Report on the Standardization of Optical Communications by the Consultative Committee for Space Data System (Second Report)

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1. Introduction

The Consultative Committee for Space Data System (CCSDS) was founded in 1982 by major space agencies under a common understanding that it is important to cooperate on space activities such as developing a mission device, supporting satellite operations, and sharing related data. The CCSDS focuses on developing and recommending international standards for space data systems while incorporating demonstration results of international standards. Recommendations known as Blue Book (BB) were developed and evaluated by the CCSDS; these will be integrated as a part of ISO standards.

This study presents information on the background, history, and the first meeting of the Space Link Service area (SLS) optical working group (OPT)[1]. Moreover, the study communicates the latest activities of SLS-OPT based on its fourth meeting held during November 9–12, 2015 in Darmstadt, Germany.

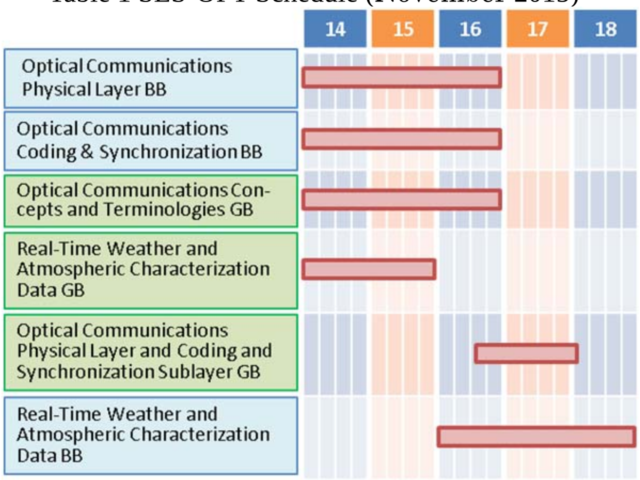
2. Activities of SLS-OPT

The SLS-OTP charter is organized into four books:
1) Optical communication physical layer BB;
2) Optical communication coding and synchronization layer BB;
3) Optical communication concept and terminology Green Book (GB);
4) Real-time weather and atmospheric characterization GB.
Based on discussions until SLS-OPT was established, the first three books contained the following three parts:
(1) Phase-shift keying (PSK) modulation system, targeting multi-gigabits per second (Gbps) optical link, including optical inter-satellite links;
(2) Pulse-position modulation (PPM) system, targeting the optical link between the Moon and Earth and between deep space and the Earth;
(3) Intensity modulation and direct detection system, mainly targeting the optical link between the low-earth orbit (LEO) satellites and optical ground stations.

The data relay optical system[2] that JAXA has started to develop is in area (1). The design of the small optical transponder (SOTA) of NICT[3][4] was launched in 2014 under a series of experiments, and its results will be applied in area (3).

To introduce cross-support capabilities for optical communication, SLS-OPT aims to complete its standardization activities by December 2018 under the action plan presented in Table 1. SLS-OPT has identified tasks associated with area (1) to be the most challenging because of conflicts with NASA and ESA/DLR, presented in Section 3.1. Consequently, the authors are concerned with whether the tasks in the schedule displayed in Table 1 can be accomplished on time.

Table 1 SLS-OPT Schedule (November 2015)



3. Summary of the fourth SLS-OPT meeting

The fourth SLS-OPT face-to-face meeting took place during November 9–12 in the 2015 CCSDS fall meeting period in Darmstadt, Germany. Over 30 participants who represented space agencies based in the US (NASA), Europe (ESA, DLR, CNES), Japan (JAXA, NICT), Russia (RSA), and China

(CASC) attended the meeting.

Fig. 2 Fourth SLS-OPT Meeting (photo by first auther)

3.1 Meeting results of the PSK modulation system, targeting multi-Gbps optical link, including optical inter-satellite link

As reported in reference [1], two parallel technologies has been contending for a global standard (CCSDS recommendation). One option uses 1 μm light(band), which is called laser communication terminal (LCT)[5][6]. This was developed by DLR and is being used in the European Data Relay System (EDRS) that will be launched 2016; it is also referred to as ESA/DLR methods.

The other option was proposed by NASA and uses 1.5 μm light(band). This technology will be located on the Laser Communication Relay and Demonstoration(LCRD)[7] that will be launched in 2018. It is also referred to as NASA methods. Both methods are not interoperable.

Prior to this meeting, two solutions were proposed during discussion with regard to SLS-OPT WG constructions. These include

a) two physical layer BBs based on two methods and one coding and synchronization BB that consolidates the two physical layer BBs.

b) two Orange Books (please refer to the experimental specifications in Note 1) of the two methods and no PSK area description in the BBs. In other words, a future competition between the methods will determine which of the two will be applied as the default option in actual space operations.

Solution a) was proposed at the 2014 autumn meeting. However, the WG did not figure out the "one coding and synchronization BB that consolidates two physical layer BBs." Instead, it was being investigated by NASA and ESA/DLR.

The WG held a discussion with the CCSDS Engineering Steering Group Chair and the Area Director. At this meeting, the working group reached a consensus, and a plan was proposed to write the two methods in parallel based on the BB recommendations, specifically with the building-block concept. Despite obtaining these results, the authors are apprehensive about conducting parallel writing in one book because it does not adhere to BB philosophy.

Within this WG, JAXA presented the outline of a new program called data relay optical system [2].

These technologies will also be applied high speed data relay between GEO satellite and airplane including UAV, based on NASA and DLR presentation.

3.2 PPM system, targeting optical link between the Moon and Earth and between deep space and Earth

NASA JPL indicated the draft BBs of the physical layer and coding and synchronization layer. With regard to this theme, the WG reached a consensus to apply 1.5 μm band from spacecraft to the Earth. The WG held a discussion to determine how to indicate wavelengths in the BBs. WG defined only polarization to apply IEEE definition. Many items has not reached consensus. Various options were proposed about how to indicate wavelength (frequency) in BBs; show a specific wavelength (frequency), write only the "C-band," or apply the ITU grid for terrestrial optical fiber communications. Moreover, options were proposed on how to indicate the data speed; however, a consensus was not reached. NASA JPL will continue to conduct further investigations in this area until the next meeting.

Consensus was reached with regard to the uplink wavelength (i.e., the link from the ground to spacecraft). As the starting point, the 1.5 μm band, which is safer for the human eye than the 1 μm band, will be applied as the uplink. However, the 1 μm band will also be allowed for uplink because

- the kW class laser is required for a deep-space mission, and the kW 1.5 μm laser is no more eye-safe;
- a kW-class 1.5 μm laser has still not been realized.

Agencies that will be using the uplink need to find a solution that avoids optical

communication operations while an aircraft is flying around any optical ground station. This solution must be based on agreements with flight control agencies in each nation. This type of operation is used for the space laser ranging system in JAXA's Masuda Communication and Tracking Station under an agreement with the Civil Aviation Bureau in the Ministry of Land, Infrastructure, Transport and Tourism. Thus, this method has been determined to be sufficiently feasible to apply in Japan.
BBs will be established not only book editing, but also require prototyping by member agencies. For prototyping, the WG has reached a consensus about the type of hardware test that will be conducted on the physical layer and the software simulation that will be run for the coding and synchronization layer.

3.3 LC area

In this area, the team responsible for drafting a BB is led by DLR-IKN in Munich in cooperation with NICT, CNES, and JPL. In the WG, this are is called "Low Complexity (LC)" since the feature of this area low-complex and low-cost hardware. At this meeting, data speed definition was the main topic. The discussions were open, and one candidate suggested the use of the SONET/SDN definition that facilities the efficient connection of a data stream to an optical ground fiber network. NASA showed much interest in the potential applications of the civil CubeSat program. On the basis of this response, NASA requested an Mbps data rate lower than that defined in the BB. This request will be investigated by the team.
The uplink wavelength beacon will be described in terms of 1 μm and 1.5 μm, same as that described in Section 3.2. ESA determined that an optical ground station (telescope) greater than 60 cm diameter can reduce optical power density; thus, it is sufficiently safe for the human eye, even at 1 μm. As presented in Section 3.2, in Japan, JAXA has an agreement with the Civil Aviation Bureau in the Ministry of Land, Infrastructure, Transport and Tourism. Thus, the recommendation for both 1 μm band and 1.5 μm band uplink wavelengths has been determined to be acceptable.

3.4 Real-time weather and atmospheric characterization GB

Concerning real-time weather and atmospheric characterization GB, NICT edited and presented the second draft, and discussions in the WG were conducted. Technical discussions were concluded, and this GB will be finalized with the WG at the next face-to-face meeting. The NICT proposed the release of the Magenta Book (Recommended Practice; to describe best practice of the technology) of this area. Decision will also be made at the next face-to-face WG meeting.

4. Other topics

CNES reported its experimental results between its optical ground station and SOTA. By applying adaptive optics technology, CNES achieved a stable focus of received light used by adaptice optics technique. Please see reference [8] for further details.
ESA presented a deep-space optical communication demonstration in the Asteroid Impact Mission (AIM). Concerning the application of the AIM, please refer to reference [9] for further details. The AIM will equip optical terminal serves as both the optical communication and thermal imaging camera. ESA has a plan to have an optical communication demonstration working at up to 0.5 AU (75 million km) by 2022. This will be the first deep-space optical communication demonstration ever performed by man. During this WG meeting, NASA confirmed its willingness to participate in this demonstration. On the basis of ESA's investigation, the use of a 1-m-diameter optical ground station (telescope) is sufficient for this demonstration. Because both NICT and JAXA have optical ground stations of this size, the authors believe that it is feasible for Japan to also participate in this demonstration. Discussions involving all interested Japanese parties on this matter will be needed.
CASC presented its research on the Chinese optical data relay program, which was not previously presented on any other occasion. CASC is investigating PSK demodulation based on the digital coherent technique. The target user data rate ("bit rate" in the CCSDS definition) is 2.5 Gbps, which is higher than those of EDRS and JAXA's optical data relay system. CASC has a plan on how to realize the Chinese data relay satellite on GEO in three years, and currently, it has no plan with regard to the LEO user satellite. Its presentation showed sufficient research progress with respect to the aforementioned dedicated components and other components.

5. Conclusion

In this study, recent standardization activities by SLS-OPT within the CCSDS are summarized.

Recently, optical communication is drawing attention as a prospective technology to satisfy demands to increase data transmission volumes with advanced space activities and/or to achieve significantly faster communication speeds for commercial use. We will continue to participate in these activities that will establish standards for various future optical communication users in space.

Note 1: The Orange Book, "Experimental Specifications", does not consist of recommendations that are meant to be global standards. However, Orange book have the potential to be BBs or global standards.

5. References

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8 "Adaptive Optics Results with SOTA" Cyril Petit et. al., A Proceedings of International Conference on Space Optical Systems and Application (ICSOS) 2015

9 "Multi-Purpose Laser Communication System for the Asteroid Impact Mission" Zoran Sodnik et al, A Proceedings of International Conference on Space Optical Systems and Application (ICSOS) 2015