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*Editorial*

# Advanced Technologies in Optical Wireless Communications

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## 1. Introduction

Optical wireless communication (OWC) is expected to be a key component of future wireless communication networks, with a wide range of applications such as indoor visible-light communication (VLC) [1,2], visible-light positioning (VLP) [3], underwater OWC [4], and satellite communications [5]. These diverse application scenarios highlight the potential of OWC technologies to complement or even surpass traditional radio-frequency (RF)-based wireless systems in terms of bandwidth availability, security, and energy efficiency. However, they also introduce new technical demands related to channel modeling, optical beam steering, device integration, and system optimization across varying environments. While significant progress has been made in developing related technologies over the past decade, many critical challenges remain unsolved or require further research.

This Special Issue aims to address some of the ongoing challenges in OWC by presenting a collection of 16 peer-reviewed articles, which are listed in the "List of Contributions" section. These contributions come from research institutions and universities across nine countries, including Australia, Belgium, China, Japan, Germany, Greece, the Netherlands, Spain, and Ecuador, reflecting the global collaborative effort undertaken to advance research in this field. This Special Issue concludes by summarizing these articles and categorizing them into five topics: VLC, VLP, space optical communication, modulation and multiplexing techniques, and OWC with photonic integrated circuits (PICs).

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## 2. Visible-Light Communication (VLC)

Indoor VLC is an important form of OWC that uses white-light-emitting diodes (LEDs) for indoor illumination and wireless data transmission simultaneously. The performance of a VLC system depends on various factors [6], including the characteristics of the LED transmitters, the sensitivity of the photodetector (PD) receivers, the optical components integrated into the system, and the signal modulation schemes used. Moreover, in a transmission system with multiple LED transmitters, the spatial configuration and alignment of the transmitters and receivers also play an important role in determining overall system performance.

This Special Issue presents five articles related to VLC. Like other communication systems, the performance of a VLC system is influenced by the bandwidths of both the LED transmitter and the electronic circuits used to drive the LEDs. To enhance the bandwidths of LED transmitters, Contribution 1 investigates how different crystal orientations of the GaN structure impact the light emission lifetime of LEDs and, consequently, their modulation bandwidth. Contribution 2 focuses on improvements to the LED driving circuit, particularly enhancements to boost/buck DC-DC converters.

Another notable challenge in VLC is mitigating interference from adjacent LED transmitters. Contribution 3 explores the use of a liquid lens to adjust the receiver's field of view (FOV), therefore reducing interference from nearby transmitters. In transmission scenarios involving multiple LED transmitters, the layout of these LEDs is crucial and must also satisfy illumination requirements. Contribution 4 investigates the optimization of LED layout while considering practical illumination distribution constraints. Finally, Contribution 5 presents a study on the channel characterization of visible-light bands in an industrial scenario and compares it with that of RF bands.

## 3. Visible-Light Positioning (VLP)

VLP is another important form of OWC, often considered a subset of VLC. In VLP, light signals emitted from LEDs are used to determine the position of objects or users within an indoor environment. By analyzing the properties of the received light signals, such as the received signal strength (RSS), angle of arrival (AoA), or time of flight (ToF), VLP systems can achieve higher accuracy in indoor localization compared to their RF counterparts, such as the global positioning system (GPS) [3]. Another advantage of VLP is that it can be seamlessly integrated with VLC, using the same LED infrastructure for both indoor positioning and wireless data transmission.

In this Special Issue, we present three articles on the topic of VLP. Since VLP systems typically require multiple transmitters and photodetectors for triangulation calculations, Contribution 6 adapts this configuration to support multiple-input single-output (MISO) and multiple-input multiple-output (MIMO) transmissions. Like MIMO used in RF wireless systems, this approach aims to enhance either data transmission rates or the reliability of received signals. Contribution 7 also investigates the integration of VLC and VLP. A key contribution of this work is the use of a solar cell array, rather than conventional photodetectors, for signal detection. An experimental setup is implemented to demonstrate the system's performance in terms of both data transmission and positioning accuracy. To achieve a more accurate positioning system using AoA, Contribution 8 studies the performance of an angular diversity receiver with aperture structures. This design was originally proposed in [7] for VLC MIMO communications and later adapted for a VLP system in [8]. As an extension of [8,9], this work focuses on optimizing the layout of the LEDs to improve the positioning accuracy. These improvements are demonstrated through simulations, considering the Cramér–Rao bound (CRB) as the performance metric.

## 4. Space Optical Communication

Space optical communication is another emerging and important form of OWC that enables high-speed data transmission between various types of satellites, as well as between satellites and ground stations. These systems typically operate across different orbits, including geostationary Earth orbit (GEO), low Earth orbit (LEO), and high-altitude platform stations (HAPS), each offering distinct advantages in terms of coverage and latency. As a complementary technology to terrestrial wireless and optical fiber networks, space optical communication is expected to play an important role in the next generation of global connectivity [10]. However, it also faces several technical challenges, such as solar interference, atmospheric disturbances, and the complexities of accurate tracking and alignment in dynamic space environments.

This Special Issue presents three articles that explore different aspects of space optical communication. Like other OWC systems, the performance of the transmission link in space optical communication highly depends on the sensitivity of the photodetector used. Avalanche photodiodes (APDs) are well known for their high gain and stable performance and are therefore promising candidates for space applications. Contribution 9 investigates the performance of APDs by simulating their behavior under various channel impairments, including turbulence-induced beam scintillation, pointing errors, and AoA fluctuations, using a detailed channel model and by analyzing the theoretical symbol error rate (SER). Moreover, unlike RF wireless and fiber optics, the signal received in space optical communication can be highly distorted. In recent years, there has been a trend toward exploring the use of AI-related algorithms for signal equalization [11]. Contribution 10 studies a neural network (NN)-based approach for signal equalization and compensation of distortions caused by free-space channels. Finally, Contribution 11 presents a model that examines the optical power requirements for satellite constellations throughout their orbital periods, taking multiple system parameters into account.

## 5. Modulation and Multiplexing Techniques

Similarly to strategies used in fiber optics and RF wireless communications, one of the most effective approaches to increasing the transmission data rate of OWC is the use of multiplexing techniques. In OWC, since light carries the transmitted data, many multiplexing methods commonly used in fiber optics can potentially be adapted for OWC. These methods include wavelength-division multiplexing (WDM) [12], polarization-division multiplexing (PDM) [13], and orbital angular momentum (OAM) multiplexing [14]. Moreover, because the OWC channel is wireless, multiplexing techniques from RF wireless systems can also be applied. Examples include multiple-input multiple-output (MIMO) [15,16], non-orthogonal multiple access (NOMA) [17], and orthogonal frequency-division multiple access (OFDMA) [18]. These multiplexing techniques are summarized in Figure 1. Despite the many possible ways to implement transmission multiplexing in OWC, a key challenge lies in managing crosstalk and interference between channels, which increase as the number of multiplexed channels increases.

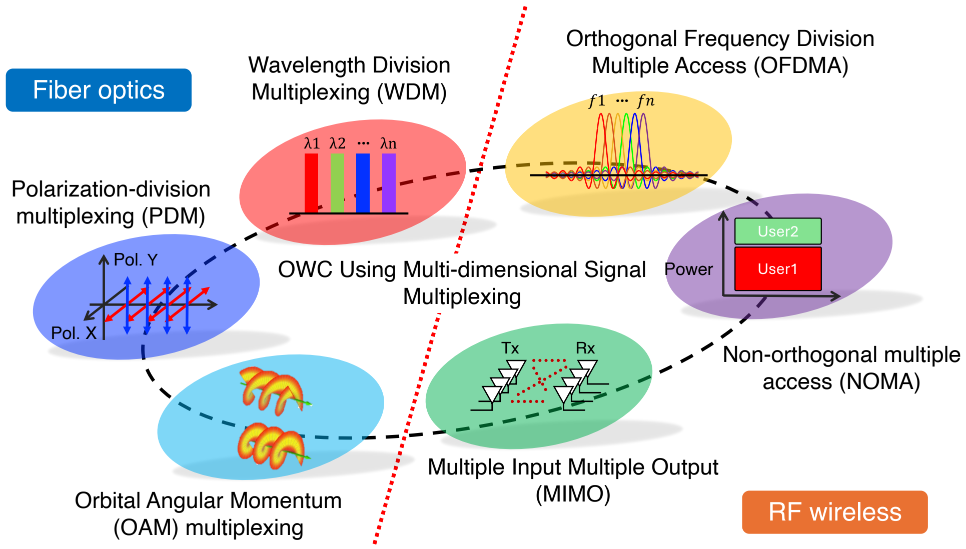


**Figure 1.** A wide range of transmission multiplexing techniques used in fiber optics and RF wireless communications can potentially be applied to OWC to achieve high-dimensional multiplexing.

This Special Issue includes four articles in the category of modulation and multiplexing techniques. In Contribution 12, an OWC system that combines MIMO with Faster-than-Nyquist (FTN) signaling is studied. This approach aims not only to increase the transmission data rate, but also to improve spectral efficiency. However, in this case, crosstalk occurs between different MIMO channels, and FTN introduces strong interference. To overcome this issue, a machine learning-based approach combining a convolutional neural network (CNN) and a bidirectional long short-term memory (Bi-LSTM) network is proposed for interference mitigation. Contribution 13 focuses on the study of NOMA in OWC. In particular, NOMA is integrated with the concept of cognitive radio (CR) to achieve high spectral efficiency.

Regarding modulation methods, OFDM is often considered in OWC as it is already widely used in many existing wireless communication standards [18]. However, because of the high peak-to-average power ratio (PAPR) of OFDM signals, clipping noise often occurs [19]. Contribution 14 investigates a receiver-based signal processing method designed to mitigate clipping noise in optical OFDM systems. In Contribution 15, the use of code shift keying (CSK) in an intensity modulation/direct detection (IM/DD)-based OWC system is studied. Unlike conventional CSK, which is based on orthogonal codes, this work focuses on the use of non-orthogonal codes to improve the transmission efficiency of OWC systems.

## 6. Photonic Integrated Circuits (PICs) for OWC

In recent years, there has been a growing trend toward integrating PICs into optical communication systems, especially in optical fiber communications, to meet the increasing demand for compactness, energy efficiency, and high-speed signal processing. The use of PICs in OWC remains relatively underexplored. This Special Issue includes a review article, Contribution 16, which highlights some of the recent progress in PIC development for OWC, particularly focusing on the PICs developed by Fraunhofer HHI.

## 7. Conclusions

In summary, OWC remains a rapidly developing technique that requires continuous research. This Special Issue highlights a diverse collection of articles within the field, covering many of the most active and popular areas of OWC research. We sincerely thank all of the authors who submitted their work to this Special Issue and contributed to its success.

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