Mathematical Modelling of Engineering Problems
Vol. 11, No. 8, August, 2024, pp. 2083-2092
Journal homepage: http://iieta.org/journals/mmep

A Systematic Review of Relay-Aided Dual-Hop FSO Device-to-Device Communication Systems Using STLC and STBC Techniques

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https://doi.org/10.18280/mmep.110809

Received: 6 July 2023
Revised: 9 October 2023
Accepted: 22 October 2023
Available online: 28 August 2024

Keywords:
free space optical communication, relay device, device to device, Space-Time Line Code, Space-Time Block Code

ABSTRACT

This study explores the use of optical relay devices to provide dual-hop communication between two devices using an FSO link without a base station. The central theme of this essay revolves around enhancing the reliability and spectral efficiency of device-to-device (D2D) communication. The primary goal is to establish robust and high-speed connections while minimizing the processing burden on the relay device (RD). The challenge lies in securing a stable connection over extended distances in D2D communication, safeguarding against signal degradation and link disruptions. The study emphasizes the importance of signal processing where RD does not need to estimate channel state information, whether at RD's receiving or sending sides. To realize this objective, the study suggests employing Space-Time Line Code (STLC) for encoding between the first device and the RD and Space-Time Block Code (STBC) for encoding between the RD and the second device. This strategic combination aims to optimize processing within the RD, thus enhancing overall communication performance. Furthermore, the investigation explores the potential implementation of orthogonal and quasi-orthogonal STLC-STBC techniques to mitigate delays and improve power efficiency. This systematic review uncovers several promising avenues for researchers to bridge existing gaps in wireless communication technologies by addressing the challenges related to relay-assisted D2D communication and refining encoding strategies.

1. INTRODUCTION

Free space optics (FSO) is a line-of-sight communication technology that employs light amplification by stimulated emission of radiation (LASERs) and photodetectors to establish optical connections between two locations without optical fiber [1]. For high-data-rate applications of mobile gaming, multimedia streaming, augmented reality applications, etc., that D2D connection is a strong candidate to meet that growing demand [2]. The challenges are many, and the communication requirements are many in fifth-generation (5G), such as high bandwidth, speed, reduced power consumption, and virtual reality [3]. The FSO Link is a backup system in a high-transmission data backup or when disaster strikes [4].

With its main benefits being a large amount of available bandwidth and fast throughput, FSO has surfaced as a promising technology.to achieve broad adoption of this technology, significant research efforts are needed to address some basic limitations of FSO technology, such as limited or no support for NLOS communication, limited or no support for mobility, and the effect of atmospheric turbulence [5].

Noteworthy, FSO operates in the vicinity of near-infrared rays and offers a massive data flow, much like optical fiber links. Still, it does not require building permissions, requires no road drilling, is simple to implement, and cannot take a long such as optical links [6]. Unlike radio frequency systems, FSO communications do not need spectrum licenses and, thus, are not subject to electromagnetic interference. Opposite, the reliability of the FSO link is rugged and limited to a short dimension. Relay-assisted FSO systems have gained much attention recently as a way to reduce these effects [7]. STLCs and STBCs were considered practical alternatives because they don't require CSI on both communication sides. Their practical deployment is straightforward compared to other diversification approaches [2]. STLC is used in Link D_1-ORD. For this, ORD didn't need the CSI to decode signals that were being received. Overall, less time, energy, and processing will be required as a result.

D2D communications is a promising technology for the fifth generation and beyond, without needing a base station to meet high data requirements and transmission speed. This ensures limited power consumption [8]. In addition, line of sight (LOS) in optical communication is necessary between two devices that rely on FSO technology to transmit different data over limited distances. As the distance between the two devices increases, the attenuation due to weather conditions on the laser beam affects this in particular [9].

Distance restrictions are an essential factor in determining the reliability of a D2D connection. Poor connection or link drop is easy to lose. D2D, with the help of a dual-hop relay, addresses this potential shortcoming and improves system communication as the relay node is placed to expand the communication distance. Thus, it meets speed, power consumption, time, and quality advantages in D2D communication [10]. Similarly, the range of a link is more extensive in next-generation network (NGN) communications, where long-distance FSO communications require careful measures of link survival reliability. Link broadening is achieved by shortening the optical beam interval [11]. A dual-hop system has become a focus of researchers' interest for its high spectral efficiency and for achieving reliable, energy-efficient communication [12]. The FSO dual-hop relay system was analyzed under the assumption of blind channel estimation [13]. In Cui et al.'s study [14], the relay node contributes to the survival of the D2D connection since the two devices are not on the same line for the FSO connection. The relay nodes were used between D2D links. Joint beamforming technologies with MIMO enhance network capacity in 5G and achieve high-performance connectivity [15].

To evaluate and compare the transmit and receive diversity techniques to modern wireless communications that can be achieved with MIMO in 5G and beyond and to ensure that reliable connection and low complexity to achieved for D2D with relay assistant, several requirements are proposed to validate these approaches, given their relevance to improving system performance in Encoding the symbols when they are sent or when decoding the symbols on the second device. Still, we will dispense with decoding those symbols in the relay and the lack of the need to provide channel status information (CSI). Two main questions arose from these procedures: First, what are the relevant criteria for providing high-gain diversity connectivity that must be met in an evaluation? Second, what appropriate method can be used to minimize processing in RD?

The following is a summary of the contributions to this review paper:

(1). This paper thoroughly reviews contemporary wireless transmission diversity methods that increase channel gain for compatibility in large data streams.

(2). It reviews the evolution of transmission methods to increase gain and achieve reliable communication.

(3). Analyze most methods that shorten RD delays or handle received symbols.

(4). We find the transmission technique represented by STBC and STBC's developments that would help this paper accomplish its goals.

The devices are relatively far from each other. It is an assumption that we will adopt in this paper. For mobile users, the link between devices degrades due to harsh channel conditions, causing a significant degradation in the direct D2D performance of FSO connections. The RD is proposed as a link between the transmitter and the receiver. On the other hand, signals in RD are subject to processing and often cause delays in retransmission and may cause power consumption, which is undesirable in connection performance due to the need for speed in D2D connections. It is a central problem that we are about to mitigate if we prefer to propose some crucial techniques to address this lack of diversity and simple computational complexity when encoding on the sender side D_1 and when decoding on the receiver side D_2. We found that when using STLC and STBC in symbol coding processing, it is less complex and detectable in an RD device, in addition to reducing signal power consumption.

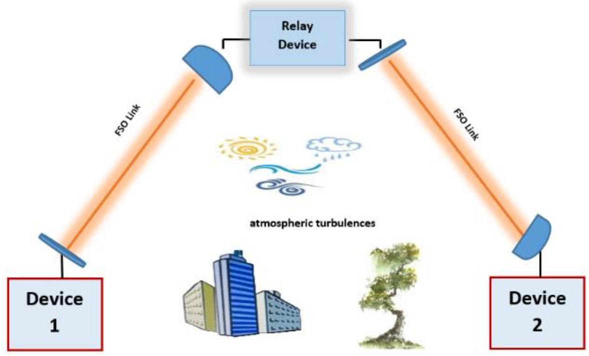

Figure 1. Environmental dual-hop FSO system

To achieve minimal processing on the RD device, the RD should not need to estimate CSI, and there is no decoding when the signal is received. Also, all processing units are optical in RD. The solutions proposed in our paper are a suitable algorithm represented by Space-Time Line Code (STLC) and Space-Time Block Code (STBC) used to reduce processing in RD to achieve low latency. Furthermore, it is proposed to use the beamforming technique to maximize the overall signal-to-noise ratio (SNR) of an FSO dual-hop in RD. The parts of a wireless communication system proposal will be implemented by implementing a D2D-assisted RD model for a dual-hop scenario based on FSO communications, as shown in the proposed Figure 1.

MIMO communication system assisted relay node with multi antennas for transmitting and improving to increase the data flow and send it to the interface using STLC technology between the transmitter and the relay node and using STBC technology between the relay and the receiver to send data to the receiver to improve the power consumption of the relay node [16]. The spatial diversity of the symbols was implemented based on STLC and STBC technologies, with the need for channel information at the sender and receiver; this was verified using multi-antennas at the sender. The two techniques complement a complete diversity order [17].

Both full-orthogonal STLC (OSTLC) and full-orthogonal STBC (OSTBC) and the novel quasi-OSTLC and quasi-QOSTBC pair are used to offer an appropriate diversity gain through the MIMO technique by antennas at RD. OSTLC-couple pairs are necessary to achieve better energy. Also, (QOSTLC-QOSTB) import essentialisms the processing delay at RD [2]. Quasi-orthogonal Space-Time Block Code (QOSTBC) was created. A decoding technique for QOSTBC was introduced by Jeong [18] to obtain a result with a lower BER than the conventional methods and to address the rank-deficient issue.

ORD merely needs to combine all the received signals to extract symbols. STLC-STBC can achieve the full rate by utilizing its orthogonality and quasi-orthogonality. Instead of using other strategies, it has been adequate to obtain a complete transmission rate. Orthogonality in STLC-STBC reduces computation to assist achieve low latency, but it has no impact on energy consumption [19]. As a result, we are attempting to use quasi-orthogonality for STLC and STBC to improve their energy efficiency. The aim of this study can be accomplished. On the other hand, this causes more symbol overlap. To reduce the consequences of this and increase the overall SNR, respectively, we advise adopting MIMO and beamforming in the RD of a dual-hop FSO system. As a result, channel estimations that generate complexity and delay in processing do not exist in the relay device, which generates less power drain and less time delay in receiving and retransmitting signals.

The rest of this paper is organized as follows: Section 2 provides a description and inquiries into the systematic literature review. Section 3, proposes low complexity processing of D2D RD by using STLC-STBC. Section 4 introduce new and future directions. Also, examine the end-to-end of SNR operating (STLC) and (STBC). Finally, Section 5, Conclusions and future recommendations of the paper.

2. RESEARCH TAXONOMY ON DUAL-HOPS FSO CONNECTION WITH RD

This part of our study shows a comprehensive classification of FSO Dual Hops between two devices with one deportation assistant. Optical communication systems have become increasingly significant in the past few decades due to their low-cost, high-speed connectivity [20].

Accordingly, we divide the study here into two parts. The first part is that the deportation falls within the FSO dual-hop, where each wireless access technology has advantages and limitations. The second part is to find ways to study the problem resulting from the relay and reduce it as much as possible, which we are working on to suggest a suitable way to obtain the diversity of the transmission device and the future through which we can unify the way to help reduce the delay time in the visual signal processing in RD and then send it to the interface. In addition, we seek to reduce and collect signal consumption for the maximum possible energy that can be transferred, or rather to increase SNR to the maximum. Besides energy consumption, the beam formation is applied in the deportation device to increase the power signal and send it to the recipient. Previous literary articles are classified as shown in Figure 2.

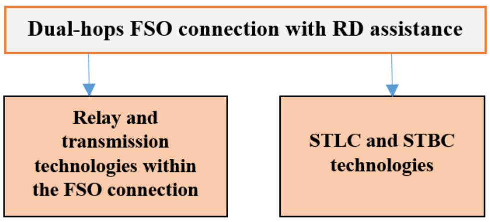

Figure 2. Research taxonomy of D2D connection with RD assistance

2.1 Related work of relay within FSO

D2D is a strong candidate to meet the requirements of the fifth generation, where the connection is direct without the need for a central management network [21]. Channel state information and decoding at the relay node are preferably not required. However, decoding and re-encrypting the data generates a complex computational process and takes more delay in the relay node [2]. It turns out that DF has an undesirable computational complexity despite its improved results that are superior to AF, including noise reduction and not amplification, as is the case with AF [22]. Conversely, the AF at relay FSO system was implemented using an Erbium-Doped Low Mode Fiber Amplifier (EDFA) [23]. A proposed MIMO system to improve data transmission in a FOS link to improve BER by mitigating the effect of atmospheric fields (such as electric *fields*) affecting signal transmission [24].

However, various technologies have been introduced to meet the requirements of D2D communication, where Orthogonal Time Frequency Space Modulation (OTFS) has been implemented to provide higher transmission rates. On the other hand, it generates interference rates with data codes that require complex processing in the receiver [25], which leads to unwanted delays.

Research has come to link multiple transmission technologies where Multiple-Input Multiple-Output (MIMO) orthogonal frequency-division multiplexing (OFDM) MIMO-OFDM is considered to have high transmission capacity and low cost. Still, it needs more linearity and simplicity of complexity. This shortcoming is overcome using 2×2 Almaout's, as detecting when encrypted tokens are received is less complex [26]. 2×2 and 4×4 MIMO-OFDM is a transmission system whose results have been verified by Tang et al. [27] as it adopts STBC codes. However, it requires channel estimation, which is difficult to achieve because it consumes time and processing power when decoding symbols. Using channel pre-parameters, a new approach to detect STBC symbols for OFDM transmissions has been established, processing delays and computational complexity in the generated detection, thus undesirable [28]. To achieve better communication links instead of a direct connection between two devices. An experience is done FSO dual-hop relay system, an all-optical forward regeneration, and forwarding (AORF) technique applied in relay instead of the amplification and forwarding (AF) scheme achieved a significant improvement in the BER instrument but taking more delay than using AF for fixed SNR [29]. In addition, several tech methods have been proposed for the dual-hop link to achieve better reliability. Since we do not want delayed processing on the relay, we suggest using amplification and steering AF for its simplicity of processing instead of DF, although it helps to increase noise as AF has been dispensed with in RD [22].

So far, a paging-based FSO system that adopts modern wireless transmission technologies has yet to be described so we will focus on the two STLC-STBC technologies in full. In this paper, STLC-STBC is fully applied to achieve our purposes of this paper and uses techniques that can reduce delay and power consumption in RD and that achieve high data stream diversity gain.

MIMO optical wireless connection achieves reliable connection. However, near channels negatively affect the connectivity, as spatial multiplexing has been proposed to mitigate these effects by using intense LEDs (light-emitting diodes) and PD (photodiodes). It is necessary to detect the optical signals from the receiver except when adjusting the tilt angles of both the LEDs and the PD because signal vector detection is difficult since the channel gain of each LED is the same. Signal detection is achieved through maximum likelihood (ML) detection [23]. This generates computational complexity in detection and causes processing delays, so it is not considered successful, especially after increasing the distance of the link. Generalized MIMO modulation and encrypted modulation have been used to improve the high spectral efficiency in the wireless optical communication system [30].

The nonlinearity of the LED in the channel link increases and decreases in order, and as a result, generates difficulty in detecting the received signal in spatial multiplexing of the MIMO transmitter to achieve the receiver diversity gain and the equal-gain combination (EGC) algorithm is proposed for this lack of detection [31]. Research has *developed* a new technique based on space-time in which the Khatri-Rao space-time (KRST) coding is proposed for double or triple hop *system* the MIMO for joint estimation of CSI and symbols. The transmission of the training sequence is used to obtain the matrix information of the channel and the characters in the string [32], which leads to the processing delay and computational complexity of dual hops or triple hops. In addition, as presented by Han et al. [33], KRST coding is proposed to encode symbols in the transmission for MIMO communication of the dual-hop system, and channel estimation is required in the relay. Using the Parallel Factor Interface (PARAFAC) in the relay and PARATUCK2 in the interface is suggested. However, this generates computational complexity and a delay in detecting symbols.

Space-time coding (STC) is a spatial diversity technique proposed in transmission with MIMO to mitigate multipath fading in wireless communication until it reaches the receiver, thus improving SNR. Increasing the number of outputs and inputs reduces the bad BER result. STC is combined with spatial diversity to achieve better results in BER [34]. Li et al. [35] presented a design for a non-coherent space-time system in a non-coherent wireless communication environment with dual outputs at transmit and massive inputs at the exit. To ensure maximum detection, the USTC (unitary space-time code) is proposed as it contributes to mitigating the worst-case double error. Furthermore, the USTC achieves full diversity at the receiver with many inputs.

In Mthethwa and Xu's study [36], Uncoded Space-Time Labeling Diversity (USTLD) is a strong candidate for ensuring reliable wireless connectivity while maintaining the spectral efficiency of the link STBC with labelling diversity results in a USTLD system-furthermore, a Neural Network Machine Learning (NNML) has been proposed for blind channel estimation required when using the USTLD-MIMO system instead of traditional estimation techniques as it reduces the bandwidth requirement when channel estimation. Spatial diversity and multiplexing are essential in modern communication technologies. USTLD scores better in diversity gains than Alamouti STBC [37] as USTLD achieves spatial diversity and labelling diversity together to obtain the best improvements in system performance [38]. The authors proved by Patel [39] that USTLD does not achieve a high data rate, although it allows any number when sending. Therefore, a high-rate USTLD has been proposed to earn high rates. However, this generates more complexity in detecting processing low complexity detection techniques presented on the HR-USTLD system.

In Choi and Joung's study [40], the system generalized STLC suggested that CSI must be fully available at the sender, but when receiving, the CSI is optional to be complete. Optimal precoding with linear combining is required to derive generalized STLC where the minimum BER is achieved with optimal precoding. A codebook consisting of a permutation matrix with STLC decoding has been proposed to reduce computational complexity at the receiver without symbol doubling. Implementing the STLC is possible using a simple, straightforward linear encoding and decoding process. These benefits have led to further research on STLC-based communication approaches [40]. Joung et al. [41] proposed STLC to reduce the power consumption of an unmanned aircraft system. In Pang et al.'s study [42], STLC-MIMO gains full diversity for the transmitted symbols. It is done by providing channel information in the transmitter. BER is improved upon antenna selection (AS) for STLC rather than traditional STLC. Additionally, Space-frequency line code (SFLC) has been proposed by Wu et al. [43]. SFLC was combined with orthogonal frequency division multiplexing (OFDM). The results were verified by simulation, and it was found that for multiple paths, the BER performance of SFLC-OFDM is slightly worse than that of STLC-OFDM. By increasing the number of outputs and inputs, the BER performance improves. But STLC-OFDM is better in terms of delay spread. The two schemes were merged so that STLC/SFLC-OFDM achieves complete diversity, as it needs to provide channel information to encode symbols at the transmitter, and CSI is incomplete at the receiver.

In Lee et al.'s study [44], a new technique known as space-time line coded spatial modulation (STLC-SM) is proposed with MIMO. Constellation rotated STLC for the transmission codes, after which two modulation codes are sent through one of the outputs of the transmitter, where CSI must be available when transmitting but without the total need for it when decoding the codes at the receiver. A maximum-likelihood detector placed at the receiver to detect received symbols STLC-SM is of lower complexity and better performance in BER than STLC performance. Nevertheless, integrating quasi-orthogonal STBCs (QOSTBCs) with SM further improved the system's spectral efficiency [19].

Double space time line code (DSTLC) was designed with many transmitting outputs and four receiving inputs, as it needs CSI when encoding the symbols to be sent. It increases spatial diversity and better performance of BER and data rate compared with spatial multiplexing and STBC. Thus, the pre-coded (SM) gain is negligible when the modulation sizes are identical. It has been proven that (D-STLC) is a promising candidate at high SNR and has spatial diversity and multiplexing. It transmits two parallel STLC streams to achieve additional multiplexing gains [45]. The diversity of codes for transmission helps to reduce the degradation of wireless signal propagation, and the reception of the signal to the receiver is less corrupt. Space-Time Trellis Codes (STATs) were introduced to achieve diversity and increase communication reliability, and decoding is done in the receiver using Viterbi decoding [46]. Space-Time Trellis Code Modulation (STTCM) is suggested to achieve high data flow, power efficiency, and access to increase spatial diversity significantly. Gain diversity grows as the number of inputs and outputs rises. The receiver uses the iterative decoder for various input conditions and numbers. It makes use of the Viterbi algorithm and feed-forward encoder construction. As BER is preferable to using Space-Time Trellis Codes, the recursive decoder (STTCM) is recommended [47].

STLC is proposed by Mavares et al. [48] to achieve the full rate by using the orthogonality of STLC and the quasi-orthogonality of STLC. It realizes it is adequate for a full transmission rate instead of other techniques. Average Likelihood Ratio Test (ALRT) technology was used to achieve Low-Complexity in the STBC borrowing system for a little SNR, as it turned out that the system achieved an accurate performance against CSI estimation error variance [49].

This part of the paper included a focused review of transmission technologies that meet the high need for high data flow requirements and simplicity in the computational complexity of encoding data codes or decoding them upon reception. Most of the techniques mentioned above come to me in several matters, the most important of which is the computational complexity of encoding and the difficulty in decoding. Secondly, some require CSI when receiving or sending, which will delay processing and lead to more power drain. Therefore, technologies that cause these two things will be dispensed with. When we decided to use a relay device between two devices, the shortcoming we referred to in the above two points must be eliminated, requiring minimum processing of relay/power/time resources in RD. Therefore, to achieve minimum processing in the RD device, we must make RD. it does not need CSI estimation, and there is no decoding when sending and receiving the signal in the RD device.

Here, we propose to use a suitable algorithm represented by Space-Time Line Code (STLC) and Space-Time Block Code (STBC) to reduce RD processing and time resources. So that there is no need for CSI to be available when receiving symbols in RD encoded with STLC technology. Also, there is no need when send symbols encoded with STBC technology when they are sent. Orthogonal STBCs are special cases of STBCs that allow for simplified linear decoding of a single symbol. It is noted, however, that OSTBCs in FSO systems are capable of a maximal coding rate of one. Therefore, higher transmission data rates require STBCs with a high coding rate [19]. Therefore, orthogonality in STLC and STBC contributes to reducing processing, i.e., low latency, but it does not mitigate the effects of energy consumption. Consequently, we are working on using semi-orthogonality for STLC and STBC, where these two technologies eliminate shortcomings in energy consumption. We can achieve the goal of this paper. On the other hand, this increases the overlap between symbols. Hence, the MIMO contributes to reducing the effects of this, and the beamforming technique maximizes the total SNR, which we propose to use in the RD of a dual-hop FSO system.

2.2 Proposed system model

We propose a dual-hop FSO communication system in which, at a particular distance, two devices are connected without the use of a base station (BS). Through an optical relay device outfitted with (k) receiving PDs to constitute a D_1-ORD transmission at the first hop and (j) transmitter of LEDs of ORD-D_2 transmission at the second hop, the first device (D_1) with (M) transmitting LEDs communicates with a second device (D_2) with (N) receiving PDs. The primary goal of this study is to use STLC at the first hop and STBC at the second hop as two coding approaches to achieve low time/energy processing at the ORD. According to Figure 3, the AWGN is modelled as a received noise with zero mean and variance σ^2 and independent for each receiver.

On-Off Keying (OOK) modulation is employed for the initial hop from D_1 . It is one of the most significant modulations that is frequently employed in optical communication in space. When there is no optical intensity during transmission as zero, and one occurs for (M) LEDs from D_1, no optical intensity is communicated during that time. The driver will next transform the electrical signal into an optical signal, after which even subcarriers will employ DC-biased, where before transmitting the signal to RD in parallel, each LED receives it in series. The signal will then be received by the PDs at ORD, where LED illumination can achieve lower power consumption and a longer lifespan; however, to demodulate the receiving signal, we apply coherent demodulation for the OOK modulation method. ORD merely needs to combine all the received signals to extract symbols. However, it uses the maximum ratio combining (MRC) technique, which maximizes SNR at RD and combines all received signals for k-M routes. Therefore, the received signals multiply the beamforming factor (W) at stage (Beamforming). Then, the signal is retransmitted as a block of symbols loaded in j of LEDs to reach the second device equipped with N of PDs. Then, the fate will be towards the detection process of signal optical (i.e., IM/DD detection) for decided such as original signal transmitted. The effect of the amount of noise added during the two jumps should not be neglected, in addition to the existing fading of the signal and its effect on it due to weather effects.

Ali et al. [50] presented that to enhance overall SNR, linear beamforming is suggested and created for dual-hop amplify-and-forward (AF) systems with relay nodes. A computationally effective Fukunaga Koontz Transform is employed to tackle the beamforming optimization problem when CSI is applied between source-relay nodes and relay nodes-destination. In addition, Beamforming technology has been used in a wide range of radio communications in RD to achieve maximum signal-to-noise ratio (SNR). The M-ary phase shift modulation (M-PSK) scheme is adopted for beamforming [51].

The beamforming technique maximizes the overall SNR ratio of the double-hop FSO system in our proposed system, where the quality of the link between RD and D_2 is enhanced.

The optical signal is prepared to be sent again through several LEDs using STBC encoding, as it does not require the provision of CSI, so the energy consumption is reduced. Point-to-point System Tool Analysis of the FSO System with Migration Assistant is fundamental. Turbulence attenuation and routing error attenuation in a channel link is essential for evaluating communication quality. A near-ideal disturbance condition is challenging, but the FSO link is often exposed to moderate to severe conditions. The MIMO technique used here increases diversity and thus reduces signal reception losses. Our proposed system is by placing the relay device between the D2D connection. There are two links for the first link (first hop) between D_1 and RD. and the second link (second hop) between RD and D_2. Each has a different channel state from the other, where the SNR1 will be at RD and SNR2 at D_2.

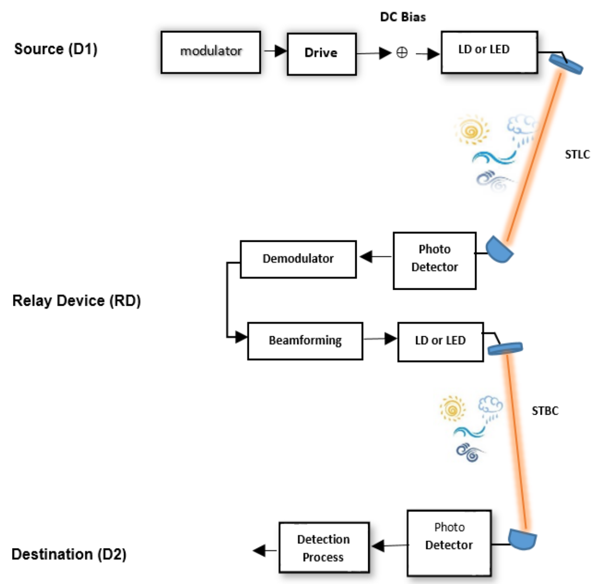

Figure 3. Proposed system model

It is necessary to analyze the system's performance and discuss the tools used in its analysis. We used important parameters such as SNR and Capacity C to evaluate the system's performance. Measuring their amount (SNR and C) at each hop and their total at D_2 is necessary to evaluate the system's overall performance. We consider a cooperative transmission from a D_1 to D_2 via an ORD that uses AF relaying to amplify the received signal and retransmit the data to the intended recipient. Let SNR_1 represent the signal-to-noise ratio (SNR) of the first FSO hop from D_1 to ORD, and SNR_2 represent the SNR of the second FSO hop from ORD to D_2. The end-to-end SNR can then be expressed as $\mathrm{SNR}_o = \frac{\mathrm{SNR}_1\,\mathrm{SNR}_2}{\mathrm{SNR}_2 + \mathrm{G}}$, where G is a fixed relay gain [52].

The two FSO hops (i.e., D_1-ORD and ORD-D_2) are assumed to be subject to independent but not necessarily identically distributed type of fading. Where that distance is approximately equal between the D_1-ORD and the D_2-ORD, we assume that a high-energy FSO system's performance is constrained by shot and thermal noise. In this instance, the noise can be accurately modelled as AWGN. Bits are modulated into symbols at the D_1 before being sent to the STLC encoder. The transmitted signal of STLC for the first device is denoted by:

$$\bar{S}_{D_1} = \sqrt{\frac{P_T}{M}} \sum_{i=0}^{k} s(i) \tag{1}$$

where, $\mathrm{S}_{D_1} \in \mathrm{R}^{\mathrm{M}\times 1}$ and P_T denote the transmitted power Let's assume that there are (M) LEDs at D_1 with (K=2) PDs.

In the first hop, the SNR is denoted by:

$$SNR_1 = \sum_{m=1}^{M} \sum_{k=1}^{2} \frac{\left[H_{D_1\_k,m}\right]^2 . \sigma_S^2}{2\,\sigma_n^2} \tag{2}$$

Here, $\left[H_{D_1\_k,m}\right]^2$ denotes a channel gain between the K-th ORD receiving PDs and the M-th D_1LEDs, where, $E\{[s]^2\} = \sigma_S^2, CN(0, \sigma_S^2)$ and because the sum of two independent AWGNs is also an AWGN, i.e., $\mathrm{CN}(0, 2\sigma_{\mathrm{w}}^2)$.

In the second hop, the SNR is denoted by:

$$SNR_2 = \frac{R\, P_T \left|\overline{W}^H H_{ORD-D_2,j}\right|^2 . \sigma_S^2}{8\|W\|^2 . \sigma_n^2 I} \tag{3}$$

where, R is PDs responsivity, W is the beamforming factor, H is denoted to the Hermitian matrix for W, and $H_{ORD-D_2,j}$ denotes a channel gain between the J-th ORD LEDs the N-th D_1 receiving PDs. We concede J=8 LEDs and N=8 PDs. The overall SNR of the first and second hops for the proposed system is calculated by Zedini et al. [52]:

$$SNR_O = \frac{SNR_1 SNR_2}{SNR_2 + G} \tag{4}$$

The i-th parallel channel capacity for MIMO channels is shown by:

$$C_i = log_2(1 + SNR_{Oi}) \tag{5}$$

Figure 4 simulates and compares the capacity of several different STBC-MIMO and QOSTBC-MIMO with beamforming techniques under various SNR conditions. 2×2 STBC provides better performance. It also achieves diversity gain but not spatial multiplexing. 4×4 STBC offers both diversity gain and spatial multiplexing. The capacity increases with SNR due to the combined effects of spatial multiplexing and improved SNR. 8×8 QOSTBC provides the highest capacity due to its significant spatial multiplexing potential, especially at higher SNR levels. The QOSTBC versions generally outperform their STBC counterparts. We can increase the channel capacity by increasing the full transmitter diversity using QOSTBC and increasing the number of LEDs and PDs.

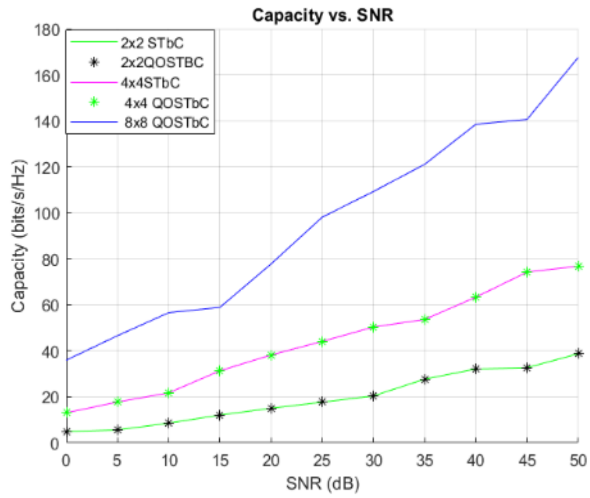

Figure 4. Capacity and SNR of 2×2 and 4×4 STBC, and 2×2, 4×4, and 8×8 QOSTBC

3. STLC AND STBC WITH LOW-COMPLEXITY PROCESSING

In our paper, a two-hop wireless optical communication system with a relay device is the proposed model presented in Figure 1. In this paper, we suggest D_1 is equipped with (M=4) optical emitters (as light-emitting diode (LED)). In contrast, D_2 is equipped with (N=8) receiving photodetectors (PDs). ORD is fitted with four photodetectors weighted with eight optical emitters (LEDs). Symbol transmission is performed via one relaying device with low complexity and minimum processing. In this relay-aided D2D communication, it is necessary to deploy a transmission algorithm that requires a minimum of ORD processing/energy/time resources. Decoding and full CSI estimates in ORD lead to a delay in processing, and the optical signal's energy efficiency can be significantly impacted.

Increased outputs when using STBC increase the diversity of the spatial Modulation, which leads to a decrease in the system's spectral efficiency. In Zhu et al.'s study [53], OSTBC for Space Modulation is proposed to improve system effectiveness.

Full transmission rate desirable in modern communications, QSTBC with massive MIMO is challenging to implement. It reduces system performance. Beamforming with spatial precoding was proposed as a solution to this shortcoming, which would minimize channel case expenses. BER attenuation was verified compared with conventional QSTBC [54]. The beamforming-based spatial precoding method has been proposed to reduce the overheads of the CSI feedback in

Multiple-Input-Multiple-Output (MIMO) systems. However, the original method suffers from using a set of pre-defined fixed beamforming coefficients. Moreover, beamforming spatial precoding can greatly reduce the interference and alleviate the mutual coupling effect on the performance of massive MIMO [55]. Here, in the first hop, the connection between a transmitting device (D_1) and receiving device (ORD) is implemented the novel full-orthogonal and novel quasi-orthogonal Space-Time Line Code (STLC) for relay with four LEDs, and the connection between the transmitting device (ORD) and receiving device (D_1) with eight LEDs. At ORD, STBC symbols deployment doesn't require any CSI, while the receiver requires full CSI, meaning that the receiver side is the most complex.

Reducing orthogonality in coding generates a higher coding rate than OSTBC, so the reliability of the connection is achieved [56]. However, OSTBC cannot reach a full transmission rate for transmission symbols, Whereas the QOSTBC application uses symbols. OSTBCs can code at a maximal rate of one. As a result, the orthogonality is loosened to allow for transmitting more symbols in each time slot through the development of QOSTBCs to provide better rates.

As can be observed from QOSTBC, there needs to be complete orthogonality among the symbols. As a result, inter-symbol interference (ISI) will cause BER performance on both trips to decrease. In addition to AWGN, this impact of ISI can be minimized through massive MIMO at the D_1, RD, and D_2. Also, using all optical components improves the system's performance, and with MIMO in the FSO connection, the system was made by Abdulameer and Mahdi [57].

Information symbols are encoded utilizing various channel gains (in space and time) and broadcast sequentially (in time) with Space-Time Line Code (STLC) encoding. The coded symbols are line-shaped instead of the STBC block shape since they are sent sequentially over a single transmitter, and several independent STLCs are built in parallel lines. The receiver Relay Device (RD) can decode the STLC symbols without complete Channel State Information (CSI) since STLC utilizes CSI for the transmitter's encoding. Analytically and statistically, it is demonstrated that Space-Time Block Code (STBC) and STLC offer the same performance levels even when the CSI is unclear. However, limited critical functionality may exist in minimally functioning lightweight devices, such as time and frequency synchronization, direct current offset estimates, and channel estimation just before the data transmission. As a result, if CSI is not available, supporting such devices without suffering significantly degraded performance is challenging [58]. Combining the proposed STLC and STBC will allow for the provision of minimal-function lightweight devices, such as those that require low cost, low complexity, and low power consumption [59]. The maximum diversity gain is offered by Orthogonal STBC (OSTBC), improving dependability in fading channels and ensuring that the transmitted streams are orthogonal, which makes decoding easier. On the other hand, Performance may be impacted by the quantity of transmit antennas, making it less adaptable to varying environmental factors. Because Quasi-Orthogonal STBC (QOSTBC uses quasi-orthogonal designs, its transmitted signals don't always have complete orthogonality but suffer from less interference. However, it reduces the decoding complexity and performance of fully orthogonal architectures. Although it strikes a balance, QOSTBC might not perform as well as totally orthogonal designs. QOSTBC provides a performance-complexity trade-off, making it a practical choice in situations where simplicity and acceptable performance are crucial, like real-time communication systems with limited resources [2, 19].

The STLC-STBC and their development offer many benefits. First, it allows the designing a minimal-capability device using the STLC diversity scheme. This enables achieving full diversity gain even with minimal functions at RD. Second, the STLC-STBC reduces the frequency of required CSI estimations. While conventional systems require CSI for both devices. This reduced need for CSI estimations leads to efficient usage, especially in block-fading channels. Third, the channel estimation process is simplified. This ease of channel estimation enhances the system's overall efficiency [58, 60]. Therefore, it performs better than QSTBC but takes a larger delay and saves CSI. Despite the capabilities of the aforementioned technologies, they fail to provide what we want to achieve in this paper, which is the least possible processing in RD for less delay time and less energy consumption, as most of them require CSI and generate complexity in processing in addition to the delay caused by these technologies. Therefore, STLC The proposed STBC achieves what we aim for in this paper.

4. NEW DIRECTIONS AND FUTURE WORK

A single relay is sufficient to reduce the communication distance in the FSO link for relatively long distances, as we explained earlier, instead of having a multi-relay between the two devices, as this does generate high and complex parameters that must be observed to preserve the data as it reaches its final destination (D_2). We are concerned about the loss of the path at the propagation time of the light beam due to strong atmosphere conditions between D_1-ORD or ORD-D_2, as well as increasing Hops, which reduces data flow as it consumes data power. We have contributed to proposing a solution for this by using the two techniques in Section 3.2. in RD, all the handling is optical to reduce the delay in processing, as it will dispense with converting the light signal into electrical and then vice versa, and also will reduce the complexity and side effects of that, and beamforming of the optical signal in the RD, a critical proposal to achieve maximum energy of signal at RD.

Here, we propose new directions for developing this approach and fill in the possible gaps. In the case of weather conditions, they are at their best (almost ideal). Here, the presence of RD is not necessary, so it requires sensing the conditions at RD to stop its work. Where we can suggest some sensing mechanisms, including but not limited to Sensor at ORD. Here, the sensor has provided information about the region's parameters that will be monitored near ORD. features of this sensor device are operated and controlled based on their sensitivity as well as the range of sensing; necessary sensing and controlling actions will be taken depending upon the conditions, like fixing the threshold value of BER, SNR, periodicity of sensing, etc. Based on the data analysis, the parameter threshold values or normal working conditions are turned on/off ORD. Also, can be used in Adaptive Learning, implementing machine learning algorithms to predict future channel conditions and performance based on historical data. This adaptive learning can aid in making informed decisions about activating the RD or maintaining the D2D connection. Reinforcement learning techniques can be employed to learn optimal policies for activating the RD or maintaining the D2D connection based on the historical performance of different decisions [61]. Q-learning and Deep Q Networks (DQN) are examples of reinforcement learning algorithms. Also, Recurrent Neural Networks (RNNs) are well-suited for sequential data, making them suitable for time-series predictions like channel conditions. Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU) are popular variants of RNNs that can capture temporal dependencies in the data.

Achieving a direct D2D connection without using a RD can be challenging due it requires LOS. There is a gap in that case, that RD must be on the same line as the two devices or the possibility of modifying the adaptation of the relationship between the two devices automatically within specific algorithms to ensure the direct connection of D2D. Here, after monitoring the ATs at D_1 by the sensor node. If communication conditions change or become unstable, communication switching is managed without RD, but there are some limitations and considerations to take into account, such as range and proximity. D2D link is usually limited to short ranges due to the physical limitations of wireless technologies. Interference: The lack of intermediate RD means that devices may have to deal with higher levels of interference, which affects communication quality. So the connection is directed to the second device. For the reliability of a stable FSO connection, we have to focus on a better tool for the paging device from several things, the most important of which are:

1- A wireless place suitable for the RD position between the two devices and free from everything that impedes communication, such as buildings, trees, or even thick smoke, providing line-of-sight communication.

2- Increasing the application of diversity in RD, which increases the reception and transmission of data streams but requires finding better technologies to mitigate the impact of complex processing and significant delays.

3- Making the communication process a full duplex; Achieving the exchange of transmission and reception between the two devices may increase the complexity, but it is helpful in essential applications.

4- We suggest another developmental trend: An additional RD parallel to the primary RD when communication with the main RD device is interrupted or the line of sight is lost.

5. CONCLUSIONS

This paper includes a comprehensive review of a relay-assisted dual-hop FSO communication system, especially regarding the benefits of using RD within a dual-hop FSO system, especially for relatively long distances. Diversity techniques used in modern wireless communications have been reviewed to achieve the full diversity of transmission, as some of these techniques require estimation of the channel at the receiver of encrypted codes (at RD). Additionally, others are very complex in the processing process, where it needs to decode the symbols, increasing the computational delay and the consumption of signal energy. The effect of these shortcomings, this paper's Mitigation of their occurrence was achieved from the systematic study of the literature related to our research. STLC and STBC technologies have been proposed as promising technologies in conjunction with MIMO technology to increase the full diversity of data coding and improve signal processing in the first and second hops, respectively. The optical signal pool in RD led to delays in transmitting data to the receiver in addition to power consumption, which necessitated using an orthogonal STLC and orthogonal STBC (OSTLC and OSTBC) to mitigate the effect of delay in processing, as well as the use a quasi-orthogonal of STLC and quasi-orthogonal of STBC (QOSTLC and QOSTBC) to reduce the energy consumption of optical signal at RD. AF effectively minimized the computational complexity when receiving symbols at RD. In addition, Beamforming, the technique applied in RD to achieve the best possible SNR, the research on double-hop FSO communication techniques still needs more proposals in transmission methods and reception to meet the requirements of modern communications.

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