Space Laser Communications for Beyond 5G/6G

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***Abstract*—Advanced communication networks in Beyond 5G and 6G are expected to realize seamless connections between terrestrial and non-terrestrial networks. Beyond 5G and 6G will require further global spatial expansion of the network exceeding that of the current 5G, whose direction is toward not only two-dimensional expansion so far but also three-dimensional expansion for non-terrestrial networks in the future. Recently, many mega-constellation systems have been planned and launched from various countries. Although the frequency spectra will soon be exhausted, space laser communications have potentially wider bandwidths in the optical spectrum with smaller and lower-power-consumption onboard equipment, and are a viable alternative. Because optical communications do not have regulatory restrictions or licensing issues, they can revolutionize the space system architecture. This paper introduces the trend and future vision of the space laser communication technology in the Beyond 5G and 6G era.**

Keywords—free-space optical communication, satellite communication, satellite constellations, quantum cryptography

I. Introduction

In recent years, satellite communications have become more sophisticated and active worldwide with, for example, the digitization of communications satellites and the launch of many small satellites in satellite constellations. The 5th generation mobile communication system (5G) was introduced in earnest in 2020 on the ground, and research and development for the so-called Beyond 5G (B5G) and 6th generation mobile communication system (6G) has started around the world. It is necessary to create a three-dimensional seamless network required for a safe and secure smart society in the 2030s. 3GPP, which promotes standardization, defines the category of Non-Terrestrial Networks (NTN), and the International Telecommunications Union (ITU) B5G future technology trend survey indicates that NTN are important for B5G/6G networks.

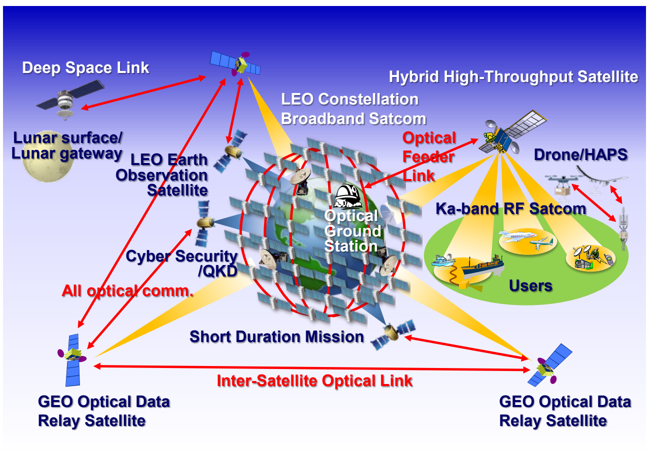

Fig. 1. Major applications for space laser communications.

Among these technologies, space laser communication technology is highly resistant to interference, has features suitable for miniaturization and weight reduction, and is attracting attention as a means of high-speed, large-capacity communication that cannot be achieved with radio waves (RF). It is expected to help bring about an innovative leap forward in global telecommunications [1]. This paper describes the role that space laser communication technology should play in wireless communication required in the B5G and 6G era, and the future vision of this communication technology with NTN.

II. Trends in Space Laser Communications

Figure 1 shows major applications for space laser communications, including short duration optical communication missions, optical data relay satellite communications, deep space optical communications, advanced optical communication technologies, and satellite quantum communications [2].

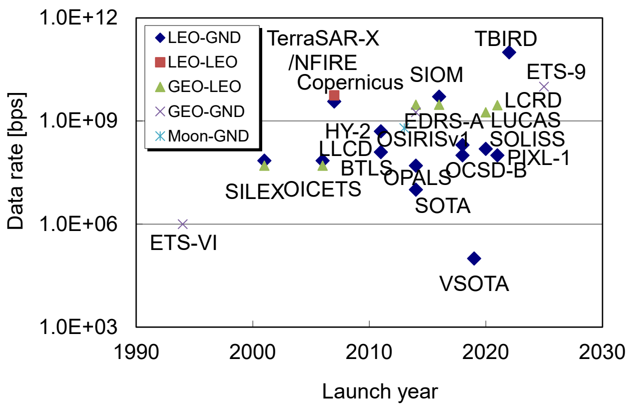

Fig. 2. Trends in the data rate for space laser communication programs verified and planned in orbit.

Figure 2 shows the trends in the data rate of space laser communication programs in space. 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 for micro-satellites has increased and the overall number of in-orbit demonstrations has doubled. In the future, Wavelength Division Multiplexing (WDM) technology can further increase the data rate.

III. Trends of Satellite Communication Technologies and Future Prospects

Figure 3 shows the recent trends in mega-constellation services and applications with small satellites. The applications are categorized in five areas: laser communications, cyber security, broadband satellite communications, Earth observations, and IoT/Machine-to-Machine (M2M). Earth observation and IoT/M2M CubeSats are already in service. Figure 4 summarizes the technological trends and future services as a function of the frequency usage for each service based on Fig. 3. The existing Ku/Ka-band GEO satellite service will remain to preserve the interests of RF license holders. In the expansion of the LEO satellite communications markets, frequency allocation will be the key issue for mega-constellations. Because the IoT/M2M applications for mobile platforms will be used more, it is important to connect the broadband satcom and IoT/M2M/5G networks. Integrated network control technology will be important to optimize the traffic among the heterogeneous network components in the future.

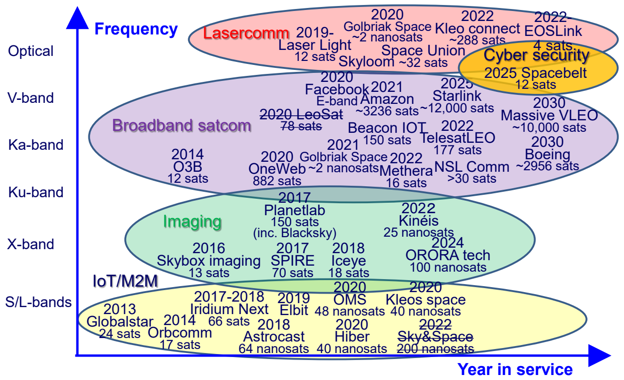

Fig. 3. Frequency map for mega-constellation satellite services and applications.

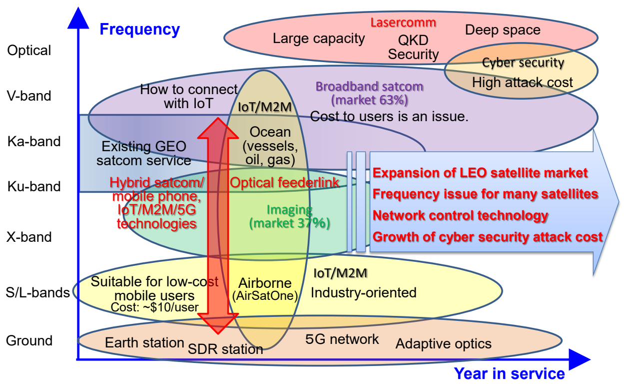

Fig. 4. Trends in mega-constellation satellite communication technologies as a function of frequency.

Figure 5 shows applications and link scenarios of space laser communications for mega-constellations. Space laser communication is categorized in five areas: short-duration missions based on ground-to-satellite links, GEO data relay, broadband satcom using tens of thousands-class satellites, all-optical high-speed communications, and cyber security guaranteed by Quantum Key Distribution (QKD) technologies. Optical systems will be used in networks such as ultra-broadband due to the problems with frequency allocation. In addition, quantum cryptography and QKD based on laser technology can enhance space cyber security; however, appropriate treatment is needed because the atmospheric turbulence effect and difficulties with the synchronization process in the QKD system would create a potential loophole for security. The establishment of space cyber security is expected in the future space network.

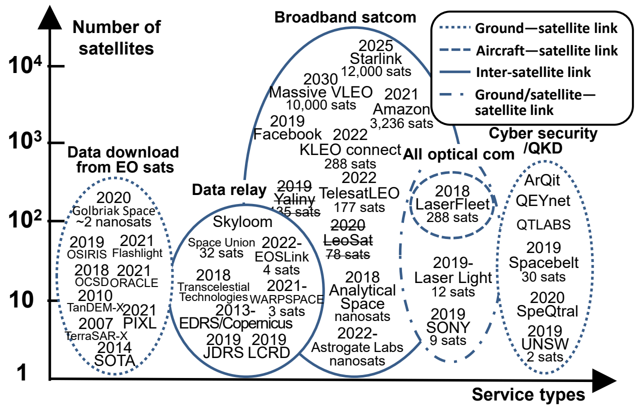

Fig. 5. Applications and link scenarios for space laser communications for mega-constellations.

IV. Conclusion

This paper introduces space laser communication technology that will play an important role in expanding NTN's ultra-coverage in the B5G/6G era. Securing a frequency band for high speed and large capacity in wireless communication with NTN are important issues. The space laser communications are expected to be used for various applications because they have no regulation issue. In-orbit demonstrations of space laser communication technology have been performed in various countries around the world, so it is expected that the use will expand by various users in the future. Many satellite constellation projects are emerging, and construction of a backbone communication network using optical communication technology in the B5G/6G era is expected. In the sense that ultra-scalable, high-speed, and large-capacity communications to the moon will be necessary in the future, optical communications will be essential for the communications infrastructure. The research and development in this field has mainly been carried out by public research institutes so far, but development in the private sector is also becoming active, and it is expected that the spread will further accelerate in the future. Such trends should be closely monitored because it is worthwhile to see how the space laser communications will be utilized by viable ventures.

References

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[2] 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.