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1 The Special Issue

It is our pleasure to introduce this Special Issue on optical-wireless communications (OWC), highlighting the recent research and development in this emerging field. The Special Issue is based on extended versions of the selected best papers presented at the 4th Colloquium on OWC as part of the 9th IEEE/IET International Symposium on Communication Systems, Networks & Digital Signal Processing (CSNDSP), which was held in Manchester, UK, in July 2014. The Special Issue is composed of one invited paper and fourteen research papers. The invited paper, as well as four regular papers, is dedicated to visible light communications (VLC), and ten papers are in the area of free space optic (FSO) communications and OWC body area network.

VLC is an emerging technology that has been vigorously developed in recent years thanks to the invention of the light-emitting diode (LED) and its extensive usage in general illumination, both in indoor and outdoor environments. The first contribution is an invited review paper by Saha *et al.,* a "*Survey on optical camera communications: challenges and opportunities*", which gives an overview on the activities of the proposed revision of IEEE 802.15.7r1, addressing some of the shortcomings of the IEEE 802.15.7 standard for optical camera communication-(OCC-) based VLC systems. The paper also outlines the current research activities, issues, and solutions, as well as application scenarios for OCC.

In order to increase the spectral efficiency in VLC, a number of modulation schemes have been proposed and investigated. Yoo *et al.* study the M-ary variable pulse position modulation (M-VPPM) scheme, which is adopted as part of the IEEE 802.15.7 VLC standard to increase the data rate of the VPPM scheme whilst offering good dimming control functionality, which is more suitable for modern VLC applications. The paper includes modelling of the transmitter, optical wireless channel and the receiver. Both theoretical analysis, and simulation of the error probability considering the dimming ratio and the modulation order, show tight analytical bounds, thus providing key insights into the performance trade-off of M-VPPM in a dispersive VLC channel environment. Luna-Rivera *et al.* outline a new colour-shift keying (CSK) modulation scheme for indoor VLC systems, which transmits data by modulating the intensity of red-green-blue (RGB) LEDs using a colour coding format, thus offering reduced complexity and maintaining the compatibility with the premises of the IEEE 802.15.7 standard. There are two main contributions from this work, including a new RGB-based flexible and versatile modulation scheme, and a novel single-photodiode based receiver. Jia *et al.* investigate the symbol error rate (SER) for the CSK scheme using RGB LED-based VLC. The paper presents the mapping from a 3-dimensional signal space of CSK signals to a 2-dimensional plane for signal analysis, thus enabling the error probability calculations. An analytical model is developed for 4-CSK and 16-CSK schemes and simulation results for the SER are included, which accurately confirms the predicted data given.

The Special Issue also presents the work on integration of VLC and the optical fibre communications that bridges the wire and wireless communications systems in the optical domain so that higher data speed can be achieved. The first-time practical demonstration for VLC and multimode fibre communications (MFC) system is featured in the paper by Huang *et al.* 600 Mbit/s of data, using the 64-QAM-OFDM scheme over a 100 m fibre and a 60 cm VLC link, is reported, thus illustrating the potential of VLC for optical interconnect systems.

The range of applications for VLC and OWC has been extensively expanded in recent years and one of the interesting areas is the OWC body area network (BAN). Using OWC to establish on-body links constitutes a promising solution to address radio-frequency (RF) interference issues in BAN, especially concerning medical applications. To evaluate OWC performance in BAN, Chevalier *et al.* investigate on-body communications between a BAN node and the central unit, attached to the patient while moving around within a room. Considering a non-line-of-sight (NLOS) diffuse optical link configuration with reflections, the authors have proposed an adaptive, fast and simple method to determine the link performance in terms of the outage probability, taking into account reflections from objects within the room.

Developing more robust and effective channel models for OWC is ongoing within the research community. Zifeng Wu *et al.* report on the finite-state Markov chains as an effective tool for modelling communication channels with correlated fading for terrestrial FSO communications, which has been improved by optimising the state space partitioning of the models. The authors have investigated the properties and approximation accuracy of Markov models that are optimised according to information-theoretic considerations. They validate and evaluate their approach using a set of experimental measurements over a 12-km transmission link. The obtained results confirm that optimised Markov models can provide improved accuracy at lower state complexity, yet there remain shortcomings in capturing the auto-covariance of the fading process. On the channel modelling, Linchao Liao *et al.* characterise the long-distance NLOS UV communication channel by using experimental data and theoretical modelling. The authors report and analyse their experimental measurements of path loss and pulse broadening effects at distances of up to 4km, and provide comparisons between the field-test data and a Monte Carlo multiple-scattering channel model provides strong evidence for the validity of the theoretical modelling approach.

Relay-assisted FSO systems have recently emerged as an effective method for extending the transmission distance, especially in the presence of atmospheric turbulence. Two papers in this Special Issue deal with different relay-assisted system configurations: one with the mixed dual-hop RF/FSO, and another with multi-user relay-assisted FSO using optical CDMA. More specifically, Anees *et al.* report on the error performance and the capacity analysis of dual-hop RF/FSO system. The RF link is characterised by Nakagami-m fading, and the FSO link is characterised by path loss, Gamma–Gamma distributed turbulence and the pointing errors. The authors present novel closed-form mathematical expressions for cumulative distribution function, probability density function and moment generating function of the equivalent signal to noise ratio in terms of Meijer-G function. Using these channel statistics, new finite power series-based analytical expressions are obtained for the outage probability, the average bit-error-rate (BER) for various binary and *M*-ary modulation techniques and the average channel capacity of the considered system in terms of Meijer-G function. The simulations provided validate the mathematical analysis. In the other paper,

Pham *et al.* report on the chip detect-and-forward (CDF) scheme used at relay nodes to avoid complex multiuser decoding processes. The system performance is analysed in terms of BER and transmission confidentiality under the atmospheric turbulence condition, as well as considering multiple-access interference and background noise. The numerical results show that the relay transmission is an efficient solution to improve the system performance by the way of lower BER, long distance, and a large number of users. The authors also show that higher level of confidentiality can be attained by accurately configuring system parameters including the transmitted power and/or reducing the signal beam width.

The Special Issue also features three papers on system design issues. First, Sagias *et al.* discuss the mitigation of negative-exponential fading in OWC, which uses a semiconductor optical amplifier (SOA). As a regenerator, the SOA gain saturates during normal link operation and increases when the link experiences a fade. This unbalanced SOA operation is being used for equalisation of the signal power at its output and fades become less severe and of reduced duration. Analytical results show that the fade probability is reduced by over 90%, the scintillation index is improved by 75% for an optimal level of the received power, and the average duration of fades is reduced by 68% for the same power level. The SOA used as pre-amplifier at the receiver provides a static sensitivity increase of at least 10 dB at 10 Gb/s, depending on the target BER. Borges *et al.* present the concept and the implementation of a fully photonics-based and reconfigurable multi- band RF transceiver for future OWC networks. The proposed device is based on frequency multiplication using optical external modulation technique, which enables one to achieve discrete tuning of the wireless frequency by simply manipulating the modulator bias voltage. The physical mechanism behind the frequency multiplication is analytically explained and experimentally demonstrated by generating RF carriers at 5.2 GHz with signal-to-noise ratio of up to 54 dB. High spectral purity, distortion absence and low phase noise of the generated RF signals have been observed. Furthermore, the photonics-based reconfigurable RF transceiver has been implemented and tested in a real optical-wireless network from the telecom operator Telecom Italia Mobile using a femtocell base station. Finally, Peter Barcik *et al.* focus on analysing the optimal distribution of optical intensity within a radiated laser beam at a transmitter plane propagating through free space turbulent channel. To analyse the propagation of an optical wave through atmospheric turbulence, the simulation, based on the split-step beam propagation method, has been adopted with the aim of determining the optimal parameters for a flattened Gaussian beam at the transmitter plane. The simulations show that the aperture averaging effect has the most impact on scintillation reduction.

Finally, performance of FSO systems over the turbulence channel is reported by Nistazakis *et al.* and Zhalehpour *et al.* The first paper presents the investigation on the influence of the non-linear clipping effect of the OFDM scheme, along with the atmospheric turbulence modelled using the gamma–gamma distribution. Since both effects significantly influence the performance of the link, the authors have derived closed-form mathematical expressions for the estimation of the average signal to noise ratio, the outage probability and the average BER that is vital for FSO system performance characterisation. Predicted and simulated results show the dependence of these key metrics on turbulence, constellation size and the photodetector's active area, which can be used for design of OFDM FSO links. Zhalehpour *et al.* consider multiuser multiple-input multiple-output (MU-MIMO) FSO communications and investigate the performance of various scheduling protocols, which provide different degrees of trade-off between throughput and fairness. For the proposed system, the central node and each user node are equipped with multiple transmit and receive apertures and equal gain combining is employed at the receiver side. Also adopted are round robin, opportunistic round robin, select-max, and *m*-th best user selection scheduling protocols. The authors derive closed-form outage probability expressions for each scheduling protocol over log-normal turbulence channel assuming non-equidistant placement of users, which are verified with Monte Carlo simulations.

2 Conclusions

The Special Issue has covered a number of key areas in OWC, both in VLC and FSO. In VLC, there is a strong interest in modulation techniques, and the efficient usage of the available modulation bandwidth and the colour spectrum, in order to achieve high speed data communications. In addition, the emerging trend in VLC is the integration of this technology with daily applications such as the body area networks as well as the optical fibre communication system. An overview on the latest on the IEEE 802.15.7r1 has been presented and the state-of-the-art OCC has been comprehensively discussed. In OWC, channel modelling and the link-performance analysis are the key landmarks continuing to attract research and development in the form of fundamental theoretical analysis and simulation, as well as practical implementation. FSO systems, even under clear channel turbulence, still remain a hot topic with a number of contributions outlined in this Special Issue. Furthermore, a number of papers have focused on the FSO system level aspect where relay features and multiple user capabilities have been explored. Papers have also been presented on the system design covering components such as SOA for mitigation of negative-exponential fading in OWC, optimal distribution of optical intensity of radiated laser beam, and a fully photonics-based and reconfigurable multi-band RF transceiver for future OWC networks. These extended works enhance the features and the sustainability of future OWC networks.

As Guest Editors, we would like to thank the authors for their submissions and the reviewers for their thoughtful and timely assessments of the contributions to this Special Issue. Finally, we would very much like to express our thanks and appreciations to the Chief Editor, the Editorial Team and The IET for giving us the opportunity to put together this Special Issue.

The 10th CSNDSP conference is planned in July 2016, in Prague, Czech Republic.

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