Diversity Coding Techniques for Mitigation Atmospheric Turbulence Channel in FSO-Communication Systems

Entesar Alareefi Saad[1] Fayez W. Zaki[2] Bedir B. Yousif[3]

Abstract

One of the most significant steps in improving any communication system is to pay attention to modulation and encoding, as well as the channel in which the transmission will takeplace. In this paper to obtain a method with Rayleigh fading channel efficiency capabilities, we combine the advantages of modulation and Reed Solomon coding with AWGN and Rayleigh fading channels the (STTCs) with and without optimal beam-forming were reviewed and analyzed. Weighted space is a space-time trellis code of perfect beam-forming at the transmitter antenna that offers a large number of alternatives, from single input multiple outputs that capture more energy to increase the receiver's signal to noise ratio to multiple input multiple output (MIMO) which increases the number of data through FSO link. To assess the accuracy of space-time trellis coding, and use the maximal ratio combining (MRC) and diversity measures (STTC). Atmospheric turbulence will degrade the efficiency of free space optical (FSO) communication system significantly. Exploiting diversity to increase efficiency of MIMO-FSO connection may be an effective approach. The Gamma-Gamma distribution function is used to represent the atmospheric turbulence channel. The numerical simulation results demonstrate, increased efficiency at the expense of somewhat higher decoding complexity. There is a significant improvement in bit error rate performance over than uncoded situation.

Keywords: *MIMO-FSO systems, Reed Solomon, space time trellis code(STTC), channel coding, space time block code(STBC), signal to noise ratio, atmospheric turbulence, free space optical communication, scintillation index.*

1. Introduction

Contact with Free-Space-Optical (FSO) has won a lot of recent attention [1]. Systems of FSO have Many benefits over traditional equivalents to RF (radio frequency), such as unlicensed electromagnetic Spectrum, larger band width, incredibly stable access, low cost of deployment and the velocity of deployment and optimal security are among the most successful in FSO qualities [2][3]. FSO technology uses the atmosphere as a channel for transmitting data in a free Space communication system and it is affected by various unpredictable environmental factors such as clouds, rain, fog and dust, it directly affects the quality of communication and the correct transmission of data due to the weakness of the optical signal and the limitation of the link distance in which the data can be sent. Many effects limit FSO contact yet (dispersing, absorption, atmospheric conditions). Atmospheric Turbulence (AT) (such as fog, cloud,) is the most powerful one that can induce extreme performance degradation in bit error rate (BER) to deteriorate the signal [4]. Because of these problems in optical communication systems, many researches have been conducted to meet the challenges that occur in the atmosphere, which reduce the transmission of the required data. In some research, various techniques such as modulation schemes and coding using different channel models and detection technique has been used to deal with this problem, such as output (MIMO) scheme [5–9], and polar code are used in a MIMO FSO communications systems to reduce turbulence-induced fading [10]. The irradiance of the sun is affected by at atmospheric scintillation, which is a transmitted optical beam, causes serious damage and causing the link's efficiency to deteriorate [11,12]. Also, the FSO / RF-FSO hybrid correlation adaptation schemes were used [13]. Coding plays the most important role to reduce the AT in optical communication systems. A novel channel coding method created by the serial concatenation of low-density irregular's interleaver linked parity control (LDPC) and trellis code modulation (TCM) codes are suggested [14]. One of the basic requirements for digital communication systems is the reliable transmission of information over fading channels. Here, where the transmission is in space, for example via free-space optical channels, the transmission is required in time by storing information in the appropriate storage media, and because of this requirement, the Communication systems rely heavily on channel coding. Noise is a basic parameter that pollutes the signal when it is transmitted. The relationship between broadcast signal and noise is defined by the Signal to Noise Ratio [15]. It is all about being able to detect or correct errors introduced on the channel, it must also be efficiently enforceable. In the telecommunications industry, Reed Solomon (RS) codes are a type of linear block code that excels at repairing burst and random symbol errors [16-18]. Researchers have begun to show some interest in evaluating the efficiency of different forward error detection and correcting codes over the past few years. The efficiency of various wireless networking uses forward error-correcting methods have been compared and evaluated in Ref. [19]. A new approach based on (RS) coding is proposed to enhance the effectiveness of the (MPSK) and (MQAM) concatenated (STBC) MIMO System in minimizing bit error rate in the Rayleigh, Rician and Nakagami channels [20]. As a result, RS codes are linear block codes that are widely found in many process systems [21,22]. SNR lowers the BER benefit;

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additionally, increasing SNR also requires increasing signal strength, which is a significant communication restriction. The use of code to control these variables is a smart way to do so. For the need for very high data rate point-to-point connectivity, free-space optical (FSO) communication is a promising option [23]. The information-carrying laser beam in the FSO system is projected through a line of sight to the optical receiver. FSO has a number of advantage over radio frequency (RF) technologies [24-26], including a large bandwidth, strong transmission security, immunity to interference. For the past few years, FSO devices have received a lot of interest for the range of application and market, including last mile networking, optical fiber backup, business connectivity, and so on [27]. There are two kinds of multiple input multiple output (MIMO) techniques with channel information at the receiver only: spatial multiplexing systems and diversity systems. When there are a set number of receive antennas, Bell Labs layered space-time (BLAST) systems or spatial multiplexing [24, 28] transmit separate data stream from transmitting antennas, for spectral efficiency at the expense of diversity advantages. Diversity modulation, also known as space-time coding [25-30], employs code words that optimize the transmitted information's diversity advantage. The existence of channel information at the transmitter also influences the signaling technique. MIMO, for example, does not necessitate channel intelligence at the converter, but it does benefit from better efficiency when channel information is available [31-34]. Space Time Block Code (STBC) [28] and space time trellis code (STTC) [29, 34-36] are the key strategies used by MIMO channels to have spatial diversity. Both provide complete spatial diversity. There is no coding advantage in space-time block codes. As a result, they're typical concatenate with an outer channels codes isolated by interleaver to ensure locally uncorrelated modulation bit [36-38]. The rest of the paper is organized as follows: Section 2 describes system modeling and its structures. Section 3 presents various space time coding techniques to mitigate the adverse effects of the atmosphere. Section 4 explains the numerical simulation results for a recent study on Space-time trellis code based FSO system using channel coding and adaptive optics for turbulence mitigation. Section 5 presents a summary of the results.

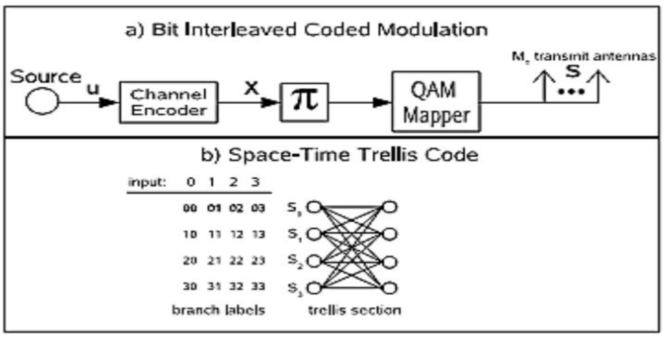

Fig.1 a) bit interleaved coded modulation b) space-time trellis code

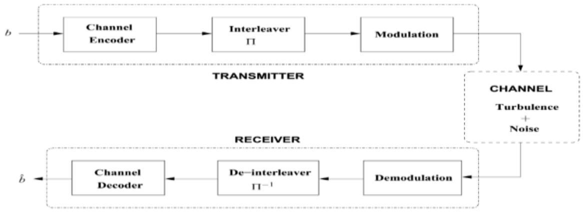

Fig. 2 System block diagram [37].

2. System model

The state-of-the-art encoder is seen in Figure 1: a) bit interleaved coded modulation b) For 4-QAM, 4-states, and 2 receive antennas, a space-time trellis code is used. Figure 2 depicts the overall machine block diagram. The following sections go over each of the three key blocks of the transmitters channel and receivers.

2.1. Transmitter

After that, the encoded bits are interleaved before being translated to symbols (the modulation block) and sent over the channel. In this paper, we assume pseudorandom interleaving, which permutes the encoded bits in a random (but known to the receiver) manner [36]. We also take into account the most often used amplitude modulation technique, non-return-to-zero on off keying. As a result, the occurrence of a durational impulse is represented by a binary bit 1 (On state), while the absence of a durational impulse is represented by a binary bit 0 (Off state) [34-37].

2.2. Channel modeling

We look at the time fluctuations using the theoretical block fading model, in which the channel fading stays constant for block (corresponding to the channel coherence interval) and then transitions to a new independent value from one block to the next [30-32]. Let's call the small and large scale irradiance fluctuation h_y and h_x respectively, The Gamma distribution is used to describe the statistical independence of h_x and h_y. On the basis of this assumption, intensity fluctuation h = $h_x h_y$ where the probability density function (PDF) and Gamma-Gamma distributions are as follows [34-36].

$$p(h) = \frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} h^{((\alpha+\beta)/2)-1} K_{\alpha-\beta}(2\sqrt{\alpha\beta h X}) \quad (1)$$

$$\alpha = \left\{ exp\left[\frac{0.49\sigma_R^2}{(1+0.65d^2+1.11\sigma_R^{12/5})^{\frac{7}{6}}}\right] - 1 \right\}^{-1} \quad (2)$$

$$\beta = \left\{ exp\left[\frac{0.51\sigma_R^2\left(1+0.69\sigma_R^{12/5}\right)^{-5/6}}{1+0.9d^2+0.62d^2\sigma_R^{12/5}}\right] - 1 \right\}^{-1} \quad (3)$$

Where d=$\sqrt{KD_{RX}^2/4l_{fso}}$ is the normalized receiving collecting lens (RCL) radius, D_{RX} is the RCL diameter, σ_R^2=$1.23C_n^2K^{7/6}\,l_{fso}^{11/6}$ is the Rytov variance [40], C_n^2 is the refractive index structure constant (ranging from ~ $10^{-17}m^{-2/3}$ to ~$10^{-13}m^{-2/3}$), l_{fso} is the FSO link length, K = 2 /λ is the wave-number [39].

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2.3. Receiver

Following the detection of the signal, (the demodulator block) and de-interleaving, channel decoding takes place at the receiver (see Fig. 2). The demodulation is done depends on the amount of light of the received signal. After the optical/electric conversion, the electrical signal is [38]:

$$\boldsymbol{r_e = \eta(I + I_a)n} \qquad (4)$$

Where

I is the intensity of the light of the receive signal, I_a is the remaining ambient light intensity after frequency and spatial filtering. So, the received signal before demodulation is [38-40]:

$$r = \eta I + n \qquad (5)$$

And the noise variance equals

$$\sigma_n^2 = {}^{\mathrm{N_0}}\!/_{\mathrm{2T_S}} \qquad (6)$$

Where I as the product of I_0, the intensity of the light that is emitted, h with the PDF in the channel atmospheric turbulence given as [40]:

$$\mathbf{I} = \boldsymbol{hI_0} \qquad (7)$$

Instead of fixed values 0 or 1, the demodulator's output gives logarithmic probability ratios on the transmitted bits.

3. Error Correcting Codes

It is important to have a mechanism allowing recovery a lost data due to a number of errors when digital data are transmitted over a disturbed channel. Encoding is a process by adding a number of redundant bits to user data string. When reconstructing the original message at the receiver, it starts by examining a possibly corrupted version of the encoded message, and then makes a decision. In this section, we introduce some techniques of bit error correction.

3.1 Reed-Solomon Coding

Reed–Solomon (RS) code is error correcting codes. They are made up of $m - bit$ strings, where m can be any positive integer. This values in excess of 2. Codes $RS\ (n, k)$ on m-bit symbols for both n and k, n number of symbols in the code and k number of message symbols.

$\boldsymbol{0 < k < n < 2^m + 2}$ As an example, utmost common RS (n, k) codes [41]:

$$(n,k) = (\boldsymbol{2^m - 1},\ \boldsymbol{2^m - 1 - 2t}) \qquad (8)$$

pattern error correction capacity of symbols are expressed by t Code, while $k = 2$ represents the number of symbols of parity. To RS Code, the code's minimum distance is determined by [41]:

$$\boldsymbol{D_{min} = (n - k + 1)} \qquad (9)$$

Any mixture of t and less can also be corrected by the code Errors, t is given as [41]:

$$t = [\frac{d_{min}-1}{2}] = [\frac{n-k}{2}] \qquad (10)$$

3.2 Space Time Coding

Space-time coding (STC) [24] takes advantage of the MIMO channel's diversity in both the space (antenna) and time realms, greatly enhancing device capability and improving wireless connection efficiency. STTC is a signaling technique that combines channel code architecture with transmitting and optionally receiving antenna diversity. A well-designed STTC can also achieve a certain amount of coding benefit in addition to the diversity advantage. A trellis encoder is used by STTCs to add redundancy to the transmitted symbol stream and to achieve coding advantage [32, 38]. The code advantage is determined by the encoder memory length and the code's construction parameters. For STTCs, a variety of structures have been proposed [35].

3.3 Space Time Trellis Code

V. Tarokh, H. Jafarkhani, and A. R. [27] suggested the STTCs with multiple transmiter antenna concept in 1998. STTC can provide significant coding gain, spectral performance, and diversity enhancement all at the same time. However, as the number of antennas and modulation size grow, the decoding complexity grows exponentially, which is a big disadvantage [27-30]. Figure 3 shows a MIMO configuration of "nR" receive antennas and "nT" transmit antennas.

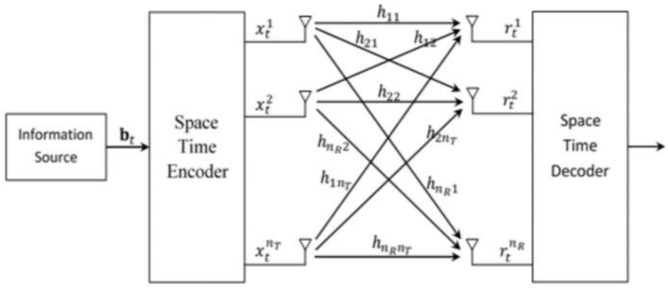

Fig. 3. Space-time coded MIMO system.

Where n_R is the signal received at the receiving antennas. And n_T is a noisy overlay of the transmitted signals that have been channel faded. The signal is received at antenna j, when j = 1, 2, n_R at the time represented by r_t^j is given by [32, 36],

$$\mathrm{r_t^j} = \sum_{\mathrm{i=1}}^{\mathrm{n_T}} \mathrm{h_{j,i}^t x_t^i + n_t^j} \qquad (11)$$

As a result, the received signal vector may be written as [32],

$$\mathbf{r_t = H_t x_x + n_t} \qquad (12)$$

On the MIMO channel, we assume that the receiver's decoder uses to accomplish maximum likelihood (ML) decoding, the Viterbi algorithm is used, and the receiver has optimal conditions channel state knowledge. [32-35]. The transmitter has no idea what channel it's on. The decision metric is measured at the receiver using the squared Euclidean distance between the theorized and obtained sequences, as described in [38-40].

$$\mathrm{x_t^i} = \sum_{\mathrm{k=1}}^{\mathrm{m}} \sum_{\mathrm{j=0}}^{\mathrm{\upsilon_K}} \mathrm{g_{j,i}^k b_{t-j}^k} \quad \mathrm{mod\ M} \qquad (13)$$

$$\mathrm{U} = \sum_{\mathrm{k=1}}^{\mathrm{m}} \mathrm{\upsilon_k} \quad \mathrm{mod\ M} \qquad (14)$$

3.4 Viterbi Algorithm for STTC

As the decoded chain, the path is determined by the Viterbi algorithm at the lowest path scale. [10]. The spectral efficiency of the system is [36-38],

$$\mathrm{H} = \frac{\mathrm{r_b}}{\mathrm{B}} = \mathrm{m}\ \frac{\mathrm{bits}}{\mathrm{sec}}/\mathrm{Hz} \qquad (15)$$

3.5 Near-maximum-likelihood Viterbi Decoding of the Space Time Bit Trellis Code (STbitTC).

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Because of their binary trellis configuration, STbitTCs have a lot of versatility when it comes to modulation and antenna constellations. The following part is about the encoding for the encoder in Fig. 2. There is the same amount of states in the present symbol trellis. as the old one and measures $N = NC/Q$ steps in duration (look at Fig. 3). Since the code structure has not been violated by an interleaver, each state only needs 2^{RQ}transitions rather than 2^Q transitions.

Table 1 -Physical parameters of simulation system

Parameter	Symbol	Value	Value [42]
Wavelength	λ	1550 nm	1550nm
Receiver radius	A	6 cm	5cm
Link distance	L	1550m	1000m
Refractive index structure parameter	C_n^2	1.5x10-15	1.5x10-14
Beam waist radius	W_0	2cm	2cm
Inter Spacing between Tx	D	20cm	20cm
Phase front radius	F_0	-10cm	-10m

4. Numerical Simulation Results Discussion

One of the most important aspects in the development of any communication system is the attention to modulation and coding as well as the channel in which the transmission will take place. Various modulation simulations will be investigated with different coding schemes, in free optical communication channels under the influence of atmospheric turbulence. System performance is measured in terms of bit error rate (BER) as a function of signal-to-noise ratio (SNR). Using the variables in Table 1 that Lists simulation parameters used for the FSO MIMO diversity system. In this paper, a series of simulation experiments will be conducted as follows

4.1 Reed-Solomon code

Various mod simulations, uncoded and encoded, in AWGN, and Rayleigh channels using code Reed Solomon will be investigated in this paper. High-level modifications are also considered in this study. We will conduct simulation experiments and study the performance of RS codes using a different (code word) in each experiment separately RS (k, n) RS where the symbol k refers to the encrypted word and the symbol n refers to a data byte.

4.2 Maximum Ratio Combining Diversity (MRC) with Alamouti STBC

We used coding and diversity schemes to study the extent to which reliability can be improved by increasing the number of transmission NR, as well as BER and probability of outage in free space optical link by analyzing the performance during no diversity and comparing it with Alamouti (2x1) STBC, Alamouti (2x2) STBC, (1X2) MRC and (1X4) MRC, coding types.

4.3 Space Time Trellis Code (traditional QO-STBC, MMSE and O STBC, Alamouti STBC with SISO and MISO)

We compared the efficiency of the proposed algorithm with that of algorithms (QO-STBC, MMSE, conventional O STBC, Alamouti STBC with SISO and MISO) with different signal-to-noise ratios (SNRs). This is to see the extent to which the system performance is increased and the error rate in the system is reduced, taking into account that the data that we use in (STBC) is not lost.

4.4 Average received irradiance

We will analyze the BER performance under weak perturbation considering background noise and thermal noise and consider quantum limit condition, thermal noise condition, background radiation condition and thermal noise condition.

4.5 Scintillation Index σ_I^2

Because of the importance of studying the scintillation index (SI), it is a major measure of optical communication in free space, and measures the standard intensity variance caused by atmospheric turbulence. In this paper, we will study the effect of the luminescence indicator on the received signal with the change of the signal strength each time and the increase in the strength of the turbulence in the atmosphere.

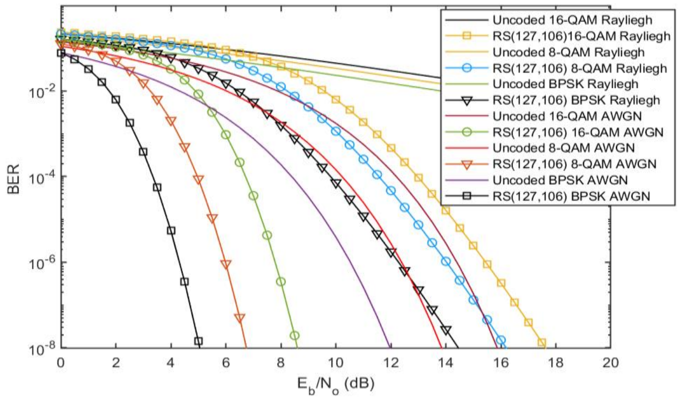

Fig. 4 Coding and Uncoding error probability for (127,106) RS-code using BPSK and 16-QAM, 8-QAM with (AWGN, Rayleigh fading) channel.

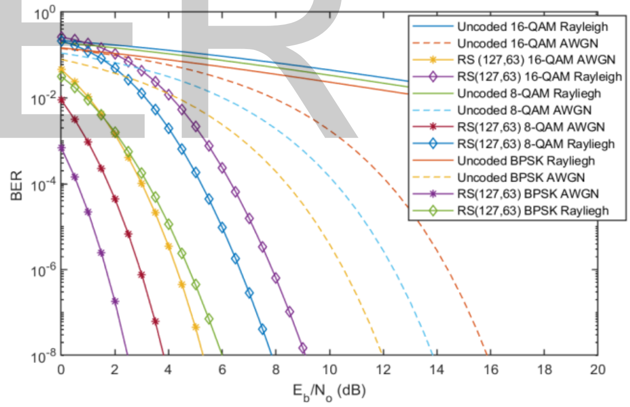

Fig. 5 Coding and Uncoding error probability for (127,63) RS-code using BPSK and 16-QAM ,8-QAM with (AWGN, Rayleigh fading) channel.

I n Figures. (4) and (5) RS (127, 106) and (127.63) were simulated, and the results of BER versus SNR were shown for RS coding in Gaussian and Rayleigh channels The BER decreases as the SNR increases much for RS (127,63) it is better than RS (127,106) in 16 -QAM and 8- QAM more encoded than Uncoded.

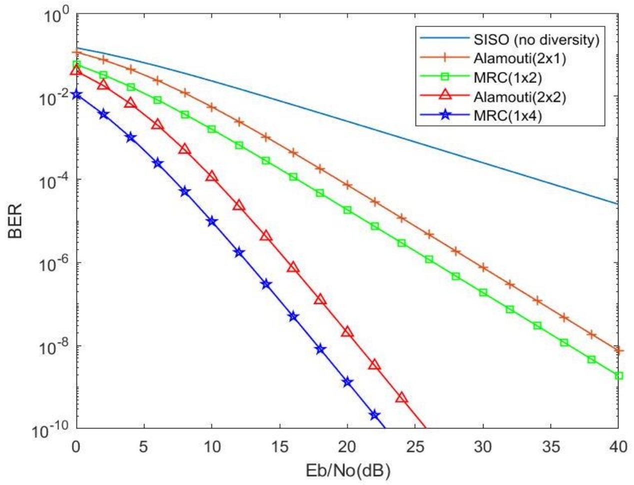

Fig. 6 BER versus Eb/N0 performance of Maximal Ratio combining diversity and Alamouti STBC.

According to Figure 6, we analyzed the performance of Alamouti (2x1) STBC and Alamouti (2x2) STBC (3dB) below (1X2) MRC and (1X4) MRC, and we observed that the error decreases in the data transmitted with higher signal-to-noise ratio (SNR) We were able to mitigate the impact of weather disruptions on the FSO, which was created through inter-channel partnerships and future weather disruptions following the implementation of MIMO diversity. We noticed that the percentage of improvement is high after comparing SISO (no diversity) with Alamouti STBC and MRS combining diversity with change the number of sender and receiver.

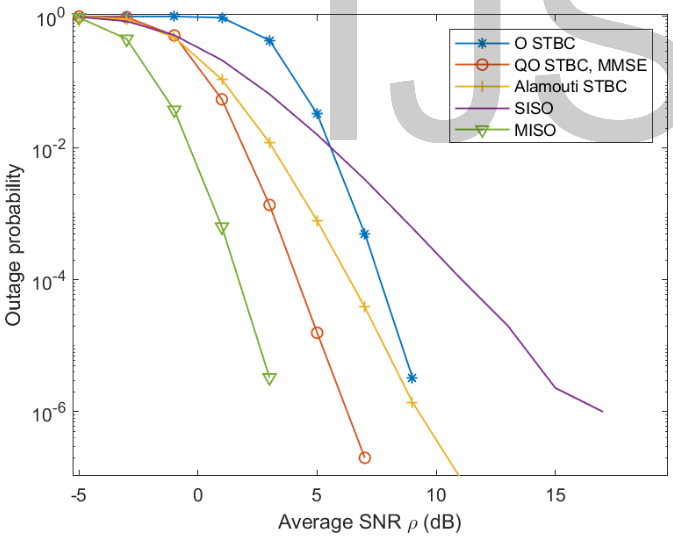

Fig. 7 Outage Probabilities Vs SNR for different diversity coding combining techniques channel.

In Figure 7, we compare the efficiency of the proposed algorithm with that of (traditional QO-STBC (4X4), O STBC MMSE (4X4) and Alamouti STBC (2X2) algorithms with SISO and MISO (4X1)) with noise ratios (SNR) ranging from -5 to 15 dB, we noticed that increasing the number of NR symbols improves the BER performance and the outage probability on the receiver side was analyzed using multiplicity and diversity plots. The channel coding rate and outage probability were studied for the previous types of FSO-MIMO diversity coding techniques, which increases the system performance in order to reduce the system error rate and without losing the data we use (STBC).

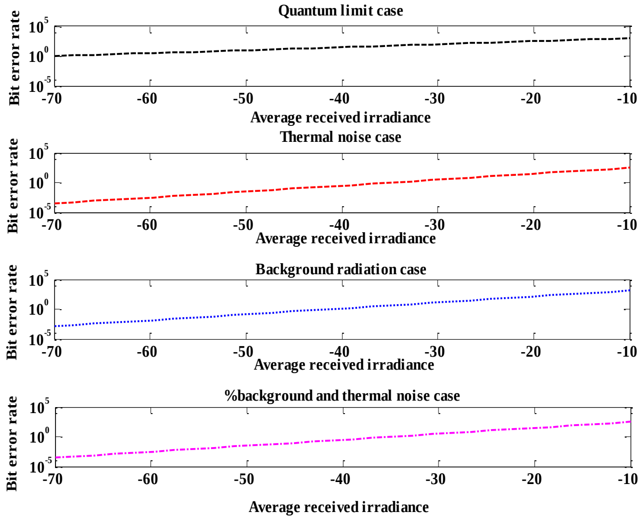

Fig. 8 Average received irradiance against the BER for all cases: (a) quantum limit case (b) thermal noise case (c) background radiation case (d) background and thermal noise case.

In Fig. 8 the resulting average radiation versus bit error rate (BER) is plotted for all the cases we studied in atmospheric noise and turbulence. Additionally, we analyzed the performance of the bit error rate (BER) under weak perturbation considering background noise and thermal noise. For the quantum limit case, thermal noise case, background radiation case and thermal noise case, we were able to demonstrate the variance of all noise variances. Also, the effects of different noises on system performance were reduced, and the effect of thermal noise on the average BER is the strongest.

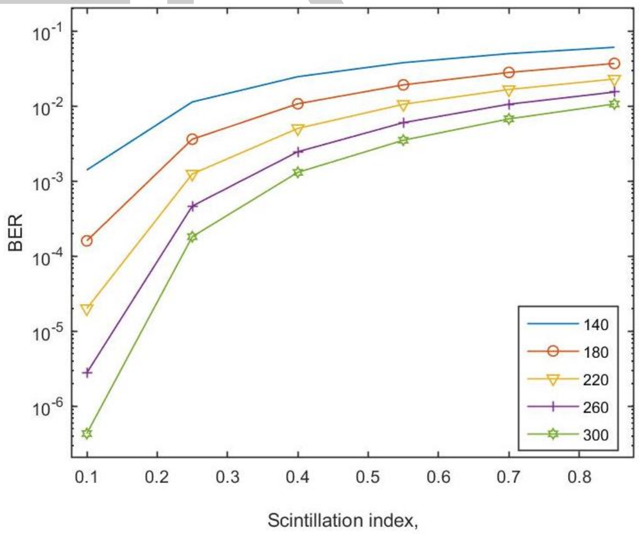

Fig. 9 BER of the BPPM modulation for FSO under the weak turbulence.

Figure 9 shows the BER of the binary PPM for FSO at different levels of scintillation in the presence of weak turbulence. As atmospheric scintillation increases, the necessary signal level to achieve a given BER rises as well. At low scintillation indexes, increasing signal intensity can be used to reduce the scintillation effect, but as turbulence strength increases, the BERs all appear to a high BER asymptotic value.

5. Conclusions

We compared the efficiency of channel coding strategies used in the presence or absences of time diversity for FSO transmission links subjected to various turbulence conditions. The performance of the non-encoded and encoded system was evaluated using the RS codes which terms of the bit error rate (BER), and each time the Word and bit bytes were changed. The results obtained showed that for the coded signals, the performance was better. The results were better when using the BPSK modulation scheme with RS codes. There was a decrease in BER performance for modulations arrangements. The efficiency of STTC and STBC are improve by increase the number of transmitters and receiver antenna. We study a for a laser transceiver with transmission over free space optics in order to achieve an optimized and united structure that is resilient and unaffected by channel turbulence. The findings show that in a simple environment with a relatively high signal to crosstalk ratio, to solve issue of crosstalk and fading, MIMO and diversity strategies have been used to create an interconnected and united structure that is not influenced by channel turbulence. It was concluded that when using space-time trellis coding (STTC) technology and (MRC) for reception diversity, the MIMO communication system performs better. The simulation results show that, between Alamouti and STBC, STBC is the better choice for wireless communication systems. Since they have a low bit error rate than non-coded contact, they have a lower bit error rate. The efficiency of STBC is improve by increase the number of transmitter and receive antenn

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