Optical Engineering

GUEST EDITORIAL

Special Section Guest Editorial: Free Space Optical Communications

Szymon Gładysz,[a] Morio Toyoshima,[b] Miranda van Iersel,[c] and Linda Thomas[d]
[a]Fraunhofer IOSB, Ettlingen, Fraunhofer Institute of Optronics, System Technologies and Image Exploitation, Ettlingen, Germany
[b]NICT, Wireless Networks Research Center, Tokyo, Japan
[c]University of Dayton, Department of Electro-Optics and Photonics, Dayton, Ohio, United States
[d]U.S. Naval Research Laboratory, United States

The concept of free-space optical communications (FSOC) goes back to the 1880s and Alexander Graham Bell's experiments with the photophone. Military applications were responsible for sporadically occurring developments in this technology, particularly during both World Wars, but it was not until the invention of lasers in the 1960s that FSOC could fulfill its promise of secure, directional, and high-data rate transmission over long distances. Already in 1981, the first FSOC downlinks through the atmosphere, the clouds and ocean water from an aircraft flying at 12 km to a submerged submarine were demonstrated.

As of 2024, we are witnessing the coming of age of commercial FSOC due to demands for higher data rate wireless communications due to the limited frequency resources of radio frequency bands. Several major players—such as Amazon, which achieved successful 100-Gbps intersatellite links, and SpaceX, which also announced successful 200-Gbps intersatellite link demonstrations based on the COTS devices—as well as hundred or so smaller companies are pursuing several FSOC concepts and technologies. Space agencies such as NASA and ESA have demonstrated uplink, downlink, and relayed communications with lasers in space. Laser terminals aboard deep-space missions are also becoming a reality, as the recently launched Psyche mission shows.

Closer to Earth, Li-Fi (light fidelity) technology uses light from light-emitting diodes (LEDs) to enable high-speed communications, especially over short (∼10 s of meters) distances and indoors. For underwater communications, links based on LEDs and lasers, using classical as well as quantum security, have been demonstrated in laboratories, and first commercial entities offering this technology have emerged.

While the future certainly looks bright for FSOC, there remain research challenges in different areas, like pointing, acquisition, and tracking with narrow beams and moving platforms, hybrid FSO networks, the influence of background light, channel distortions due to scattering, fog, atmospheric turbulence, etc. These research challenges need to be addressed to come to a fully mature commercialization of this technology. This special section offers a broad overview of FSOC sub-disciplines including aspects of light propagation through the atmosphere, adaptive optics, quantum key distribution (QKD), satellite FSOC, and deep-space FSOC.

In this special section, Stotts and Andrews provide a comprehensive tutorial review of optical communications in atmospheric turbulence. Gupta, Dhawan and Gupta give an overview and recent advances on UAV-based FSOC. For the onboard FSOC systems, Badás et al. offer a survey on opto-thermo-mechanical phenomena for satellite FSOC. As a possible application to deep-space FSOC, Jarzyna et al. discuss the photon information efficiency limited by the Gordon-Holevo capacity bound. Toselli devised a focal-plane analysis for atmospheric turbulence-affected laser beams, Ruff and Bradley experimentally demonstrate self-healing free space optical link in atmospheric turbulence, and Shishter, Ali and Young carried out Bessel-Gaussian beam propagation through turbulence. Patel et al. propose a fiber bundle-based beam tracking approach for FSOC, Peng, Mao and Qi present an improved prediction algorithm for the single-mode fiber coupling, and Kiasaleh examines the receiver architecture for on-off-keying FSOC in the presence of residual spatial tracking error. Häusler et al. propose to characterize the atmospheric background light in satellite-to-ground QKD scenarios.

The guest editors extend their gratitude to the authors for their valuable contributions, as well as to the reviewers for their time and thoughtful feedback. We also express our deep appreciation to the *Optical Engineering* editorial staff for their tremendous assistance throughout the preparation of this special section.

Szymon Gładysz is head of the Adaptive Optics Group at the Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB. His research interests are in FSOC, speckle statistics, atmospheric turbulence, adaptive optics, and image restoration. He has been awarded awards and grants from the University of California, US Air Force Office of Scientific Research and from the Office of Naval Research Global. He authored or co-authored around 150 publications in journals and conference proceedings and serves as conference and program chair, committee member, and senior editor for *Optical Engineering*.

Morio Toyoshima received a PhD in electronic engineering from the University of Tokyo, Japan in 2003. He joined the Communications Research Laboratory (CRL, Ministry of Posts and Telecommunications) in 1994 and shortly after was engaged in research for the Engineering Test Satellite VI (ETS-VI) optical communication experiment. He joined the Japan Aerospace Exploration Agency (JAXA; formerly, NASDA) to develop the Optical Inter-orbit Communications Engineering Test Satellite (OICETS) from 1999 to 2003. He spent one year as a guest scientist at Vienna University of Technology, Austria in 2004. In April 2006, he returned to National Institute of Information and Communications Technology (NICT; formerly CRL), where he performed ground-to-OICETS laser communication experiments in 2006. He was involved in the development of the Small Optical TrAnsponder (SOTA) for 50-kg-class satellites and conducted the first satellite-to-ground quantum communication experiments. He was also involved in the development of the Engineering Test Satellite 9 (ETS-9). He is now the director general of the Wireless Networks Research Center in NICT since April 2021. He is on the editorial board of *Optical Engineering* and serves as committee member in SPIE conferences. He is a senior member of IEEE and a fellow member of IEICE, Japan.

Miranda van Iersel is an assistant professor in the Department of Electro-Optics and Photonics at the University of Dayton. She received her MS degree in physics from the Catholic University in Nijmegen, the Netherlands, and her PhD degree in physics from the Vrije Universiteit in Amsterdam, the Netherlands. Current active research areas include atmospheric turbulence, laser beam propagation through the atmosphere and water, optical communication, and atmospheric characterization. She is a member of Optica and senior member of SPIE, an associate editor for *Optical Engineering*, and serves as conference chair and committee member for Optica and SPIE conferences.

Linda Thomas is a senior research engineer with the U.S. Naval Research Laboratory. Her research interests include free space optical communications, satellite laser ranging, low noise optical photodetectors, and heterogeneous optical and radio frequency transport architectures. She received her PhD and MS from the University of Maryland at College Park in atmospheric propagation of lasers, and her BSE from Duke University in Durham, NC. She serves on the program committee for the SPIE Free Space Laser Communication Conference and has previously led the SPIE Conference on Atmospheric Propagation and is a SPIE life member. She has made contributions to over 60 manuscripts and has received the Department of the Navy's Top Engineer award for her innovative research contributions in free space optical communications.