International Journal of Satellite Communications and Networking

WILEY

EDITORIAL

Special Issue on "Advances in Optical Space Communications"

Dirk Giggenbach[1] | Ramon Mata Calvo[2]

[1]German Aerospace Center (DLR), IKN, Munich, Germany | [2]European Space Agency (ESA), ESTEC, Noordwijk, Netherlands

Correspondence: Dirk Giggenbach (dirk.giggenbach@dlr.de)

Received: 5 January 2025 | **Accepted:** 6 January 2025

Keywords: Deep Space Optical Communications | Laser Terminals | Optical Ground Station | Optical Inter-Satellite Link | Optical Space Communications | Quantum Secured Key Exchange

Optical space communications has long been considered the most efficient means for transferring information and keeping high-rate connection to various space assets, from Low-Earth Orbit via GEO and Moon towards the planets in our solar system. While technological boundaries prevented its use in the first place after the invention of the laser, initial evaluations of interorbit links for data repatriation in the 2000s proved its advantages (*SILEX*, *OICETS*, *LCTSX*). After that, *Space Data High Way* has demonstrated operational service provision with the EDRS constellation. Also, in deep space communication scenarios, *LLCD* and currently *Psyche* confirmed the advantages of optical communication in reaching the farther spots of our Solar System.

Nowadays, optical intersatellite links are already the technology of choice for network interconnects in LEO Mega-Constellations. In future, in Very-High-Throughput Satellite Systems (VHTS), the RF-feeder link will be replaced by optical feeders providing several Terabit/s in one beam instead of requiring a multitude of RF ground stations spread over several countries.

Furthermore, quantum key exchange and network securing by discrete particle states are already in early application phase on ground and in space applications, and finally, the application of deep space optical communications for Planetary Exploration promises not only extreme increase in data throughput but also new sensing and observation opportunities, up to the interplanetary internet as is required for human settling on other planets and asteroids, allowing to finally overcome the frontier of our terrestrial legacy.

This Special Issue on "**Advances in Optical Space Communication**" comprises seven articles on the most relevant topics in the field:

> The number of Cube-Sat missions highly increased due to the affordability and the relative short time to demonstration. These missions are contributing on increasing the space technology diversity and accelerating the evolution of the existing ones. Additionally, due to their low cost-impact and the required miniaturization, there is an impact in any field of space missions. Here the application to optical communications and quantum links is reviewed, investigating current example missions.

> Global Optical Ground Station Networks shall enable incessant connectivity to space assets in the highly dynamic structure of LEO-constellations together with cloud blockage events and ground connectivity. A combination of an Austral-Asian with a German OGS-network is described and its performance analyzed in the second contribution.

> The crucial field of quantum-secured links for current and near-future missions is analyzed in the next document. The QKD functionality in general, its application to satellite links, security-proofs, as well as the current status of Sat-QKD, is delineated,

and different alternatives for the BB84-protocoll are discussed.

Applying Deep Space Optical Communication (DSOC) will enable a completely new class of missions to planetary exploration, since communication data-rates will increase by orders of magnitude with the much-reduced signal spread of optical carrier frequencies. The general scenario is assessed, and the former reference mission "Lunar Optical Communications Link (LOCL)" together with the ongoing mission "Psyche" are investigated in a review article, tackling major subjects such as data rate limits, atmospheric and other noise effects, adaptive optics, or reception by single photon counting technology.

On the topic of miniaturization, photonic integrated circuits (PIC) play a major role to achieve space qualification. A view of the different components making up a PIC in high-speed optical communications is given for waveguides, modulators, lasers, optical amplifiers, and photo detectors. The current state-of-the-art in using PICs for OISLs is reviewed and advises given to leverage the advantages in SWAP compared to systems made of discrete components.

Another contribution analysis is the coherent digital signal processing for high-speed communications. Coherent optical satellite links enable high-throughput communications and high accuracy ranging to and between satellites. Special attention is given to the timing and phase recovery under atmospheric scintillation and the space environment.

The optical LEO-Uplink scenario has been underrated in contrast to the data repatriation information flow but recently gained attention due to the need of high-rate uplinks for feeding data into satellite constellation networks. Also, security issues of conventional RF-Uplinks—such as satellite-highjacking or eavesdropping—become more and more relevant, as well as the limited uplink transmission bandwidth for tasking and firmware-upload in RF. Such issues can often be overcome already on the physical level with optical uplinks. In optical connections to LEO satellites, however, the frequent low elevations with long atmospheric path sections challenge communications.

Concluding, we would like to cordially thank all the authors for their excellent contributions and their perseverance during the long reviewing and publication process. We also compliment the reviewers for their valuable comments and suggestions which helped to further refine the quality of all papers. We trust that the readership will perceive this special issue beneficial and will take it as a reference for future developments in the field of Optical Space Communications and their scientific application.

Conflicts of Interest

The authors declare no conflicts of interest.