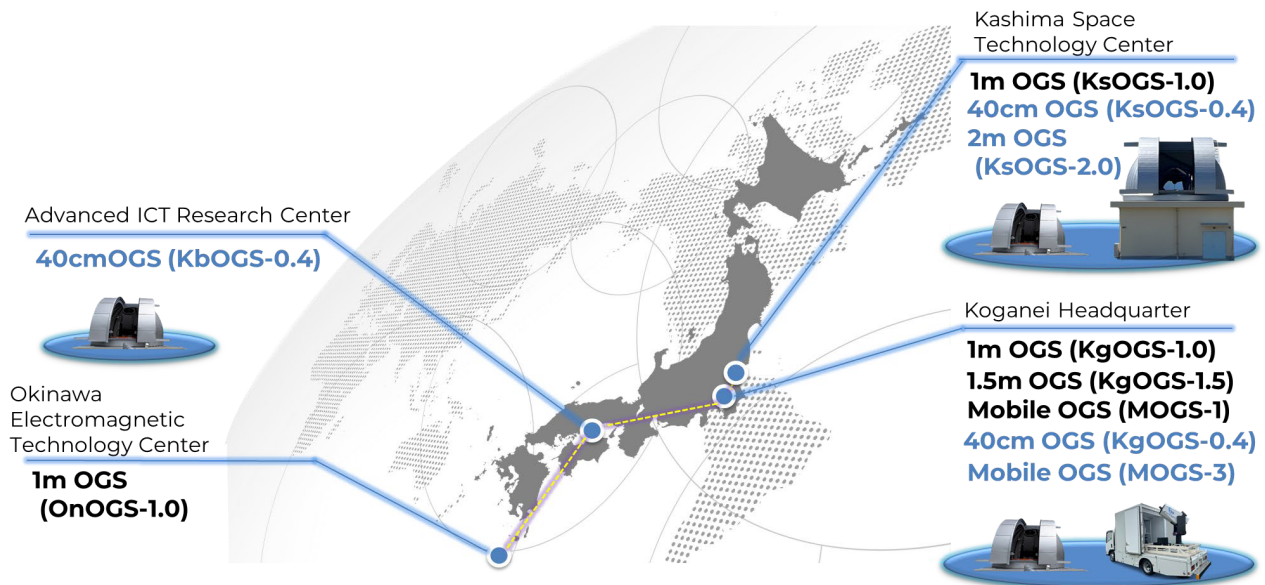


Figure 2. NICT OGS (Optical Ground Station) network, as of 2025. New OGSs shown in blue text. [3]

4. CONCEPTIAL DESIGN FOR LAIDEN PROJECT DEMONSTRATION

In LAIDEN project, A demonstration of bi-directional laser communications and experiment of the site-diversity system of which the communication link OGS is switch an OGS to other OGS, are planned. At the conceptual design, the use of multiple the 40cm small-scale OGSs was envisaged, considering the results of the link design between OCT onboard LEO satellites and OGSs. These OGS features include: These OGSs are relatively easy to bring in equipment, and the main purpose of those is to demonstrate the communication equipment or the optical system used for coupling communication laser beam, which are provided by the user. The available focal point is the Coudé focal point, where an optical surface plate is installed and the equipment brought in can be installed there. The main specifications are shown in Table 1. The LAIDEN project plans to conduct site diversity experiments at two of these three sites. At the other NICT's OGS site, various data regarding laser communication link quality will be monitored for future site diversity study.

Fig.3 shows a simple block diagram OGS architecture for LAIDEN project. For this project, the OGS facility including the telescope is intended to utilize the previously mentioned 40 cm small-scale OGSs. A key aspect of this project is as follows: generally, the time available for communication with a LEO satellite while dependent on altitude, is limited to a maximum of about 10 minutes. Therefore, it is essential to minimize the time required for signal acquisition and tracking during the initial phase of communication. To address this, a relatively wide-beam uplink beacon system was adopted to accommodate point ahead errors such as those related to orbit predict error as effectively as possible.

Also, AO system for up and down link laser communication system which developing by NICT will be installed in Main OGS site "OGS #A-1" as a "AO" function. All of each OGS is equipped with an OGS communication quality monitor and an aircraft monitoring system utilizing ADS-B signals and 4K all-sky visible-light cameras to ensure that laser beams are not irradiated to airborne objects.

Table 1. Specification of telescope for NICT's 40cm small-scale OGSs.

Item	Specification
Diameter	400 mm
F-ratio (Primary Mirror)	F/3
F-ratio (Coude)	F/15
Wavefront Error	1/6 wavelength @ 633nm
Material of Primary Mirror	ZERODURE
Coating	Al+SiO
Range of Elevation	-5 ~ 90 deg.
Installed site	Koganei, Kashima, Kobe

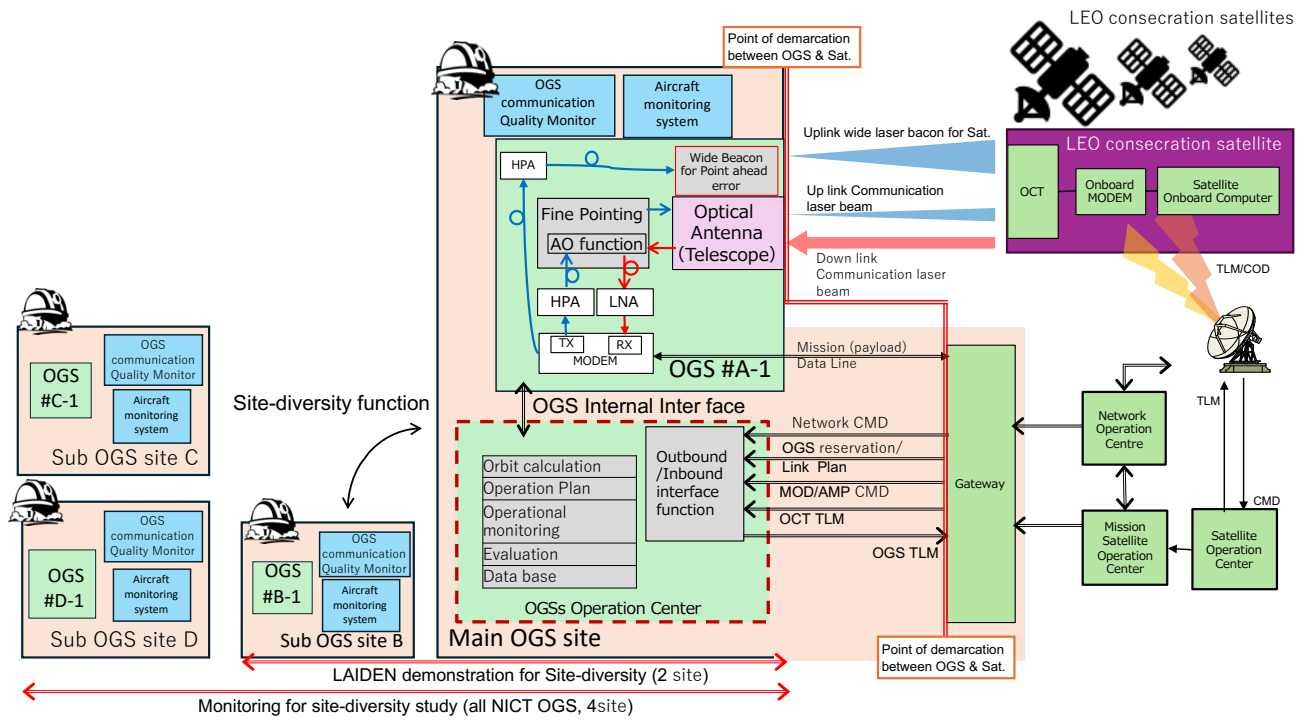


Figure 3. A simple OGS architecture for LAIDEN project.

5. CONCLUSION

In this paper, we introduced overview of “Japanese Inter-satellite LEO Optical Communication Network System development and demonstration” called LAIDEN project and currently NICT OGS Network. Then we described result of conceptual design of NICT’s optical ground station system for the LEO Satellites Constellation Project.

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REFERENCES

- [1] M. Toyoshima, "Recent Trends in Space Laser Communications for Small Satellites and Constellations," in *Journal of Lightwave Technology*, vol. 39, no. 3, pp. 693-699, 1 Feb.1, 2021, doi: 10.1109/JLT.2020.3009505.
- [2] Yoshifumi Kakiuchi, Jumpei Tanaka, Shinichi Nakazato, Ryota Tanaka, Yuma Abe, Hideaki Kotake, Mariko Sekiguchi, Fumie Ono, Hiroyuki Tsuji, Atsushi Yasuoka, Soichiro Inoue, Hideki Kayaba, Masashi Shirakura, Yuichi Shibata, and Masahiko Sugiho, "The Introduction of Japanese Development and Demonstration of Inter-Satellite Optical Communication Network System through K-Program," *Proc. 2023 IEEE International Conference on Space Optical Systems and Applications (ICSOS)*, (11-13 October 2023); <http://dx.doi.org/10.1109/ICSOS59710.2023.10491213>
- [3] C. Fuchs and F. Moll, "Ground station network optimization for space-to-ground optical communication links," in *Journal of Optical Communications and Networking*, vol. 7, no. 12, pp. 1148-1159, Dec. 2015, doi: 10.1364/JOCN.7.001148.
- [4] Yoshihiko Saito, Fumie Ono, Takayuki Usami, et al. "Development of optical ground stations in Japan and application as testbeds", *Proc. SPIE 13355, Free-Space Laser Communications XXXVII*, 1335515 (19 Mar 2025); <https://doi.org/10.1117/12.3047638>