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ADVANCING FREE-SPACE OPTICAL COMMUNICATION SYSTEM ARCHITECTURE: PERFORMANCE ANALYSIS OF VARIED OPTICAL GROUND STATION NETWORK CONFIGURATIONS

Abstract

Free-Space Optical (FSO) communication architectures are increasingly being adopted as an alternative to traditional radio-frequency methods on modern space-based systems, e.g. small-satellite mega-constellations (SpaceX's Starlink), data-relay (European Data Relay System), and deep-space communications (NASA's Psyche). The demand for higher data transmission rates, Quantum cryptography techniques, licence-free operation, smaller and more cost-effective terminals has led to the significant commercialization of FSO communication technology within the space sector. Currently, the space-to-space optical link market segment presents opportunities orders of magnitude higher than the space-to-ground segment due to the limited technological maturity and business viability factors of optical data transmission to Earth. The projected increase in laser communication terminals aboard satellites over the next decade presents opportunities to develop the ground segment and highlights the urgent need for agile space-ground infrastructure design to meet the ever-evolving data demands effectively.

Next-generation space-to-ground optical communication networks must be designed to maximise overall data throughput and system availability, while remaining affordable to procure and operate. Availability of FSO systems is predominantly influenced by localised cloud cover, whereas link performance by atmospheric turbulence and respective Optical Ground Station (OGS) characteristics, such as transmission power and tracking accuracy. Currently, high-capacity large OGS require significant capital investment and resources to build and operate. A global network of smaller portable OGS are envisaged to fulfil the role of a few large OGS by providing the flexibility and resilience of the system through high spatial diversity and terminal redundancy at a fraction of the cost, while compromising on individual terminal link performance.

This study discusses the current state of FSO technology, as well as, global trends and developments in the industrial ecosystem to identify the obstacles that stand in the way of the full realisation of optical space-to-ground communication networks. Additionally, link performance and network availability trade-off studies are presented, comparing overall system performance of portable vs. large OGS networks in conjunction with a constellation of small low Earth orbit (LEO) satellites. The paper provides an

up-to-date overview and critical analysis of the FSO industry and assesses the feasibility of low-cost portable terminals as an alternative to larger high-capacity OGS systems. This initiative seeks to better inform optical communications stakeholders, including governments and academic institutions, satellite operators, manufacturers, and communication service providers.