Journal of Theoretical and Applied Information Technology
15th June 2020. Vol.98. No 11

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

COOPERATIVE SYSTEMS IN OPTICAL WIRELESS COMMUNICATION: A SURVEY

IBRAHIMA GUEYE, IDY DIOP, IBRA DIOUM, K WANE KEITA, PAPIS NDIAYE, MOUSSA DIALLO, SIDI MOHAMED FARSSI

Department of Computer Science, Polytechnic Institute (ESP), Universite Cheikh Anta Diop ́ Dakar, Senegal

ABSTRACT

The In recent years, the broadband services demand has increased considerably. The size of the radio frequency spectrum (RF) (3 kHz to 300 GHz) should limit the growth of future wireless systems unless new parts of the spectr are opened. Even with the use of advanced engineering, such as signal processing and advanced modulation schemes, it will be very difficult to meet the demands of users in the coming decades, using frequencies existing carriers. On the other hand, there is a potential spectrum band can provide tens of Gbps to Tbps for users in the near future. Communication technology FSO (Free Space Optical), also known as optical wireless communication (OWC: optical wireless communication) has generated great interest in recent years. In some cases, the FSO is considered an alternative to existing technologies such as radio frequency. In other cases, FSO is considered a strong candidate to complete and integrate next-generation technologies, such as wireless networks 5G.Accordingly, the FSO technology is widely deployed in various indoor environments (e.g. data centers), terrestrial (e.g. mobile networks) and spatial (e.g., inter-satellite communication and deep space) and subsea systems (e.g., submarine detection). Gradually, as the portfolio of applications of FSO technology develops, the need for a clear investigation for cooperative systems FSO links is the same. Most surveys of existing cooperative systems are surveys at one level and therefore not inclusive enough to reflect changes and recent and emerging developments in different configurations of cooperative systems FSO. In this article we give an overview on the most important cooperative systems encountered in OWC systems in indoor environments, terrestrial, space and underwater. We use surveys offered to review and summarize the experimental work and the major systems of cooperative systems FSO in the area until 2019.Using the survey suggested, we aim to give researchers an opportunity to tap into the growing field and expansion of cooperative systems FSO technology in different environments. The proposed survey can also help to organize and systematically present the advances in technology research cooperative FSO systems.

Keywords: *Cooperative System, Free Space Optical (FSO), Indoor, Optical Wireless Communications (OWC), Space, Terrestrial, Underwater, Wireless Communications.*

1 INTRODUCTION

You In recent years, the number of devices,applications and services based on wireless connectivity has increased exponentially causing profound changes in our ways of living. New concepts such as the Internet of Things (IoT) related to connectivity with sensors and machines will amplify this phenomenon. The last global forum on wireless networks [1] predicts 7 trillion wireless connected devices available 7 billion humans by 2020. This incredible figure is a source of many concerns. In addition to the major environmental considerations related to the production and recycling of such devices,and knowing that the term "wireless" refers primarily radiofrequency technology (30KHz to 300GHz). Today mobile operators are struggling to deploy the 4G and also already preparing to host the fifth generation of mobile networks using MIMO(Multiple-Input Multiple-Output) ranges. The increasing demand of bandwidth due to the advent of innovative services which are having high bandwidth constraints forced the worm searchess alternatives to ensure transportation information. The introduction of the optical fiber in its origins competed with the coaxial cable. The progress in research on fiber have increased performance and out of copper cables. These performances are now fiber leading carrier in the terms of capacity and also in terms of scope if we were limited to terrestrial transmission. What hinders the deployment of fiber in spite of this performance is the high cost, much of which is related to civil engineering. The decrease in cost of deployment is therefore an opportunity to face the challenges of transmitting very high speed. Research and industry are working hard to expand the capacity of existing wireless technologies (e.g. reduce interference) and develop new ones to meet the emerging needs [2], [3]. The optical free space communication (FSO), also called optical wireless communication (OWC),the subject of a comprehensive study over the past decades as an attractive alternative to the RF technology. Similar to the optical fiber, data is used to modulate a light beam in FSO. The light beam then propagates from one point to another, however, a wireless manner. The recent peak of interest in the FSO technology is the fact that FSO combines high bandwidth optical communication systems and flexibility of wireless technologies. FSO technology stems from the fact that FSO combines high bandwidth optical communication systems and flexibility of wireless technologies. FSO technology works in a wide spectrum (see Figure 1), including the bands of near infrared (NIR), visible light (VL) and ultraviolet (UV).Conventionally, FSO links terrestrial and space operate in the NIR band, as optical fiber systems [4]. Terrestrial systems can also operate in bands VL [5] and UV. [6]On the other hand, interior FSO links typically operate in the NIR bands [7] and V [8],while OWC submarine systems operate in the NIR strips [9] and V [10].

FSO technology has also been considered as a complementary technology to existing RF systems, to the extent FSO and RF do not interfere. [11]This property is very important for applications where interference with RF systems must be avoided, as in hospitals and personal entertainment systems on commercial planes to mitigate interference with the electronic navigation systems sensitive avionics RF [12]. In addition, the next generation of wireless communication systems (eg., 5G) integrate several complementary access technologies and RF technology, including FSO [13], [14].

The main features and drawbacks of OWC systems are presented here. The nature of light gives OWC immunity systems against interference caused by adjacent channels in adjacent parts. With the possibility of frequency reuse in different parts of the same building, which means increased capacity. The OWC systems offer also better security at the physical layer. This is because the light does not penetrate opaque barriers, which means that the potential for eavesdropping is reduced unlike radio systems, and it reduces the need for data encryption [15], [16]. Of moreover, the detector (photodiode) has a very large surface area, typically tens of thousands of wavelengths, which leads to an efficient spatial diversity at the receiver [16]. These favorable features combined make OWC systems suitable substitutes for conventional radio systems. However, OWC systems have several disadvantages. In the indoor systems, the optical wireless access points of different rooms must be connected via a wired network, because the light can not penetrate the walls. Moreover, due to multipath propagation, reflections and spreading of the signal, optical signals suffer from attenuation and dispersion resulting in inter symbol interference (ISI). In addition, the signal to the receiver may include firing noises induced by ambient light sources intense (sunlight, incandescent lighting and fluorescent light), and this leads to signal corruption by this background noise [17], [18]. In addition, the transmitter power is limited by the safety regulations for eye and skin [19], [20].OWC systems require a receiver with a large area photodetector for collecting the maximum optical signal, and this causes an increase in the photodetector capacity, which causes a decrease in the available bandwidth of the receiver. The OWC systems can provide higher data rates beyond 10 Gbps [21], [22], [23], [24] but the implementation of OWC systems presents many challenges. For example, fog, rain and dust reduce data rates and coverage area of open-space optics (FSO) outdoor systems, while multipath propagation, noise and receiver interferences tend to limit the capacity of interior OWC systems.

The present relay transmission can be used to overcome the atmospheric turbulence and the problems mentioned above by allowing the data transmitted using a node of relay and avoid a direct link to the destination that is severely affected by the atmospheric turbulence. There are two types of relay configurations, namely; series relay (i.e., the transmission multihop) and parallel relay (i.e., Cooperative Diversity) [25]. To the best of the authors' knowledge, a summary of cooperative systems in wireless optical communication in different environments has not yet been studied. The purpose of

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

this article is to provide an overview of the most important cooperative systems encountered in OWC systems operating in indoor, terrestrial, space and underwater environments. We use the proposed surveys to examine and summarize the experimental work and major systems of FSO cooperative systems in these areas until 2019.

The cooperative communication is an active area of research because of its ability to improve reliability and extend coverage of wireless networks while useding infrastructure existing. Cooperation techniques have been extensively studied in the context of the free space optical communication systems (FSO) as an effect of mitigation through limitation of the turbulence induced by atmospheric scintillation [25] - [26]. Existing research in field of cooperative FSO communications revolve around mainly parallel while relaying active and selective that can be implemented in the absence and in the presence of channel state information (CSI) respectively. All the active relay [25] - [27] is a diagram in two simple and effective locations where the information packet is transmitted from the source (S) to the relay (R) for the first slot and, thereafter, transmitted from the relay to the destination (D) in the second slot. In this context No preference is given to one of the relay whatever the strengths of the underlying source and relay links relay destination. On the other hand, privileges relay selective transmission along the link from start to finish ensuring the highest performance levels increased at the expense of complexity accstreet system with the need to acquire full CSI [28], [26].Also in the optical cooperative communication, performance BER systems relaying VLC attended full-duplex relay is studied in [29].The authors [30] consider the BER performance of VLC systems aided relay based OFDM (orthogonal frequency division multiplexing) where it was shown that the performance can be improved with a relay transmission. The work [31] also investigates the BER performance of VLC full-duplex relay systems that outperform those with direct links. The authors [32] proposed a cooperative framework FSO relay support as backhaul networks. They also studied in [32] the feasibility of cooperative FSO communication system 5G (5th Generation of Wireless Communication Systems) backhaul frame. A parallel system architecture OFS multi-hop to make the best use of network resources, which was found to be superior to increase reliability and throughput is introduced [33]. The authors [32] consider such FSO cooperative multi-hop relay system with DF parallel to the channel state information (CSI) is available to all OFS nodes. They focused on maximizing network throughput and promoting transmission reliability of transmission networks. They also proposed a relay selection algorithm in which the rear pressure theory is used to promote flow. In I Gueye et al [34] proposed two cooperative patterns to decode and forward (DF) based error correcting codes particularly LDPC (Low-density Parity-check) codes, namely if I, This implies choosing parallel relay, the node transmitter transmits data to the receiver node and a relay node that relays to turn the date the destination node. This form of transmission acts as a network of distributed antennas and is regarded as a cooperative approach diversity; Case II, the multi-hop relay for to spread the scope of a transmission with a limited transmission range. This approach, the signal passes a relay node to another in series. Their results show that, compared to traditional transmission mode, their cooperative FSO systems can mitigate the fainting induced by atmospheric turbulence but also to protect the information.

We believe it is necessary to have a classification can express systematically cooperative systems and applications existing FSO links emerging.

The rest of the paper is organized as follows: in section 2 we discuss cooperative systems. We devote Section 3 related work of cooperative systems in indoor environments, land, space and underwater. Research directions and unresolved issues for cooperative systems in the OWC are discussed in section 4. Finally, we conclude the paper in Section 5.

2 PRELIMINARY AND BASIC CONCEPTS

In this section, we discuss the preliminary and basic concepts of cooperative systems related to optical wireless communication.

2.1 The cooperative systems in optical wireless communication

2.1.1 Motivations and context of the study

Please The As part of optical wireless transmission, the challenges ahead relate management limiting factor what atmospheric turbulence Nearby kilometers of land, the presence of an obstacle between transmitter and receiver and swaying buildings.

Several techniques have been applied to wireless optical systems to mitigate the effects of degradation due to the weather channel. These techniques include, among others: increasing the size of the receiving antenna, the adaptive optics systems proposed to correct the adverse effects, in particular the phase distortions of the atmosphere, the use of relays and the diversity technique using the spatial diversity [35].Among these techniques, the spatial diversity is particularly interesting, because it offers significant performance gains by introducing an additional degree of freedom in the spatial dimension. It also allows different devices to share resources to create a virtual multi-antenna system.

In addition, the art and is used today to solve these problems is the notion of cooperation in wireless optical networks. cooperative communications, multiple relay nodes operate in conjunction with the source node to transmit its information to the destination. Technical cooperation advantage of the property of broadcast wireless signals. The fact that the signal from a source to a destination can to be " listened to" by neighboring nodes, allows them to process the signal " listened 'and pass it to the destination. Treatment with relay consist of a repetition of the signal "listened"(An example will decode and re-encode the information or simply amplifying the received signal before transmitting it)or more sophisticated strategies such as relaying only part of the information, or compress the signal received before passing it [36]. In Figure 1, we illustrate a model of cooperative optical communication.

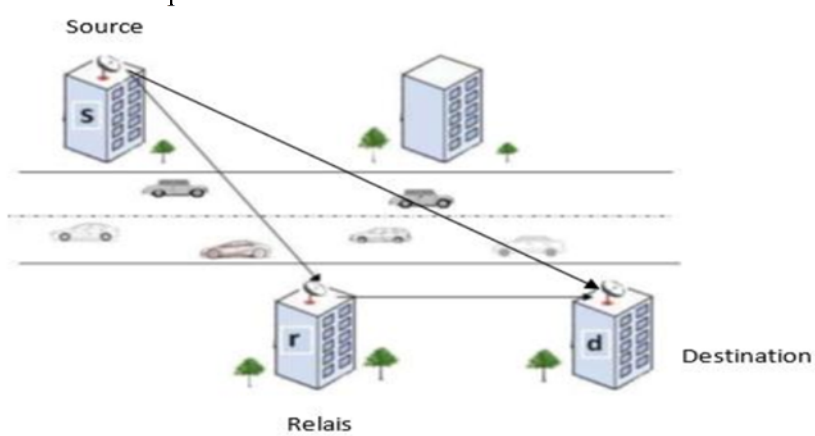

Fig 1: Cooperative Communication

In the following sections, we give a state of the art on the most important cooperative systems encountered in OWC systems in indoor environments, terrestrial, space and submarine. We use surveys offered to review and summarize the experimental work and the major systems of cooperative systems FSO in the area until 2019.

3 EXISTING SURVEYS OF COOPERATIVE SYSTEMS IN WIRELESS OPTICAL COMMUNICATION IN INDOOR ENVIRONMENTS, TERRESTRIAL, SPACE AND UNDERWATER.

After In this section we turn briefly review the various techniques of cooperative systems in the technology of optical wireless communication. The cooperative systems in the technology of optical wireless communication can be deployed in four different environments: indoor, earth and space. Recent decades have seen the development of various cooperative systems in the technology of FSO communication. Therefore, it is important to review the various cooperative systems FSO links in different environments.

3.1 Cooperative systems in indoor FSO links

It is table In this section, we discuss different conceptions of cooperative systems that can be used in VLC systems and their recent research efforts.
Visible light communication (VLC) has attracted much attention as an Inside application of optical wireless technology. [37]In the VLC system, visible light of 380-750 nm wavelength is used as the medium for data transmission. In this case, light from a light emitting diode (LED) is used for simultaneous illumination and communication of data at high data rate. [38]However, light from an LED source is naturally limited to a small area and is capable of blocking. The communication speed for data transfer in such applications is relatively low, typically of the order of a few kbit / s. One of the main challenges in such VLC systems is the limited range of a few meters for reliable communications, due to the limited transmission power, broadcast communication channel and non coherent optical communication. [39]To increase the reliable communication range, assisted the relay communications can be used. For a basic 3-luminaire relay system, a relay luminaire retransmits messages received from a lighting unit of the source device to a destination lighting. Even if a half-duplex relay can be used, where the fixture engages relay signal reception and transmission at different times, an additional time interval is required, resulting in the flow of the lower network. To address this problem, the authors [40] consider a full-duplex VLC relay namely the relay luminaire performs transmission and reception of simultaneous signals. For VLC full duplex relay, they considered in [39] a linear system topology, This corresponds to the lighting fixtures in hallways and small offices for example. In their work [40], they consider a triangular topology, corresponding to office lighting systems and cellular open. The difference between the triangular and linear topologies is that significant signal power still reaches the luminaire of the destination from the appliance the light source in the triangular topology [40]. Earlier works VLC systems on the power relay (cooperative) include [41-44].In [41], an LED VLC multi-hop system toys is demonstrated. In [42], a multi-user message transfer protocol for VLC channel is proposed. In the protocol, the message is transmitted by users to the destination when the destination is hidden / blocked. In an experimental study [43], an audio signal is successfully delivered to the destination on two terminals of intermediate relays. In [44]multi-hop transfer messages between vehicles is considered to VLC and performance is evaluated for the percentage of package delivery success based on the inter-V. The authors [45] consider DC biased W-OFDM and they also examine how cooperation between the light sources can improve the error rate performance. Their proposed scheme, a task light, like a desk lamp, acts as a terminal intermediate relay. In their jobs, they presented a vaste évaluation performance and optimizing OFDM VLC assisted relay in lighting systems constraints. They considered an office space with two light sources. One of them is placed in the ceiling for supplying the ambient light in the environment and the other isused for task lighting. Their results showed that they can be obtained up to 6 dB improvement in performance through optimal power distribution.

However, in [46], a much simpler solution to the problem is developed multipoint transmission and reception of a cooperative system is proposed and evaluated for VLC, where different VLC access points cooperating by transmitting their own data as well as additional cooperative signals that help the receptor cells voisines. The proposal provides a signal to the improvement of the noise (SNR), especially for non-line-of-Sight (NLOS) between the access point and receiver, a common situation in the corridor scenarios with many people, or in laboratories and shops with furniture. The proposal provides a improvement signal noise ratio (SNR), especially for non-line-of-Sight (NLOS) between the access point and receiver, a common situation in the corridor scenarios with many people, or in laboratories and shops with furniture. An adjustment system is also used proposed who transmission and reception Multi-Point (CoMP Coordinated) in points and simple NLOS Division Multiple Pulse Position (DPPM) in Line-of-Sight (LOS). The proposed scheme for CoMP OWC is able to provide more than 3 dB gain in SNR compared to traditional systems. This leads to a decrease in error probability.

Similarly, to increase the reliability of the connection and / or extend the coverage ceiling lights can be used as relay terminals to the other in a multi-hop fashion. Either half-duplex (HD) or full-duplex (FD) relays can be used. In the context of RF communication, relaying HD is generally preferred.

This requires that transmit and receive power levels differ from each other by orders of magnitude. In a terminal FD RF relay, high torque signal will locally transmitted the receiver and thus overwhelm the signal received much lower. The signal coupling is often called loop interference [47]. In contrary RF,FD is relatively easier to implement relay in VLC systems since the interference of the loop should be at least high due to the illumination pattern plus directional light source. There have been some attempts on FD investigation relayed in the context of VLC systems. Particularly, work in [39] and [40] intended to relay scenarios where ceiling lights arranged in triangular and linear topologies help each transmission multi-jumps. The powerful combination of OFDM transmission and power relay has been closed first in [48], later in [49].Based on the use of relaying HD it was demonstrated that significant performance gains can be achieved through cooperation in relation to the direct transmission. These gains, however, disappear as the size of modulation becomes larger, due to the fact that the HD relay uses additional time slots to relay phase, effectively reducing the spectral efficiency. FD relay improves spectral efficiency. In VLC multi-carrier systems, the authors [50] studying a VLC OFDM system with FD relay. They first developed a realistic interior VLC channel model and presents the channel impulse response (CIR) for the loop interference channel, namely, from the relay transmitter for relaying the receiver. Based on this channel model, assess the performance of bit error rate (BER) of the OFDM systems with VLC relayed FD and compare its performance to both the direct transmission (i.e., Without relay) and relay HD. Their results show that FD relaying much better results than the HD over and becomes the obvious choice for the high modulation orders.

To improve network reliability and improve the coverage, it is important to use relay in both RF and VLC networks [51] - [52].frequency systems VLC / hybrid radio (RF) have emerged to provide improved communication coverage [53], [54]. In [53]a number of VLC and RF access points are used to improve the coverage and performance overall rate system VLC / RF hybrid. In [54], VLC is integrated with an RF based wireless network to improve the achievable data rates for mobile users. The authors solved the problem of resource allocation for a VLC system / RF hybrid to maximize energy efficiency [54]. Their limits is to propose the optimal design of the energy harvest and packet transmission for the duration of the second hop [54]. A double hop VLC / RF system as a new hybrid VLC / RF approach to extend coverage inside VLC systems was presented in [55]. In this approach a second hop RF link is used to extend the coverage of a first-hop link VLC introducing a link between the two jumps. To reduce energy consumption, the relay is equipped with a photovoltaic module that collects light energy inside and converts electric power [56], [52].The relay uses the energy harvested to retransmit the data received on the first VLC-hop link to a mobile terminal on the second-hop RF link. The dual-hop VLC / RF system proposed provides low complexity and energy efficient solution for extending coverage of VLC systems. [55].

The authors [57], the design of a receiver for optical wireless communications that can harvest energy while communication. Taking advantage of such a system, the performance of the relay system can be improved by harvesting energy from the received signals and the design of an optimal time of switching protocol EH [58], [59]. The authors [60] present a framework that deals with energy problems, inefficiency of the spectrum and the issue of coverage. Specifically, their jobs are focused on a system with two users attended by a relay EH (Energy Harvesting) decode-and-forward (DF).The two LED sources and receivers communicate via the relay and not directly. These assumptions are reasonable because of the limited coverage of VLC systems. The relay receives optical signals from two LEDs via a forward link and VLC. Information on both receptors via an RF link. They assumed that the relay is self-powered, ie, is equipped with a capacity EH (Energy Harvesting). They studied the system described in the quasi-static fading where all channels are fixed. Furthermore, they emphasized the DF relaying strategy, although strategies more sophisticated relaying can provide some improvement in performance. [60].

On the other hand, [60] studied an RF / VLC EH relay system activated DF hybrid to increase the coverage of the system. The authors [52] consider an RF system / VLC hybrid with relay-based EH under delay constraints, if a parameter has been developed to control the time for excess EH and data packet and retransmission; Moreover, it was shown that the setting has an optimal value able to minimize the probability of packet loss. The authors [61] analyzed the SC of the hybrid RF / VLC network based on DF relays with jamming capacities. First, they showed how to obtain VLC-RF-based BF vectors and maximize the achievable SC. Then, they define the power optimization algorithm taking into account the power constraints in the presence of the eavesdropper. Their results show the effectiveness of signal interference to the eavesdropper which, in turn, results in lower SC achievable to the eavesdropper. In addition, the results reveal an asymmetry in the SC plots which is caused by the location of the eavesdropper [61]. Wireless data transmission in RF and VLC systems increases the risk of wiretapping attacks. The upper layers of security techniques, for example, data encryption, cryptography, etc. can be used to secure communication, but it generally requires heavy computing and processing powers which lead to high energy consumption [62], [63].On the other hand, the Physical Layer Security (PLS) is considered as a viable solution for communication and before evacuation and listening illegal attacks scrambledage. It is in this context that the authors [64] study research PLS aspects of RF hybrid networks and VLC assisted by DF relay. They consider two different energy saving policies, namely, non-cooperative power saving (CRS) and Cooperative Power Saving (CPS). For example, in the case of the SNPC, transmit nodes can be considered restricted entities peak energy which operate independently without the cooperation of power between nos nodes. On the other hand, Cooperative Power Saving (CPS) describes another case when the nodes are flexible in terms of imposed power constraints and limited only by the total average power that can be applied in the following scenario. Since the performance of the DF relaying system is mainly dominated by the lower channel, it is essential to efficiently distribute power to maximize system performance. For example, the unused power source can be used by the relay node for answer to this requirement, and vice versa. To meet the growing demands exponentially related green communications, they formulated the energy consumption minimization problem for subsystems considered both. They studied the region and the Secrecy Capacity (SC) achievable in the consumption of network scenarios considered. In addition, they evaluated the performance of the user's fault of interest to policy. To achieve the perfect secret, they exploit ZFBF (Zero-Forcing Beamforming) technique to prevent the activities of illegal listening and achieve positive SC for the desired users. Their results show that the proposed CPS cases surpassing one NCPS (Non-Cooperative Power Saving), namely, to the NCPS, SC saturation starts earlier and maximum possible secrecy is still lower than that obtained for SPC.

Statistical analysis of the radio access diversity dual-hop mixed system of RF-VLC relay was studied. [65]The relevance of such a scenario will increase in the years ahead with the deployment of small cells 5G millimeter wave and proliferation of VLC technology indoor. The main aim of their work is to obtain new analytical expressions for the probability of failure and the average BER which are used to examine the effect of system parameters on performance. They used Monte Carlo simulations to confirm analytical results [65]. They managed to demonstrate that the half angle to half the power of LEDs significantly affects the performance of the RF / VLC system. They also showed that a lower angle value results in a narrower optical signal, which leads to greater received optical power. The lower part, linked to the VLC environment, is reflected in better system performance, because the propagation path of the optical signal transmission is shorter.

3.2 Cooperative systems in Terrestrial FSO Link and Space FSO Link

In this section, we discuss different conceptions of cooperative systems that can be used in terrestrial and space systems and their recent research efforts.

3.2.1 Cooperative systems in terrestrial FSO link

Optical communication systems of free space (FSO) received the attention of the convincing research because of its leadership in the optical spectrum unlicensed bandwidth high, high capacity, robustness to electromagnetic interference (EM), easy installation, high data rate. [66]. In spite of the advantages of FSO communication, there are limiting factors that play a major role. In general, a distance of 1 km there is a significant deterioration in the quality of the signal shown in the communication system FSO communication is the source (S) and destination (D) is practically impossible. These main limiting factors are the atmospheric turbulence that causes scintillation and the other is the pointing error [66-67].This turbulence is nothing, but due to the fluctuation of the refractive index of the atmosphere due to the inhomogeneity of the temperature and pressure of the air particle. The pointing error is introduced due to the dynamic wind load, low thermal expansion quake earth which causes the tilting of the sighting path line (LOS) between transmitter and receiver. Optical cooperative communication with various combination regimens is used to obtain better performance and overcome the deterioration due to fading the FSO link. The series and parallel relay performance of FSO assisted systems AF modes and relay futures were discussed in [68].The technique of cooperative diversity to mitigate the effect of turbulence on optical links free space (FSO) has been demonstrated by Chadi AbouRjeily et al in [69]. They have developed a closed form equation for the transmission of the entire optical power along the strongest link between the source and the destination. In [70], Chadi Abu Rjeily and A. Slim proposed schema mono-relay cooperative diversity and made the analysis of non coherent FSO communications using intensity modulation with direct detection (IM / DD). The technique of cooperative relaying with modulation pulse position (PPM) and optical interleaving multiple access division to achieve spatial diversity and performance robust transmission to mitigate the effects of degradation of the atmospheric turbulence has been demonstrated in [71]. In [72], and Mr. Karimi Nasiri Kenari analyzed 3 way communication configuration FSO where in the cooperative protocol may be applied to achieve spatial diversity without much increase in hardware. Analysis of the FSO cooperative communication system for symmetric and asymmetric channel environments with PPM, Gamma Gamma AWGN channel model and has been discussed in [73].In [74] the authors analyzed a cooperative assisted single relay system with symmetrical channel environments and asymmetric with the pointing error (PE). They are used binary input On-Off (OOK) modulation for data Gamma-gamma with AWGN as atmospheric turbulent channel model and the direct detection receiver at the end of the simulation equipment using Rsoft Optsim. Various techniques of combination such as maximal ratio combining (MRC), an equal gain combining (EGC) and selection combining (SC) are used at the receiver for comparing [74]. Their results show that a significant improvement in performance is obtained in the case of cooperative communication with the use of the combination compared to maximal compared to equal winning combination and selection comb diversity combining techniques as described in the literature which deteriorates pointing error system performance. In some experiments the use of PPM and MPPM modulation gives better performance compared to OOK modulation. So given the importance of their work it would be much more important to use PPM and MPPM modulation to compare them with OOK modulation.

The use of cooperative has also been recommended for FSO systems where technical relaying all active and selective have been implemented [68], [75]. All assets relay is set when all participating relay the cooperative effort by simultaneously decoded versions or Forwarding amplified symbols Information received at the destination node. This approach is characterized by a remarkable simplicity, because it can be implemented without the need to acquire any form of channel state information (CSI) [68]. The selective relay has been presented as an alternative to reship all assets where one relay is selected from all relays available depending on the condition of FSO network. The selective relay is the superior relay to all active relays at the expense of increased complexity since we need to have CSI for reasons of choosing the relay with the best link - at the end of [76], [75]. In addition to adopting conventional two-phase source relay techniques and relay destination techniques, exploiting inter-relay links was found to be beneficial either through one-way links or links in both sense [77]. The added value of inter-relay links has been studied in the case where only adjacent relays are connected [77]. The authors [78] extend the adjacent connectivity model in [77] for the complete connectivity model with 2 and 3 relay systems. They considered the bridging selection scenarios so they compared the all active and selective regimes, both analytical and numerical, and showed that they achieved the same order of diversity.

To improve the network reliability and improve the coverage, it is important to use relay in both RF and FSO networks. Mixed systems relaying RF-FSO have been widely discussed in the literature: The literature there has been a growing interest in how the FSO and RF link can be used in a double-hop configuration to support the uplink [79- 80] and downlink transmissions [81-82]. On the downlink, the rate of high flow FSO is demultiplexed and served more RF users. In an FSO-RF mixed system, both links experience fading. In the RF link, fading is due to multipath propagation of the signal while in the FSO link is due to the turbulence atmospheric. In the literature on FSO systems it uses several different distributions to model the statistical behavior of irradiance fluctuations turbulence channels of the atmosphere, such as log-normal, K, Gamma-Gamma and double Weibull. For the RF link, Nakagami-m distributions or Generalized Nakagami-m (GNM) are generally assumed [81, 83, 82] and Generalized-K, the κ-μ models and Rice [84, 85]. In order to provide a general framework on the performance analysis of mixed FSO-RF systems, the authors [86] considered a dual-hop system where FSO and RF links experience respectively Double Generalized Gamma (DGG) and Generalized-K extended (EGK) fading and their model works well in different situations of turbulence (ie weak, moderate and strong). They described closed-form expressions for the probability of interruption (OP), probability of bit error (BEP) and the ergodic capacity (EC) of mixed FSO-RF systems. They also performed an asymptotically-noise signal (SNR) analysis to obtain the achievable diversity commands. Their results show that diversity controls depend on a number of system and channel parameters, RF fading and gravity shadowing, FSO turbulence parameters, alignment errors, type of detection and relaying technique [86] .

In [87-88] the authors are investigating the double hop mixed systems (DH) using a relay system based Amplify-and-forward (AF) relay with a source liaison RF and a relay link to FSO. Furthermore, in [88], the expressions of closed shape for the outage probability and the rate of average bit error are derived using distribution Malaga, which is regarded as a generalized model for the fading FSO link. In the case of AF relays, the relay node amplifies the received message signal and then transmits the amplified version to the destination node. However, the noise at the same time that the signal is also amplified, which is the main drawback of AF relay system. In [89], a similar mixed system RF-FSO DH using a relay system according to decode-and-forward (DF) was studied. In [90, 91], a relay-based system FSO-DF with a source-destination link is studied. In [92], an RF-FSO mixed system based DF is viewed with a single input multiple-output (SIMO) RF source-relay links and a mono-mono-input-output (SISO) FSO relay desiwe link. In all RF mixed FSO above systems, the FSO is considered only as a last mile access link. Furthermore, in [92] expressions in the closed form of the failure and the probability ergodic achievable rate for the RF-FSO multihop relay-based DF and mesh networks are studied. In [94], the performance of an FSO-based hybrid switch / RF system is designed for an SH scenario, which is restricted to lognormal fading for the FSO link. In [90] the switching system is considered as a source to destination link OFS live and a mixed link DHB ackup RF-FSO with an RF link relay source and a relay to FSO link. In addition, [94,95], two different link switching strategies are discussed, including a single regime FSO threshold which offers simplicity in the transceiver design, and a dual threshold FSO system that prevents unnecessary switching between the primary link and the FSO backup RF link or a mixed RF/FSO backup link. In [96], the authors analyzed the performance of a hybrid transmission FSO/RF-based switching in a DH scenario with selection combining (SC).The derived exact expressions, however, are too complex and therefore the simplest asymptotic expressions are needed. A switching system for an FSO/RF bridge DF based hybrid system using maximal ratio combining (MRC) to the destination [97].The system consists of a DF-relay-based FSO and RF subsystems, which are activated by means of a switching mechanism, with given priority subsystem FSO. The FSO subsystem initiates the transmission as the signal instant on noise (SNR) at the optical receiver exceeds a certain threshold, γth. When the SNR falls below γth the pass system to the RF subsystem, while putting the FSO subsystem standby. To overcome the traditional shortcomings DF relaying, the authors [97] used a protocol DF selective relay where the transmission is conditioned based on a Skein from successful decoding at the relay. [98]In the proposed scheme, they considered switching the entire subsystem and not at the level of individual link. [97]The results of their simulations show that the hybrid system proposed by the MRC outperforms the hybrid HS system and cooperative FSO systems with the MRC in rouse diversity and benefits of switching, respectively.

Despite the advantages of selecting relays, there are practical questions regarding the acquisition of CSI required for selection of relays that can have a significant impact on system performance relaying selection, following a channel estimation error and delay in the return channel, etc. Today, there are few studies on the impact of CSI on the performance of a mixed RF-FSO system with AF relay selection, in which the partial relay selection scheme has been used [99] .In [100], the authors consider an RF-FSO mixed system with a double-hop AF relay in which a part of relay selection scheme was used to select the best relays. They also consider the RF channels are under constraints and Rayleigh spectrum sharing while the FSO channel is assumed to follow the Gamma Gamma distribution. By using multiple simulation results, they assessed the impact of the feedback delay and relay selection on the system performance under different system settings.

3.2.2 Cooperative systems in space FSO links.

For Satellite systems have been widely used in navigation, broadcasting, and emergency disaster because of the advantage of offering a service over a large area with a data transmission high rate, especially in scenarios where terrestrial wired or wireless communication systems are not available [101]. However, the availability of satellite signals can often be hampered by the masking effect, observation and obstacles that block the line to which the communication link (LOS) between the satellite link and a terrestrial user [102]. Disaster recovery is an important issue that requires the establishment of a broadband access from a disaster area the rest of the world. If the terrestrial infrastructure is destroyed, then geostationary satellites may be used to provide broadband communication links in the disaster area. On the other hand, systems of free space optical (FSO) offer very high data rates over short distances and can support more users compared to those taken supported by radio frequency (RF).In [103],it is under duress as transportable ground stations of cooperative relays can be used to provide broadband access in areas affected by thedisaster; these ground stations receive satellite signals and relay the received signals to a destination node on the link masked FSO. The satellite / terrestrial hybrid FSO cooperative systems are not only profitable, but can also be deployed very quickly [103]. The authors [104] analyzed the amplify-and-forward (AF) protocol [105] on the basis of the cooperation of the federative hybrid satellite and terrestrial FSO systems, where the satellite-relay link follows the Ombré-Ricienne terrestrial mobile satellite model (LMS); and the FSO-relay destination link follows the Gamma-Gamma fading. Their hybrid satellite-terrestrial FSO cooperative system considered is different from a generic RF link tandem / FSO where the RF link following statistical fading much simpler. They derived the moment generating function (m.g.f.) For hybrid bond; use the m.g.f, the rate of approximate average symbol error (SER) of the respective cooperative system is obtained. In addition, they derived the order of analytical diversity from the AF-based reflected hybrid cooperative system. It was found that the diversity of satellite-based systems FSO hybrid AF has a direct dependence on the parameters of atmospheric turbulence FSO link. However, the maximum achievable diversity is limited by the satellite link [104]. Furthermore, in [106], the performance of the asymmetric radio frequency (RF) / FSO hybrid cooperative system FSO-terrestrial satellite with two decode-and-forward (DF) relays was studied. They other [107] analyzed the cooperative system hybrid satellite / terrestrial FSO recital DF relay. They adapted a more general and model complex Lutz presented in [108]which considers the LMS channel is a Markov model with two states with a good (unshadowing) and bad (shadowing) states. They also modeled the intensity fluctuations of the optical signal caused by atmospheric turbulence by a gamma distribution gamma [107].

In addition, according to the report of the ITU [109]about half of the world population are still not connected to the Internet with most of them living in the least developed countries. Therefore, the cost FSO hybrid satellite solution is also a very promising technique for reducing the digital divide in least developed countries, which generally inadequate fiber optic network and wireless network infrastructure. [109]It is shown for the safety of the physical layer (PLS) theory [110] that the secure transmission of information can be obtained when the quality of the link indiscreetis lower than that of the legitimate link. This motivates research into communication security from the point of view of information theory [111], [112]. In [113], the robust secure beamforming performance for the fifth generation (5G) wireless systems operating at millimeter wave frequencies and coexisting with a network of satellites is Studied. The performance of the secret of a satellite network and terrestrial cognitive in the presence of an eavesdropper equipped with multiple antennas is studied in [114] or the interference mobile base station is deliberately introduced to improve the safety of the satellite link. Motivated by the latest advances in physical layer security analysis [115], [116] - [117] and the potential of the hybrid satellite-FSO system in various scenarios, the authors in [118] studied the performance of the secret of the satellite-FSO hybrid cooperative system for the two relay cases, Amplifier-and-forward (AF) and decode and forward (DF) in their document. They have largely modeled the discoloration of the satellite link the shaded-Rice model while the FSO channel fading is modeled by the Gamma-Gamma distribution. They take into account in their analyzes the effects of the fused channels, the impact of the pointing error and the FSO detection techniques. They obtained the exact expression of the probability of secrecy failure (SOP) in addition to the closed form of exact expression of the capacity of medium secrecy (ASC) [118].

3.3 Cooperative systems in underwater FSO links

Paper In this section, we discuss different conceptions of cooperative systems that can be used in UOWC systems and their recent research efforts.
Wireless communication underwater have been used in many areas, including disaster warning, marine environmental monitoring, and recognition of resources. Due to the advantage of transmitting high speed, high capacity anti interference and high security, underwater optical wireless communications (UOWCs) have captured widespread attentions [119].For the sake of checking the feasibility UOWCs, several research institutes have developed corresponding devices and experiences in the field demonstrated [120], [121] and issues on the net work optimization, including the deployment node, location and routing have been studied [122] - [124]. However, UOWCs suffer from several challenges, such as limited communication range and a great loss path. The aided transmission relay a promising technique to solve these problems. In this context, the performance characterization of Power Relay UOWC was fully explored by recent research, [123] [125] - [127].The multihop connectivity with the relay in series is analyzed on absorption, scattering and turbulence channels induced for UOWC in [125], [126],where feasible transmission range and end to end error rate (BER) are derived. The transmission performance under multi-hop Amplify and Forward (AF) and the relay decoding and transfer (DF) relay is achieved and the impacts of Connectivityity multihop on location and routing are studied in [123], [127].These results indicate that UOWC aided relay can significantly extend the viable communication distance and improve network performance.

To fully exploit the advantages of cooperative relay-assisted transmission, the allocation of resources, such as relays and power, needs to be carefully studied. This resource allocation some research has been presented in order to optimize the allocation of resources for free space optical networks (OFS) [128, 129, 130] and for underwater acoustic networks, there has been sporadic research on relay selection and power problem allocation [131, 132, 133, 134]. However, these research results cannot be applied directly in the UOWC due to its distinctive properties, including noise components and link configurations. More concretely, the noise of solar radiation varies with the depth of the water in the UOWC, which has a negative effect on the communication performance. In addition, submarine NLOS links are unique, where performance and application scenarios are significantly different from those of line-of-sight (LOS) links. Most existing research only investigates the performance of direct submarine communication based on NLOS, while the performance of cooperative underwater communication based on NLOS has never been explored. It is in this context that other [135] examined the relay selection problems and power allocation for the cooperation of optical wireless networks sub-husbandborn. The UOWC cooperative transmission based on Amplify-and-forward relays (AF) is modeled, where in the noise solar radiation which varies with the depth of water is considered [135].They designed two relay selection schemes and power allocation, where in the optimization criteria are designed minimizing energy consumption and maximizing the overall signal-to-noise ratio (SNR).These two optimization problems are both shown to be strictly quasi-convex, and the Levenberg-Marquardt algorithm (LM) is used to obtain solutions [135].The effectiveness of each system is measured in both networks based-LOS and NLOS-based underwater, and there after, the main factors that influence the selection of the relay and the assignment is concluded for LOS and NLOS links [135]. These simulation results indicate that the proposed scheme shows better performance in terms of energy saving and improving SNR. Moreover, the main factors that affect performance are UOWC cooperative conclude that the balance between the path loss and the sound of solar radiation is essential for networks based on LOS, while eliminating the loss of refraction is crucial for networks based on NLOS.

4 OPEN RESEARCH QUESTIONS FSO COOPERATIVE SYSTEMS IN INDOOR ENVIRONMENTS, TERRESTRIAL, SPACE AND UNDERWATER.

We discussed various works of cooperative systems in OWC links throughout this article. As we discuss applications of cooperative systems in OWC, we highlighted future research directions related to each subdomain, cooperative systems and OWC application. The previous sections show that researchers are continually finding new applications for cooperative systems in the OWC technology. The continued expansion of technology applications portfolio OWC makes it difficult to predict the future of the OWC technology. In this section, we will give an overview of some of the future directions and applications that deserve more attention of cooperative systems in the OWC technology indoor environments, land, space and underwater.

4.1 Open research questions in systems cooperative indoor FSO links

The main current research focuses on modulation techniques, mobility, connectivity uplinks, control of change and lighting, increase the achievable data rate, use of cooperative systems hybrid RF / FSO interiors.

- The provision of channels uplink is an important issue .the solutions proposed, such as using IRC corner cube reflectors or RF systems, unfortunately does not correspond with the objective of VLC system to provide high data rate in the uplink and down link these technical peuvent conflict, ensure mobility and minimize the size of VLC devices (mobile device).Therefore, new systems to provide an uplink VLC are required. Intermediate stations (relay) have been studied for use in variety of networks to increase coverage area and capacity. Repeater stations can be used for VLC systems to: provide uplink connection forusers and enable communication between users.
- The main border in VLC and OWC is now networking. This includes networking and applied MAC techniques in the optical media for optimizing beam, detectors receptive fields of vision and guidance, and to determine the optimal allocation of resources including the wavelengths, spatial and temporal resources. Optimal front transport and backhaul network architectures using FSO systems multi-hop system FSO cooperative multi-hop relay DF parallel in canal of state information (CSI) are open questions deserve substantial attention to supply and collect data from optical or lighting sourcesand IRC detectors.
- Using machine learning and artificial intelligence in VLC and OWC is important and timely to carry out the optimal allocation of resources descrite above, to allow the network to self-configure, self-adapting, taking into account interference, capacity, energy consumption, flow, reliability and availability are considered.
- The use of relays in VLC and mixed systems of RF-VLC relay was studied to increase the coverage area and network capacity. The use of error correcting codes include LDPC codes, Polar codes and codes fountains in cooperative systems in VLC to protect information and increase network reliability are open questions deserve substantial attention.
- For hybrid RF networks / VLC secret ability based on a DF relay jamming capabilities analyzed in the literature. Moreover policy SPC is proposed for hybrid RF / VLC using a DF relay to allow nodes to share efficiently redundant power supply to improver confidential transmission. Use correcting codes of errors such as LDPC codes and polar codes associated with the use of the CS and CPS are open questions deserve atvoltage to better improve the performance of hybrid systems RF / VLC.

4.2 Open research questions in systems cooperative terrestial FSO links

Authors The main current research focuses on modulation techniques, techniques for selection relays active and selective, cooperative systems mixed RF / FSO land, control of changes and lighting, increase the achievable data rate, channel security, the error correcting codes.

- The added value of inter-relay links was investigated in the case are connected only adjacent relay. The context of all assets relay with a number of relay were but also studied selective relay. Further work is required in this area use hybrid systems RF / FSO with an associated DF relay with codes error correction to improve coverage and reliability.
- In previous work, a system hybrid FSO / RF based switched transmission has been studied for an SH scenario which is limited to the lognormal for a FSO link discoloration. Since FSO and MMW RF transmission is limited to short communication

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

from the beach, performance analysis of a DH cooperative relay scenario is needed to improve coverage and reliability. In addition, under the 5G cellular networks, cooperative relaying is necessary for efficient transmission.

- Using DF relay network for hybrid RF / VLC improves performance in terms of secrecy capacity performance measures, such as the secret ability, power consumption and failure probability secret (SOP), in the presence of the eavesdropper both SWNT and CPS case. To achieve the perfect secrecy, ZFBF technique to prevent the activities of illegal listening and achieve positive SC for the desired users. Work is needed using the secret ability, the failure probability secret (SOP) and ZFBF technical systems in hybrid RF / FSO to prevent eavesdropping activity and achieve positive SC for users desired.
- The only relay analysis of cooperative system attended symmetrical channel environments and asymmetric with the pointing error (PE) was investigated in the FSO. The binary on-off input (OOK) modulation for data Gamma-gamma with AWGN as atmospheric turbulent channel model and the direct detection in the receiver end were also used. Work is needed in this area using the same channels, OFDM modulation, error correcting codes particularly LDPC codes to increase capacity but also the reliability of the transmission of information in the FSO networks.
- FSO cooperative communication, which focus on the use of reliability and terrestrial FSO links 5G networks of resources was studied. A parallel system architecture OFS multi-hop is introduced to make the best use of network resources, which was found to be superior to increase reliability and throughput. Further work is needed in this area in hybrid systems use RF / FSO with a DF relay associated with the OFDM modulation technique, MPPM for coverage, network capacity and reliability of global networks.

4.3 Open research questions in systems cooperative space FSO links

The main current research focuses on modulation techniques, techniques for selection relays active and selective, cooperative systems mixed RF / FSO land, control of changes and lighting, increase the achievable data rate, channel security, error correcting codes, secret channel strategies.

- The transmission of signals in an optical link satellite hybrid cooperation / FSO earth is considered. In particular, the problem of AF relay in a cooperative binding hybrid satellite / terrestrial-FSO, where a masked destination node receives the transmission relayed from a FSO link was discussed. The relay satellite link is supposed to follow the fading shaded Rican, and the irradiance of the FSO link between the relay and the destination is assumed to tracking the distribution gamma-gamma. Investigations in this area are needed to consider the advantages of OFDM and MPPM to increase capacity system and make it more reliable transmission using error correcting codes particularly polar code.
- Performance-secret satellite FSO hybrid system using cooperative relaying strategies in AF and DF were investigated. Discoloration of the satellite link is modeled largely using model-shadowed Rice while the FSO channel fading is modeled by the Gamma distribution Gamma. Besides Fade channels, the impact of the error score and detection technique FSO are taken into account in our analysis. ZFBF the technical systems in hybrid satellite / FSO the activity of to prevent eavesdropping and achieve positive SC for the desired users, the use of error-correcting codes are open questions deserve attention to better improve the performance of cooperative systems hybrid satellite / FSO.

4.4 Open research questions in systems underwater FSO links

The main current research focuses on modulation techniques, relay selection techniques, channel acquisition and power allocation, hybrid cooperative systems submarines (UOWC) / acoustic submarines, increase the achievable data rate, the error correcting codes.

- Despite the advantages of selecting additional work relays are needed in this area use in the acquisition of CSI required for relay selection which can have a significant impact on the performance of relay selection systems, due to channel estimation error and delay in the return channel.
- Relay selection problems and power allocation for UOWC cooperative transmission based on Amplify-and-forward relays (AF) were studied. Further studies are needed in this area using a DF relay associated with correcting errors particularly codes LDPC codes and polars codes to improve performance and reliability of networks.

- Cooperative systems have been studied in optical submarine networks (UOWC) and acoustic submarine networks. To improve network reliability and improve network coverage, the use of hybrid optical submarine networks (UOWC) and acoustic underwater using a DF relay are open questions deserve attention for better improve performance systems.
- Cooperative systems have been studied in the optical networks in free space (FSO) and acoustic submarine networks. To improve network reliability and improve network coverage, the use of hybrid optical submarine networks (UOWC) and spatial networks using FSO DF relay are open questions deserve attention for better improve performance systems.

5 CONCLUSION

Should In this article, we presented an overview of cooperative systems in the wireless optical that focused on deployment for communication in environments the indoor, land, space and underwater. We have shown how cooperative systems technologies in optical wireless can offer a complementary technology for future wireless communications in the interior applications, terrestrial, space and submarines that could coexist with RF systems. Four distinct classes of cooperative systems in OWC (interior, land, space and submarine) were discussed. The generic components of FSO links including light sources, photodetectors, and modulations schemes, the main problems in FSO systems (indoor, terrestrial, space, submarines), cooperative systems in FSO (indoor, terrestrial, space, underwater), the open research questions of cooperative systems in optical wireless for each category were identified. This review allows us to say that the use of cooperative systems in FSO systems (indoor, terrestrial, space and underwater) increases reliability, network performance. These cooperative systems also achieve better performance in terms of saving energy and improving SNR. This review allows us to say that the use of hybrid systems cooperative RF / interior FSO (VLC), RF / FSO terrestrial, Satellite / FSO helps improve reliability and increase sewing network.

REFERENCES

[1] G. Eason G L. Sorensen and K. E. Skouby, User Scenarios2020, report, http://www.wireless-world-research.org July 2009.
[2] O.W. Hennes Henniger, “An introduction to free-space optical communications.” Radioengineering, vol. 19, no. 2, 2010.
[3] A.S. Hamza et al., “A survey on inter-cell interference coordination techniques in OFDMA-based cellular networks,” Communications Surveys Tutorials, IEEE, vol. 15, no. 4, pp. 1642–1670, Fourth 2013.
[4] I. Alimi et al., “Challenges and opportunities of optical wireless communication technologies,” in Optical Communication Technology, P. Pinho, Ed. Rijeka: InTech, 2017, ch. 2.
[5] I. Takai et al., “Optical vehicle-to-vehicle communication system using LED transmitter and camera receiver,” IEEE Photonics Journal, vol. 6, no. 5, pp. 1–14, Oct 2014.
[6] D. Han et al., “Research on multiple-scattering channel with monte carlo model in UV atmosphere communication,” Appl. Opt., vol. 52, no. 22, pp. 5516–5522, Aug 2013.
[7] A.S. Hamza et al., “Wireless communication in data centers: A survey,” IEEE Communications Surveys Tutorials, vol. 18, no. 3, pp. 1572– 1595, thirdquarter 2016.
[8] P.H. Pathak et al., “Visible light communication, networking, and sensing: A survey, potential and challenges,” IEEE Communications Surveys Tutorials, vol. 17, no. 4, pp. 2047–2077, Fourthquarter 2015.
[9] I.E. Lee et al., “Near-infrared wireless optical communication with particulates in-suspension over the underwater channel,” Conference on Lasers and Electro-Optics, p. STh3O.4, 2017.
[10] Z. Zeng et al., “A survey of underwater optical wireless communications,” IEEE Communications Surveys Tutorials, vol. 19, no. 1, pp. 204–238, Firstquarter 2017.
[11] D. Heatley et al., “Optical wireless: The story so far,” IEEE Commun. Mag., vol. 36, no. 12, pp. 72–74, 1998.
[12] D. Borah et al., “A review of communication-oriented optical wireless systems,” EURASIP J. on Wireless Commun. and Netw., no. 1, pp. 1–28, 2012.
[13] F. Demers et al., “A survey of opportunities for free space optics in next generation cellular networks,” Communication Networks and Services Research Conf., pp. 210–216, May 2011.
[14] S. Wu et al., “Visible light communications for 5G wireless networking systems: from fixed to mobile communications,” Network, IEEE,vol. 28, no. 6, pp. 41–45, Nov 2014.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

[15] A. Alexiou and M. Haardt, "Smart antenna technologies for future wireless systems: Trends and challenges," IEEE Commun. Mag., vol. 42, no. 9, pp. 90– 97, 2004.
[16] M. Kavehrad, "Broadband room service by light," Sci. Am., vol. 297, no. 1, pp. 82–87, 2007.
[17] A. C. Boucouvalas, "Indoor ambient light noise and its effect on wireless optical links," IEE Proc. - Optoelectron., vol. 143, no. 6, pp. 334–338, 1996.
[18] a. J. C. Moreira, R. T. Valadas, and A. M. de Oliveira Duarte, "Performance of infrared transmission systems under ambient light interference," IEE Proc. - Optoelectron., vol. 143, no. 6, pp. 339–346, 1996.
[19] A. C. Boucouvalas, "IEC 825-1 eye safety classification of some consumer electronic products," 1996.
[20] I. Millar, M. Beale, B. J. Donoghue, K. W. Lindstrom, and S. Williams, "The IrDA standards for high-speed infrared communications," Hewlett-Packard J., vol. 49, no. 1, pp. 10–26, 1998
[21] F. E. Alsaadi, M. A. Alhartomi, and J. M. H. Elmirghani, "Fast and efficient adaptation algorithms for multi-gigabit wireless infrared systems," J. Light. Technol., vol. 31, no. 23, pp. 3735–3751, 2013.
[22] S. H. Younus and J. M. H. Elmirghani, "WDM for high-speed indoor visible light communication system," in International Conference on Transparent Optical Networks, 2017.
[23] A. T. Hussein, M. T. Alresheedi, and J. M. H. Elmirghani, "20 Gb/s Mobile Indoor Visible Light Communication System Employing Beam Steering and Computer Generated Holograms," J. Light. Technol., vol. 33, no. 24, pp. 5242– 5260, 2015.
[24] A. T. Hussein, M. T. Alresheedi, and J. M. H. Elmirghani, "25 Gbps mobile visible light communication system employing fast adaptation techniques," in International Conference on Transparent Optical Networks, 2016, vol. 2016– Augus.
[25] M. Safari and M. Uysal, "Relay-assisted free-space optical communication," Wireless Commun., IEEE Trans. on, vol. 7, no. 12, pp. 5441– 5449, 2008.
[26] C. Abou-Rjeily, "Performance analysis of selective relaying in cooperative free-space optical systems," J. Lightwave Technol., vol. 31, no. 18, pp. 2965–2973, September 2013.
[27] B. Zhu, J. Cheng, M. Alouini, and L. Wu, "Relay placement for FSO multi-hop DF systems with link obstacles and infeasible regions," IEEE Trans. Wireless Commun., vol. 14, no. 9, pp. 5240 – 5250, Sep. 2015.
[28] N. D. Chatzidiamantis, D. S. Michalopoulos, E. E. Kriezis, G. K. Karagiannidis, and R. Schober, "Relay selection protocols for relayassisted free-space optical systems," IEEE J. Opt. Commun. Netw., vol. 5, no. 1, pp. 4790 –4807, January 2013.
[29] O. Narmanlioglu, R. C. Kizilirmak, F. Miramirkhani and M. Uysal, "Cooperative Visible Light Communications With Full-Duplex Relaying," IEEE Photonics Journal, vol. 9, no. 3, pp. 1–11, June 2017.
[30] R. C. Kizilirmak and M. Uysal, "Relay-assisted OFDM transmission for indoor visible light communication," IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom), pp. 11–15, May 2014.
[31] H. Yang and A. Pandharipande ,"Full-duplex relay VLC in LED lighting triangular system topology," 6th International Symposium on Communications, Control and Signal Processing (ISCCSP), pp. 85–88, May 2014
[32] Song Song ; Yejun Liu ; Qingyang Song ; Lei Guo "Relay Selection and Link Scheduling in Cooperative Free-Space Optical Backhauling of 5G Small Cells", IEEE/CIC International Conference on Communications in China (ICCC) 2017
[33] M. A. Kashani and M. Uysal, "Outage performance and diversity gain analysis of free-space optical multi-hop parallel relaying", Journal of Optical Communications and Networking, vol. 5, iss. 8, pp. 901-909, 2013.
[34] Ibrahima GUEYE, Ibra DIOUM, K Wane KEITA, Idy DIOP, Papis NDIAYE, Moussa DIALLO, Sidi Mohamed FARSSI " Performance of cooperative system based on LDPC codes in wireless optical communication", Future Technologies Conference – FTC, 2019.
[35] Hemeni Kaushal, V. K. Jain, Subrat Kar"Improvement of ground to satellite FSO link performance using transmit diversity in weak atmospheric turbulence", International conference on Intelligent and Advanced Systems (ICIAS), June 2010, pp. 1≠6
[36] KRAMER, G., GASTPAR, M. et GUPTA, P. (2005). ¿ Cooperative strategies and capacity theorems for relay networks À. IEEE Trans. Inf. Theory, 3037{63.
[37] C. Hongda, W. Chunhui, L. Honglei, C. Xiongbin, G. Zongyu, C. Shigang, and W. Qin, "Advances and prospects in visible light communications", J. of Semiconductors, vol. 37, no. 1, pp. 1–10, Jan. 2016.
[38] Y.-J. Zhu, W.-Y. Wang, and G. Xin, "Faster-than-Nyquist signal design for multiuser multicell indoor visible light communications", IEEE Photonics Journal, vol. 8, no. 1, Feb. 2016.
[39] H. Yang and A. Pandharipande, "Full-duplex relay VLC in LED lighting linear system topology," in Annual Conference of the IEEE Industrial Electronics Society (IECON), 2013.
[40] H. Yang et A. Pandharipande, «FULL-DUPLEX RELAY VLC IN LED LIGHTING

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

TRIANGULAR SYSTEM TOPOLOGY,» International Symposium on Communications, Control and Signal Processing (ISCCSP), 2014.

[41] N.O. Tippenhauer, D. Giustiniano, S. Mangold, "Toys communications with LEDS: enabling toy cars interaction", IEEE Consumer Communications and Networking Conference (CCNC), pp. 48-49, 2012.

[42] Z. Wu, "Free space optical networking with visible light: A multi-hop multi-access solution", Ph.D. Thesis, Boston University, 2012.

[43] L.T. Dung, S. Jo, B. An, "VLC based multi-hop audio data transmission system", Springer Lecture Notes in Computer Science, vol. 7861, pp.880-885, 2013.

[44] C. Liu, B. Sadeghi, E.W. Knightly, "Enabling vehicular visible light communication (V2LC) networks", in Proc. of the Eighth ACM international workshop on Vehicular Internetworking, pp. 41-50, 2011.

[45] R. C. Kizilirmak et M. Uysal, «Relay-Assisted OFDM Transmission for Indoor Visible Light Communication,» IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom), 2014.

[46] B. G. Guzman, A. L. Serrano et V. P. G. Jimenez, «Cooperative optical wireless transmission for improving performance in indoor scenarios for visible light communications,» IEEE Transactions on Consumer Electronics, vol. 61, 2015.

[47] T. Riihonen, S. Werner, and R. Wichman, "Hybrid Full-Duplex/HalfDuplex Relaying with Transmit Power Adaptation," IEEE Transactions on Wireless Communications, vol. 10, no. 9, pp. 3074-3085, September 2011.

[48] R. C. Kizilirmak, O. Narmanlioglu, and M. Uysal, "Relay-Assisted OFDM-Based Visible Light Communications," IEEE Transactions on Communications, vol. 63, no. 10, pp. 3765-3778, Oct. 2015.

[49] H. Kazemi and H. Haas, "Downlink Cooperation with Fractional Frequency Reuse in DCO-OFDMA Optical Attocell Networks," IEEE International Conference on Communications (ICC), Kuala Lumpur, pp. 1-6, 2016.

[50] O. Narmanlioglu, R. C. Kizilirmak, F. Miramirkhani et M. Uysal, «Cooperative Visible Light Communications with Full-Duplex Relaying,» IEEE Photonics Journal, vol. 9, 2017.

[51] J. Mo, M. Tao and Y. Liu, "Relay Placement for Physical Layer Security: A Secure Connection Perspective," IEEE Communications Letters, vol. 16, no. 6, pp. 878–881, June 2012.

[52] T. Rakia, H. C. Yang, F. Gebali and M. S. Alouini,"Dual-Hop VLC/RF Transmission System with Energy Harvesting Relay under Delay Constraint," IEEE Globecom Workshops (Globecom Wkshps), pp. 1–6, December 2016.

[53] D. A. Basnayaka and H. Haas, "Hybrid RF and VLC Systems: Improving User Data Rate Performance of VLC Systems", 2015 IEEE 81st Vehicular Technology Conference (VTC Spring), Glasgow, May 2015.

[54] M. Kashef, M. Ismail, M. Abdallah, K. Qaraqe, and E. Serpedin, Energy efficient resource allocation for mixed RF/VLC heterogeneous wireless networks", IEEE Journal on Selected Areas in Communications, accepted for publication, Mar. 2016.

[55] A.S. Weddell, N.R. Harris, and N.M. White, "An efficient indoor photovoltaic power harvesting system for energy-aware wireless sensor nodes", in Proc. of the Eurosensors XXII, Dresden, Germany, Sep. 2008.

[56] C. Li, W. Jia, Q. Tao, and M. Sun, "Solar cell phone charger performance in indoor environment," Proceeding of IEEE 37th Annual Northeast Bioengineering Conference (NEBEC), Troy, NY, April 2011.

[57] Z. Wang, D. Tsonev, S. Videv, and H. Haas, "On the design of a solarpanel receiver for optical wireless communications with simultaneous energy harvesting," IEEE J. Sel. Areas Commun., vol. 33, no. 8, pp. 1612–1623, 2015.

[58] [11] Y. Gu and S. Aissa, "Interference aided energy harvesting in decode-andforward relaying systems," in IEEE Int. Conf. Commun. (ICC), 2014, pp. 5378–5382.

[59] [12] S. S. Kalamkar and A. Banerjee, "Interference-assisted wireless energy harvesting in cognitive relay network with multiple primary transceivers," in IEEE Global Commun. Conf. (GLOBECOM), 2015, pp. 1–6.

[60] M. R. Zenaidi, Z. Rezki, M. Abdallah, K. A. Qaraqe et M.-S. Alouini, «Achievable Rate-Region of VLC/RF Communications with an Energy Harvesting Relay,» GLOBECOM 2017, 2017.

[61] J. Al-khori, G. Nauryzbayev, M. Abdallah, et M. Hamdi, « Secrecy Capacity of Hybrid RF/VLC DF Relaying Networks with Jamming », in 2019 International Conference on Computing, Networking and Communications (ICNC), 2019, p. 67-72.

[62] M. Masoud, I. Jannoud, A. Ahmad and H. Al-Shobaky, "The power consumption cost of data encryption in smartphones," International Conference on Open Source Software Computing (OSSCOM), pp. 1– 6, September 2015.

[63] J. Wu, I. Detchenkov and Y. Cao, "A study on the power consumption of using cryptography algorithms in mobile devices," 7th IEEE International Conference on Software Engineering and Service Science (ICSESS), pp. 957–959, August 2016.

[64] . J. Al-Khori, G. Nauryzbayev, M. M. Abdallah, et M. Hamdi, « Secrecy Performance of Decode-and-Forward Based Hybrid RF/VLC Relaying Systems », *IEEE Access*, vol. 7, p. 10844-10856, 2019.

[65] M. I. Petkovic, M. Narandzic, D. Vukobratovic, et A. Cvetkovic, « Mixed RF-VLC Relaying System with Radio-Access Diversity », in *2019 28th Wireless and Optical Communications Conference (WOCC)*, 2019, p. 1-5.

[66] [1] D. Kedar and S. Arnon, "Urban optical wireless communication networks: the main challenges and possible solutions," IEEE Communications Magazine, vol. 42, no. 5, pp. S2–S7, May 2004.

[67] H. G. Sandalidis, T. A. Tsiftsis, G. K. Karagiannidis, and M. Uysal, "BER performance of FSO links over strong atmospheric turbulence channels with pointing errors," IEEE Communications Letters, vol. 12, no. 1, pp. 44–46, Jan. 2008.

[68] M. Safari and M. Uysal, "Relay-assisted Free-space optical communication", IEEE Trans. on wireless Communication, vol. 7, no. 12, pp. 5441-5449, Dec.2008

[69] Chadi Abou-Rjeily and Serj Haddad, "Cooperative FSO Systems: Performance Analysis and Optimal Power Allocation", Journal of Lightwave Technology, vol. 29, No. 7, April, 2011

[70] Chadi Abou-Rjeily and A. Slim, "Cooperative diversity for free-space optical communications: Transceiver design and performance analysis", IEEE Trans. Communication, vol. 59, No. 3, March 2011

[71] Jingyuan Fan, Xiaolin Zhou, and Jun Liu, "Design and Evaluation of an IDMA Cooperative Relay Free-Space Optical System", International conference on space optical systems and applications, 2011

[72] M. Karimi and M. Nasiri-Kenari, "BER analysis of cooperative systems in free-space optical networks", Journal of Lightwave Technology, vol. 27, no. 24, pp. 5639–5647, Dec. 2009

[73] Vineeta Dubey, D.Chadha and Vinod Chandra, "Cooperative communication on free space optical communication systems", Internation Conference on Wireless Networks (ICWN) 2013, pp. 297- 300, Las Vegas, USA, July 2013

[74] V. Dubey, D. Chadha, et V. Chandra, « Effect of pointing error on cooperative free space optical communication systems under different channel conditions », in *2014 IEEE International Conference on Advanced Networks and Telecommuncations Systems (ANTS)*, 2014, p. 1-4.

[75] C. Abou-Rjeily and S. Haddad, "Cooperative FSO systems: Performance analysis and optimal power allocation," J. Lightwave Technol., vol. 29, no. 7, pp. 1058–1065, April 2011.

[76] N. D. Chatzidiamantis, D. S. Michalopoulos, E. E. Kriezis, G. K. Karagiannidis, and R. Schober, "Relay selection protocols for relayassisted free-space optical systems," IEEE J. Opt. Commun. Netw., vol. 5, no. 1, pp. 4790 –4807, January 2013.

[77] C. Abou-Rjeily, "All-active and selective FSO relaying: Do we need inter-relay cooperation?" J. Lightwave Technol., vol. 32, no. 10, pp. 1899 – 1906, May 2014

[78] M. Hamad et C. Abou-Rjeily, « FSO cooperative all-active and selective relaying schemes with backup RF antennas », in *2018 IEEE Middle East and North Africa Communications Conference (MENACOMM)*, 2018, p. 1-6.

[79] N. Varshney, A. K. Jagannatham, and P. K. Varshney, "Cognitive MIMO-RF/FSO cooperative relay communication with mobile nodes and imperfect channel state information," IEEE Trans. Cognitive Commun. Netw., vol. 4, no. 3, pp. 544–555, Sep. 2018.

[80] N. Varshney and A. K. Jagannatham, "Cognitive decode-andforward MIMO-RF/FSO cooperative relay networks," IEEE Commun. Lett., vol. 21, no. 4, pp. 893–896, Apr. 2017.

[81] E. Zedini, H. Soury, and M.-S. Alouini, "On the performance of dual-hop FSO/RF systems." in Proc. IEEE Int. Symp. Wireless Commun. Systems (ISWCS), Brussels, Belgium, Aug. 2015, pp. 31–35.

[82] Z. Jing, Z. Shang-hong, Z. Wei-hu, and C. Ke-fan, "Performance analysis for mixed FSO/RF Nakagami-m and exponentiated weibull dual-hop airborne systems," Optics Commun., vol. 392, pp. 294–299, June 2017.

[83] E. Zedini, H. Soury, et M.-S. Alouini, « On the Performance Analysis of Dual-Hop Mixed FSO/RF Systems », *IEEE Trans. Wirel. Commun.*, vol. 15, nº 5, p. 3679-3689, mai 2016.

[84] N. Zdravkovic, M. I. Petkovic, G. T. Djordjevic, and K. Kansanen, "Outage analysis of mixed FSO/WiMAX link," IEEE Photonics J., vol. 8, no. 1, pp. 1–14, Feb. 2016.

[85] I. Trigui, N. Cherif, and S. Affes, "Relay-assisted mixed FSO/RF systems over Malaga-M and κ - μ shadowed fading channels," IEEE Wireless Commun. Lett., vol. 6, no. 5, pp. 682– 685, Oct. 2017.

[86] B. Ashrafzadeh, E. Soleimani-Nasab, M. Kamandar, et M. Uysal, « A Framework on the Performance Analysis of Dual-Hop Mixed FSO-RF Cooperative Systems », *IEEE Trans. Commun.*, vol. 67, nº 7, p. 4939-4954, juill. 2019.

[87] S. Anees and M. R. Bhatnagar, "Performance of an amplifyand-forward dual-hop asymmetric RF–FSO communication system," J. Opt. Commun. Netw., vol. 7, no. 2, pp. 124–135, Feb. 2015.

[88] P. V. Trinh, T. C. Thang, and A. T. Pham, "Mixed mmWave RF/FSO relaying systems over generalized fading channels with pointing errors," IEEE Photon. J., vol. 9, no. 1, 5500414, Feb. 2017.

[89] S. Anees and M. R. Bhatnagar, "Performance evaluation of decode-and-forward dual-hop asymmetric radio frequencyfree space optical communication system," IET Optoelectron., vol. 9, no. 5, pp. 232–240, Oct. 2015.

[90] M. R. Bhatnagar, “Performance analysis of decode-andforward relaying in gamma-gamma fading channels,” IEEE Photon. Technol. Lett., vol. 24, no. 7, pp. 545–547, Apr. 2012.

[91] M. R. Bhatnagar, “Average BER analysis of differential modulation in DF cooperative communication system over gammagamma fading FSO links,” IEEE Commun. Lett., vol. 16, no. 8, pp. 1228–1231, Aug. 2012.

[92] N. Singhal, A. Bansal, and A. Kumar, “Performance evaluation of decode-and-forward-based asymmetric SIMO-RF/ FSO system with misalignment errors,” IET Commun., vol. 11, no. 14, pp. 2244–2252, Sept. 2017.

[93] B. Makki, T. Svensson, M. Brandt-Pearce, and M. Alouini, “On the performance of millimeter wave-based RF-FSO multi-hop and mesh networks,” IEEE Trans. Wireless Commun., vol. 16, no. 12, pp. 7746–7759, Dec. 2017.

[94] M. Usman, H. C. Yang, and M. S. Alouini, “Practical switchingbased hybrid FSO/RF transmission and its performance analysis,” IEEE Photon. J., vol. 6, no. 5, pp. 1–13, Oct. 2014.

[95] B. Bag, A. Das, I. S. Ansari, A. Prokeš, C. Bose, and A. Chandra, “Performance analysis of hybrid FSO systems using FSO/RF-FSO link adaptation,” IEEE Photon. J., vol. 10, no. 3, pp. 1–17, June 2018.

[96] S. Sharma, A. S. Madhukumar, and S. Ramabadran, “Switching based hybrid FSO/RF transmission for DF relaying system,” in IEEE Wireless Communications and Networking Conference (WCNC), 2018, pp. 1–6.

[97] S. Sharma, A. S. Madhukumar, et R. Swaminathan, « Switching-based cooperative decode-and-forward relaying for hybrid FSO/RF networks », *IEEEOSA J. Opt. Commun. Netw.*, vol. 11, nº 6, p. 267-281, juin 2019.

[98] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, “Cooperative diversity in wireless networks: Efficient protocols and outage behavior,” IEEE Trans. Inf. Theory, vol. 50, no. 12, pp. 3062–3080, Dec. 2004.

[99] M. Torabi and D. Haccoun, “Capacity analysis of opportunistic relaying in cooperative systems with outdated channel information,” IEEE Commun. Letters, vol. 14, no. 12, pp. 1137–1139, 2010.

[100] M. Torabi et N. Mohammadi, « Partial Relay Selection with Feedback Delay in an AF Cooperative Relaying RF-FSO System with Spectrum Sharing », in *2019 2nd West Asian Colloquium on Optical Wireless Communications (WACOWC)*, 2019, p. 26-30.

[101] R. Radhakrishnan, W. W. Edmonson, F. Afghah, R. M. Rodriguez-Osorio, F. Pinto, and S. C. Burleigh, “Survey of inter-satellite communication for small satellite systems: Physical layer to network layer view,” IEEE Commun. Surveys Tuts., vol. 18, no. 4, pp. 2442–2473, May 2016.

[102] M. R. Bhatnagar and M. Arti, “Performance analysis of hybrid satellite-terrestrial FSO cooperative system,” IEEE Photon. Technol. Lett., vol. 25, no. 22, pp. 2197–2200, Nov. 2013.

[103] E. Leitgeb, et al., “Hybrid wireless networks combining WLAN, FSO and satellite technology for disaster recovery,” in Proc. 15th IST Mobile Wireless Commun. Summit, Jun. 2005, pp. 1–5.

[104] M. R. Bhatnagar et M. K. Arti, « Performance Analysis of Hybrid Satellite-Terrestrial FSO Cooperative System », *IEEE Photonics Technol. Lett.*, vol. 25, nº 22, p. 2197-2200, nov. 2013.

[105] A. Nosratinia, T. E. Hunter, and A. Hedayat, “Cooperative communication in wireless networks,” IEEE Commun. Mag., vol. 42, no. 10, pp. 74–80, Oct. 2004.

[106] N. Sharma, A. Bansal, and P. Garg, “Performance of DF based dualhop dual-path hybrid RF/FSO cooperative system,” Wireless Pers. Commun., vol. 91, no. 2, pp. 1003-1021, Nov. 2016.

[107] M. I. Petkovic, G. T. Djordjevic, et Z. M. Marjanovic, « Analytical approach in evaluation of outage probability of DF based hybrid satellite-terrestrial FSO cooperative system », in 2017 13th International Conference on Advanced Technologies, Systems and Services in Telecommunications (TELSIKS), 2017, p. 326-329.

[108] E. Lutz, D. Cygan, M. Dippold, F. Dolainsky, and W. Papke, “The land mobile satellite communication channel-recording, statistics, and channel model,” IEEE Trans. Veh. Technol., vol. 40, no. 2, pp. 375- 386, May 1991.

[109] International Telecommunication Union (ITU), “ITU Facts and Figures,” https://www.itu.int/en/ITU-D/Statistics/ Documents/facts/ICTFactsFigures2017.pdf, 2017, [Online; accessed 16-August-2018].

[110] A. D. Wyner, “The wire-tap channel,” Bell Syst. Techn. J., vol. 54, no. 8, pp. 1355–1387, Oct. 1975.

[111] H. Lei, Z. Dai, I. S. Ansari, K. Park, G. Pan, and M.-S. Alouini, “On secrecy performance of mixed RF-FSO systems,” IEEE Photon. J., vol. 9, no. 4, pp. 1–15, Aug. 2017.

[112] H. Lei, H. Luo, K.-H. Park, Z. Ren, G. Pan, and M.-S. Alouini, “Secrecy outage analysis of mixed RF-FSO systems with channel imperfection,” IEEE Photon. J., vol. 10, no. 3, pp. 1–13, June 2018.

[113] Z. Lin, M. Lin, J.-B. Wang, Y. Huang, and W.-P. Zhu, “Robust secure beamforming for 5G cellular networks coexisting with satellite networks,” IEEE J. Sel. Areas Commun., vol. 36, no. 4, pp. 932–945, Apr. 2018.

[114] B. Li, Z. Fei, X. Xu, and Z. Chu, "Resource allocations for secure cognitive satellite terrestrial networks," IEEE Wireless Commun. Lett., vol. 7, no. 1, pp. 78–81, Feb. 2018.

[115] K. An, T. Liang, X. Yan, and G. Zheng, "On the secrecy performance of land mobile satellite communication systems," IEEE Access, vol. 6, pp. 39 606–39 620, Aug. 2018.

[116] Q. Huang, M. Lin, K. An, J. Ouyang, and W.-P. Zhu, "Secrecy performance of hybrid satellite-terrestrial relay networks in the presence of multiple eavesdroppers," IET Commun., vol. 12, no. 1, pp. 26–34, Dec. 2017.

[117] Y. Ai, M. Cheffena, A. Mathur, and H. Lei, "On physical layer security of double Rayleigh fading channels for vehicular communications," IEEE Wireless Commun. Lett., vol. 7, no. 6, pp. 1038–1041, Dec. 2018.

[118] Y. Ai, A. Mathur, M. Cheffena, M. R. Bhatnagar, et H. Lei, « Physical Layer Security of Hybrid Satellite-FSO Cooperative Systems », *IEEE Photonics J.*, vol. 11, p. 1-14, 2019.

[119] Z. Zeng, S. Fu, H. Zhang, Y. Dong, and J. Cheng, "A Survey of Underwater Optical Wireless Communications," IEEE Commun. Surv. Tut., vol. 19, no. 1, pp. 204–238, First Quarter, 2017.

[120] H. Yin, Y. Li, F. Xing, B. Wu, Z. Zhou, and R. Li, "Hybrid Acoustic, Wireless Optical and Fiber-optic Underwater Cellular Mobile Communication Networks," in Proc. IEEE Int. Conf. Commun. Tech. (ICCT), Oct. 2018.

[121] C. Pontbriand, N. Farr, J. Hansen, J. C. Kinsey, L. Pelletier, and J. Ware, "Wireless Data Harvesting Using the AUV Sentry and WHOI Optical Modem," in Proc. IEEE OCEANS, Oct. 2015.

[122] F. Xing, H. Yin, X. Ji, and V. C. M. Leung, "An Adaptive and Energyefficient Algorithm for Surface Gateway Deployment in Underwater Optical/Acoustic Hybrid Sensor Networks," IEEE Commun. Lett., vol. 22, no. 9, pp. 1810–1813, Sep. 2018.

[123] N. Saeed, A. Celik, S. Alouini, and T. Y. Al-Naffouri, "Performance Analysis of Connectivity and Localization in Multi-Hop Underwater Optical Wireless Sensor Networks," IEEE Trans. Mobile Comput., early access.

[124] J. Liu, H. Yin, F. Xing, and X. Ji, "An Algorithm of Virtual Network Mapping for Underwater Wireless Optical Networks," Photonic Netw. Commun., vol. 36, no. 1, pp. 35–42, Aug. 2018.

[125] A. Vavoulas, H. G. Sandalidis, and D. Varoutas, "Underwater Optical Wireless Networks: A k-Connectivity Analysis," IEEE J. Oceanic Eng., vol. 39, no. 4, pp. 801–809, Oct. 2014.

[126] M. V. Jamali, A. Chizari, and J. A. Salehi, "Performance Analysis of Multi-hop Underwater Wireless Optical Communication Systems," IEEE Photon. Technol. Lett, vol. 29, no. 5, pp. 462–465, May. 2017

[127] A. Celik, N. Saeed, T. Y. Al-Naffouri, and M.-S. Alouini, "Modeling and Performance Analysis of Multihop Underwater Optical Wireless Sensor Networks," in Proc. IEEE Wireless Commun. Netw. Conf. (WCNC), pp. 1–6, Apr. 2018.

[128] A. S. Ghazy, H. A. Selmy, and H. M. Shalaby, "Fair Resource Allocation Schemes for Cooperative Dynamic Free-space Optical Networks," J. Opt. Commun. Netw., vol. 8, no. 11, pp. 822–834, Nov. 2016.

[129] M. Z. Hassan, M. J. Hossain, J. Cheng, and V. C. Leung, "Statistical Delay-QoS Aware Joint Power Allocation and Relaying Link Selection for Free Space Optics Based Fronthaul Networks," IEEE Trans. Commun., vol. 66, no. 3, pp. 1124–1138, Mar. 2018.

[130] H. Zhou, D. Hu, S. Mao, and P. Agrawal, "Joint relay selection and power allocation in cooperative fso networks," in Proc. IEEE Global Commun. Conf. (GLOBECOM), pp. 2418–2423, Dec. 2013.

[131] [17] Y. Li, Z. Yu, H. Zhou, and J. Tao, "To Relay or not to Relay: Open Distance and Optimal Deployment for Linear Underwater Acoustic Networks," IEEE Trans. Commun., vol. 66, no. 9, pp. 3797–3808, Sep. 2018.

[132] X. Li, J. Liu, Y. Lei, H. Song, and X. Guan, "Relay Selection in Underwater Acoustic Cooperative Networks: A Contextual Bandit Approach," IEEE Commun. Lett., vol. 21, no. 2, pp. 382–385, Feb. 2017.

[133] G. Prasad, D. Mishra, and A. Hossain, "Joint Optimal Design for Outage Minimization in DF Relay-assisted Underwater Acoustic Networks," IEEE Commun. Lett., vol. 22, no. 8, pp. 1724–1727, Aug. 2018.

[134] A. Doosti-Aref and A. Ebrahimzadeh, "Adaptive Relay Selection and Power Allocation for OFDM Cooperative Underwater Acoustic Systems," IEEE Trans. Mobile Comput., vol. 17, no. 1, pp. 1–15, Jan. 2018.

[135] F. Xing, H. Yin, J. Xiuyang, et V. Leung, « Joint Relay Selection and Power Allocation for Underwater Cooperative Optical Wireless Networks », *IEEE Trans. Wirel. Commun.*, vol. PP, p. 1-1, oct. 2019.