Applicability of Space Laser Communications for Low Earth Orbit Satellite Constellations

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Abstract: Many satellite constellations have been planned from various countries. Optical communications are expected to realize wide bandwidths and the immunity to the interference under the environment of a huge number of satellites in the future.

1. Recent Trends of Space Laser Communications

Recently, many mega-constellation programs have been planned and launched from various countries to provide global satellite communications services by Non-GeoStationary Orbit (NGSO) satellite systems. Soon the frequency spectra will be exhausted, and spectrum allocation will become an issue in Radio Frequency (RF) bands. Figure 1 shows an example of the downlink frequency bands for nano-satellites [1]. The nano-satellite is defined as a small satellite with the mass of about 1–20 kg. In addition, the download data rate for Earth Observation (EO) satellites is increasing continuously as shown in Fig. 2 [2]. On the other hand, the terrestrial mobile communication system also needs frequency bands and is interested in using requesting frequency bands originally allocated to space. Therefore, space is forced to move to higher RF frequencies or to go to optical frequency bands directly. Optical communications can be utilized because of the large capacity as well as the tolerance against interference and no regulatory restriction which does not require international frequency coordination all over the world.

The NASA's Laser Communications Relay Demonstration (LCRD) satellite was successfully launched recently on 7th December, 2021. The trends in the data rate of space laser communication programs in space were shown in Fig. 3. From 1994–2004, the data rate increased by a factor of 1000 times. Although the data rate has not increased as dramatically since then, the number of in-orbit demonstrations has increased and doubled. Typically, a lot of in-orbit tests for micro-satellites were conducted. In the near future, Wavelength Division Multiplexing (WDM) technology can further increase the data rate.

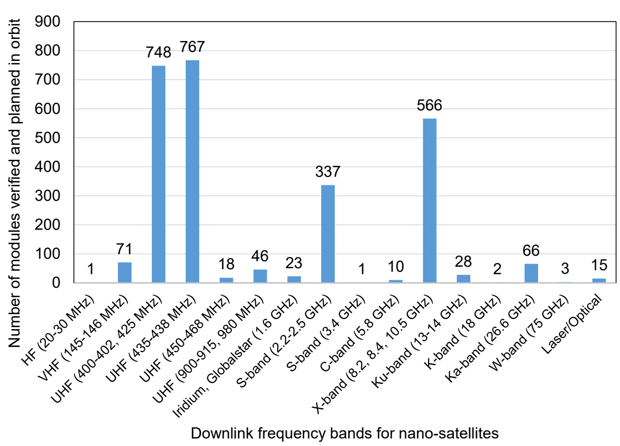

Fig. 1. An example of frequencies allocated for nano-satellite downlink bands with the optical frequency.

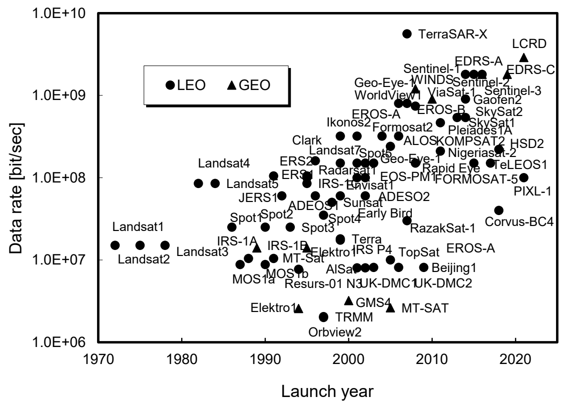

Fig. 2. Trends of the download data rate for Earth observation satellites.

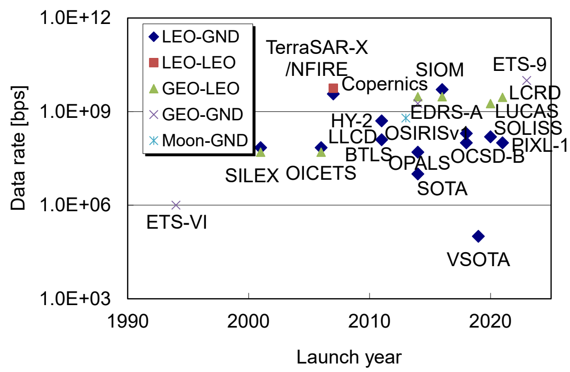

Fig. 3. Trends in the data rate for space laser communication programs verified and planned in orbit.

2. Applicability of Space Laser Communications for LEO Constellations

Compared with Geostationary Earth Orbit (GEO) satellites, the advantages of Low Earth Orbit (LEO) and Medium Earth Orbit (MEO) satellite constellations are a low latency and lower power requirements due to the shorter distance, which allows for equipment miniaturization. In addition, RF satellite communication systems require an allocated frequency in the RF bands. The use of the frequency spectra must be negotiated with many other countries, which is a time-consuming process that requires immense effort. Consequently, mega-constellation systems are expected to use space laser communications.

There are many constellation programs. Space-X has launched more than 1,892 LEO satellites since May 2019 to establish a global broadband satellite network in the Starlink program [3]. Amazon announced its plans to launch 3236 LEO satellites, called the Kuiper Systems [4]. Laser Light Communications plans to create a 12-MEO-satellite constellation and achieve a total capacity of 7.2 Tbps [5]. Analytical Space uses hybrid RF and optical downlinks to achieve high throughput and low latency user data transmissions via the nano-satellites LEO data relay network [6]. BridgeCom intends to create laser communication services based on a global optical ground station network [7]. Kaskilo will create a 288-satellite LEO constellation and mainly provide the Internet of Things (IoT) service under the Industry 4.0 policy of the German government [8]. Huawei plans to build a 10,000-satellite LEO constellation called Massive VLEO for beyond-5G [9]. Many other missions have been planned for CubeSats and micro-satellites such as Transcelestial Technologies [10], Golbriak Space [11] and so on.

Figure 4 shows applications and link scenarios of space laser communications for mega-constellations. The applications of space laser communications are categorized in five areas: (1) data download for EO missions based on ground-to-satellite links, (2) GEO data relay, (3) broadband satcom using 10 thousands class satellites, (4) all-optical high speed communications, and (5) cyber security guaranteed by Quantum Key Distribution (QKD) technologies. Optical systems will be used in networks such as ultra-broadband characteristics under the frequency allocation issue.

Considering the onboard resources for the optical communication systems, the applicable scenarios for G-bps-class space laser communication links for micro-satellites can be considered as shown in Fig. 5. There is an advantageous area for optical systems. The space laser communications should be designed for (1) G-bps-class links up to GEO-GEO link range, (2) Inter-microsat links, and (3) Nano-satellite (Cubesat) links for LEO-LEO link range. These characteristics can be realized due to the smaller onboard resource requirements of optical communications. For various link scenarios including LEO networks, the Adaptive Optical Satellite Network (AOSN) will be a possible solution to realize various optical satellite networks by controlling link parameters which include various modulation schemes and symbol rates [12]. The appropriate usage of space laser communication systems should be designed for LEO constellations.

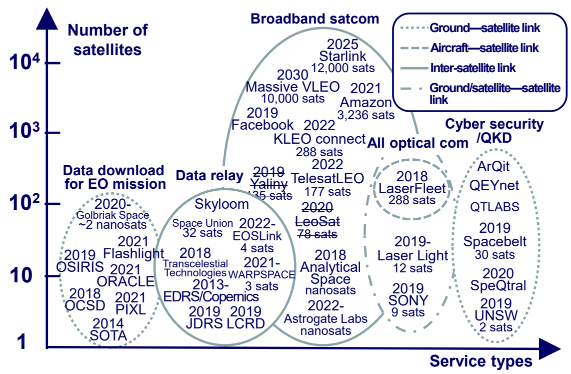

Fig. 4. Applications and link scenarios for space laser communications for mega-constellations.

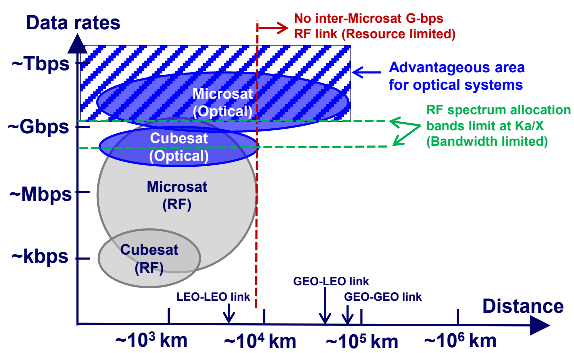

Fig. 5. Applicable scenarios for G-bps-class space laser communication links for micro-satellites

3. References

[1] E. Kulu, Nanosats Database, [Online] Available: http://www.nanosats.eu/
[2] M. Toyoshima, "Recent Trends in Space Laser Communications for Small Satellites and Constellations," JLT **39**, 3, 693–699 (2021).
[3] [Online] Available: https://www.space.com/spacex-starlink-satellites-phone-home-dimming.html
[4] [Online] Available: https://aws.amazon.com/jp/ground-station/
[5] [Online] Available: http://www.laserlightcomms.com/
[6] [Online] Available: https://www.analyticalspace.com/
[7] [Online] Available: http://www.bridgecomminc.com/
[8] [Online] Available: https://kleo-connect.com/
[9] W. Tong, "A Perspective of Wireless Innovations in the Next Decade," presented at *IEEE Globecom 2018*, Keynote Session, Abu Dhabi, UAE, December 9-13, 2018.
[10] [Online] Available: https://transcelestial.com/
[11] [Online] Available: https://www.golbriak.space/
[12] H. Kotake, Y. Abe, T. Fuse and M. Toyoshima, "Link Budget Analysis of Various Link Scenarios for Adaptive Optical Satellite Network," IAC 2021, IAC-21-B2.2.5, Dubai, UAE, October 21-29, 2021.