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EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: OPTICAL WIRELESS TECHNOLOGIES FOR 5G COMMUNICATIONS AND BEYOND

Wide bandwidth and dense spatial reuse are of extreme importance for future wireless communication networks, including 5G and beyond. In particular, these properties are important to enable future wireless networks to cope with the explosive increase in the demand for high data-rate communications. Optical wireless communications (OWC) is a promising technology for achieving this goal due to the abundant reusable license-free optical spectrum. This potential of OWC attracted significant global attention both from communications and optoelectronics viewpoints, and continues to do so.

OWC encompasses visible-light communications (VLC) and free-space optics (FSO), among other areas. VLC utilizes light-emitting diode (LED) fixtures for establishing short-range connectivity, which is suitable for indoor access points and for vehicular communication applications. Using VLC enables aggressive spatial reuse and consequently enables supporting a large number of connected devices, which is a necessity for 5G and future networks. On the other hand, FSO utilizes lasers for establishing medium- and long-range connectivity, which is suitable for cellular backhaul links for instance. This fits well within the context of cell-densification and cloud radio-access networks, where it becomes important to connect base-stations using high-capacity wireless backhaul links. These aspects promote OWC as an enabling technology for 5G and beyond. As such, this Special Section in IEEE ACCESS focuses on studying schemes that enable OWC to play this important future role.

A VLC network (also called a LiFi network) consists of multiple light fixtures acting as access points transmitting information to multiple users. Coordinating the transmissions of these access points is important to achieve good communication performance. The invited article "Centralized light access network (C-LiAN): A novel paradigm for next generation indoor VLC networks" by Kizilirmak *et al.* studies this point, and proposes centralizing all VLC access point computations. The goal is to enable joint processing of signals from different access points towards more efficient implementation of offloading, handover, interference management, scheduling, and resource allocation algorithms. This paradigm enables the implementation of cooperative multipoint (CoMP) and enhanced inter-cell interference coordination (eICIC) schemes, originally proposed for LTE-A, in a VLC network leading to significant improvements over conventional schemes.

Coordinated transmission from multiple light fixtures or LEDs enables applying multiple-input multiple-output (MIMO) schemes in VLC. Thus, in "Robust transceivers design for multi-stream multi-user MIMO visible light communication," Sifaou *et al.* focus on the design of precoding and receiving schemes for downlink multi-user MIMO VLC systems using angle diversity receivers. By formulating a max-min SINR optimization problem, they obtain robust schemes that mitigate inter-user interference and mobility-induced channel estimation errors. Moreover, Narmanlioglu *et al.* study the design of MIMO orthogonal frequency-division multiplexing (OFDM) schemes in "Link adaptation for MIMO OFDM visible light communication systems." In this article, the authors propose a scheme that switches between spatial repetition and spatial multiplexing MIMO modes based on channel conditions. Then, for each MIMO mode and each OFDM subcarrier, their scheme performs bit-loading to maximize the spectral efficiency while satisfying a target bit error rate.

Although OFDM schemes are very popular in VLC, they are challenging for optoelectronics due to their rather high peak-to-average power ratio (PAPR). Due to this, Khalighi *et al.* study an alternative scheme consisting of using pulse-amplitude modulation (PAM) or carrier-less amplitude and phase (CAP) modulation at the transmitter, and frequency-domain equalization (FDE) at the receiver in "PAM and CAP-based transmission schemes for visible-light communications." They demonstrate the merit of these schemes in achieving lower PAPR than OFDM while attaining high data rates. The lower PAPR implies a lower sensitivity to clipping noise which is a desired property.

In VLC applications, it is important to be able to steer the transmission in a specific direction for several reasons including improved reception and reduced interference. Younus *et al.* study the feasibility of beam-steering using computer-generated holograms (CGH) in their article ''CGH for indoor visible light communication system.'' They propose, design and evaluate two CGH beam-steering schemes for VLC, and demonstrate their capabilities to achieve reliable communication at high data rates while satisfying lighting constraints according to standard illumination levels. While this article considers transmitter directivity, the article ''Ultra-thin optical sheets for parallel data transmission of visible light communications'' by Yang *et al.* focuses on receiver directivity. In this article, the authors design ultra-thin flexible optical sheets with strong angular selectivity that can be mounted on photodetectors in order to narrow their field-of-view to desired values.

Realizing the future role of VLC requires not only studying the physical layer, but also higher layers. Thus, new analysis tools for studying network-layer aspects are essential for achieving this goal. To this end, Aldalbahi *et al.* developed an open source ns3-based VLC module in ''Visible light communication module: An open source extension to the ns3 network simulator with real system validation.'' This module can be used to study VLC-RF heterogeneous networks at indoor scales. The authors validated this module using a software-defined radio testbed under various modulation schemes, and demonstrated its capabilities to predict the performance of hybrid WiFi/VLC networks.

In addition to indoor applications, VLC is a promising technology for outdoor applications as well. One can use VLC to establish vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. Yamazato *et al.* investigate the latter aspect in ''The uplink visible light communication beacon system for universal traffic management.'' The authors use commercially available LED headlights and photodiodes to establish a VLC uplink between a car and infrastructure, and use bit-loading and OFDM to obtain a good performance. They also demonstrate their system experimentally under driving conditions.

On the other hand, on the FSO front, the article ''Performance analysis of a threshold-based parallel multiple beam selection scheme for WDM FSO systems'' by Nam *et al.* studies beam selection for wave-division multiplexing (WDM) FSO systems. At a given time, their beam selection scheme activates the optical chains corresponding to ''good'' wavelengths. The authors study the performance of this scheme under independent and identically distributed Gamma-Gamma fading conditions in terms of outage probability, spectral efficiency, average number of selected beams and bit error rate. These results are important for 5G backhauling using FSO.

Since future networks will be highly heterogeneous and dense, integrating various types of backhauls is important for connecting the diverse network components. One such integration involves the design of mixed FSO/fiber backhauling. In the article ''Impact of fiber nonlinearity on 5G backhauling via mixed FSO/fiber network'', Morra *et al.* study the transmission of signals from a radio-access uplink corrupted by interference to a central office via a mixed FSO/fiber backhaul. The authors study the impacts of interference, FSO pointing errors, and both fiber and FSO nonlinearities on the outage probability, the bit-error rate, and channel capacity. The results help in planning and provisioning 5G networks with mixed FSO/fiber backhaul links.

With these contributions, we believe that this Special Section serves its goals well. The articles cover various topics in OWC and its integration in future wireless networks, and highlight additional problems that should be solved to prepare OWC to assume its promised future role. We thank the authors for their valuable contributions, the reviewers for their time and efforts, and the IEEE ACCESS editorial team for their support and guidance.

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