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Research Article

Performance Analysis of MIMO with Modulation and Diversity Schemes

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Abstract

In a free space communication, for transmitting data in the order of mega bits and giga bits, usually radio frequency is used, although as an attractive technique Free Space Optical communication can be used. As the medium for the transmission of the data is air and the light pass through it, some environmental challenges are present like atmospheric turbulence and beam wander. Atmospheric turbulence is caused by random fluctuations in the temperature and the pressure of the atmospheric region through which the Free Space signal has to pass. Compare to large data rates, scintillation process is slow in optical transmission. In order to mitigate this harmful effect of atmospheric turbulence and beam wander, multiple input and multiple output (MIMO) is used. The mitigation of scintillation is achieved through multiple lasers and multiple output apertures, thereby creating a multiple input and multiple outputs (MIMO) channel. This paper investigate the performance of FSO communication systems employing on-off keying (OOK) and Q-ary pulse position modulation (QPPM) in turbulence regime. The performance results are evaluated in terms of bit error rate (BER) employing OOK and QPPM as modulation technique. It is found that the BER performance under the technique Q-ary PPM if we increase the order of Q then the performance will improve and it provide maximum 4dB improvement. In this paper the working of MIMO in Free Space Optics communication is analysed briefly along with the receiver combining techniques.

Keywords: *Multiple input/multiple output (MIMO), atmospheric turbulence, free space optics, pulse position modulation (PPM), on-off keying modulation (OOK), and diversity techniques.*

1. Introduction

Free space optics (FSO) communications, also known as optical wireless communications, has received considerable attention recently as an attractive solution for high–rate last–mile terrestrial communications (D. Kedar *et al*;2004, Free Space Optics;2007). The attractive features compared to more traditional RF solutions include ease of deployment, license–free operation, high security, and high data rates. On the other hand, FSO systems are susceptible to pointing errors, severe attenuation under adverse weather conditions (e.g. fog), and atmospheric turbulence (D. Kedar *et al*; 2004). Viable solutions to overcome these problems have to be found before widespread deployment of FSO systems will be possible. In this paper, we concentrate on the effects of atmospheric turbulence on intensity–modulated FSO systems with direct detection (IM/DD). Atmospheric turbulence caused by variations in the refractive index due to inhomogeneities in temperature, pressure fluctuations, humidity variations, and motion of the air along the propagation path of the laser beam introduces irradiance fluctuations in the received signal. The resulting signal fading causes severe performance degradation. Recently, it has been shown that similar to RF communications, the effect of fading in FSO can be substantially reduced by creating a multiple–input multiple–output (MIMO) FSO system with multiple lasers at the transmitter and multiple photodetectors at the receiver (X. Zhu *et al* ;2002, S. G. Wilson *et al*;2005). In order to evaluate the impact of atmospheric turbulence and the effectiveness of corresponding countermeasures, accurate models for the fading distribution are important.While the lognormal distribution is often used to model weak turbulence conditions, the Gamma–Gamma distribution has recently received considerable attention because of its excellent fit with measurement data for a wide range of turbulence conditions (weak to strong) (M. Al-Habash *et al*; 2001 ,L. Andrews *et al*;2001).

However, despite the popularity of the Gamma–Gamma distribution in the FSO literature (M. Uysal *et al*; 2004, H. Sandalidis *et al*; 2008), a basic understanding of the effects of Gamma–Gamma fading on the performance of (MIMO) FSO systems is not available. In this paper, we analyze the performance of uncoded transmission over single–input single–output (SISO) and MIMO FSO channels suffering from Gamma–Gamma fading. For MIMO FSO we assume repetition coding across lasers at the transmitter (S. G. Wilson *et al*; 2005, S. G. Wilson *et al*; 2005).

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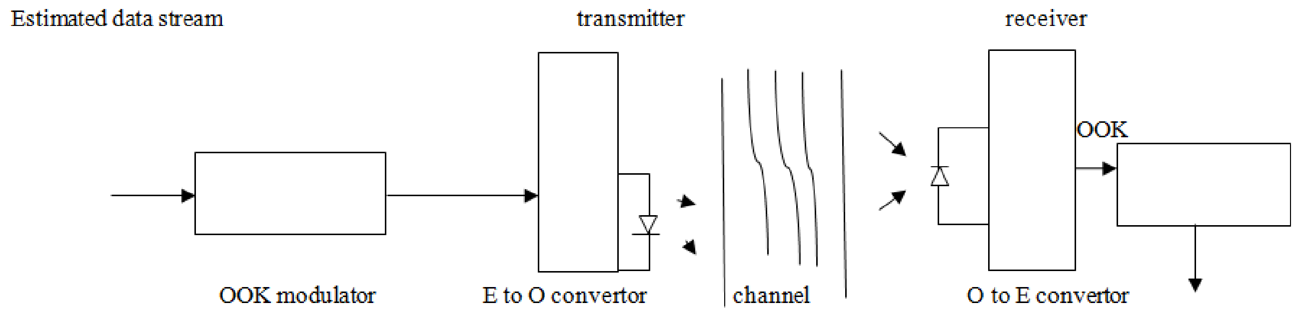

Figure 1(a): Block diagram of OOK system

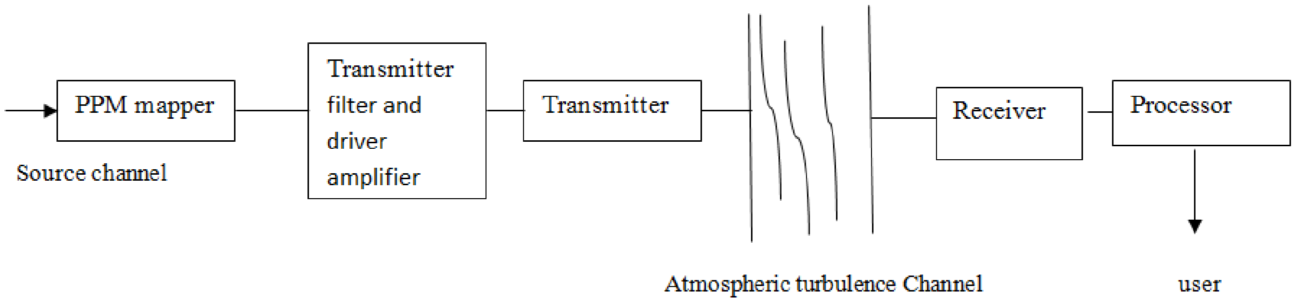

Figure 1(b): Block diagram of PPM system

And equal gain combining (EGC) and maximal ratio combining (MRC) at the receiver. The performance of the FSO link can also be improved by employing an appropriate modulation scheme that makes a good compromise between complexity and performance. In this view, different modulation techniques are employed in FSO communication system but well reputed modulation techniques are OOK, PPM, etc. The pulse position modulation (PPM) is one of the modulation techniques which has the interesting advantage of being average energy efficient (S. G. Wilson *et al*; 2005.). Moreover, for the general case of Qary PPM, propose a simple soft-demapping method of low complexity. The receiver complexity remains then reasonable in view of implementation in a terrestrial FSO system. Again the On-Off keying (OOK) signalIing format has been widely used in the commercially available FSO systems. But in channels with the atmospheric turbulence induced fading, the OOK scheme requires adaptive threshold to perform optimally (M. Al-Habash *et al*; 2001, L. Andrews *et al*; 2001). It has also been shown that using a fixed threshold OOK scheme results in suboptimal system, which is not only inferior to a SIM modulated FSO link but also has a BER floor. Although an on-off keying (OOK) intensity modulated based FSO link is widely reported, its major challenge lies in the fact that it requires adaptive threshold to perform optimally in atmospheric turbulence condition (X. Zhu *et al*; 2002). And the noise, which is modelled as additive white Gaussian comprises of both the background radiation and the thermal noise. In this paper, we propose an analytical approach to evaluate the BER performance under three modulation techniques. The bit-error rate (BER) performance results are evaluated in the presence of background radiation for Gamma-Gamma distribution.

Block diagram of Fig. 1 depicts the physical system under study. Fig.1 (a) shows the block diagram of OOK system, Fig. 1 (b) represent the block diagram of QPPM system. For all cases, the laser beam-widths are narrow, but sufficiently wide to illuminate the entire PD array. However, to exploit all potentials of FSO communication systems, the designers have to overcome some of the major challenges related to the optical wave propagation through the atmosphere. Namely, an optical wave propagating through the air experiences fluctuations in amplitude and phase due to atmospheric turbulence. In Fig.1 (a) the transmitter modulates data onto the instantaneous intensity of an optical beam. First we consider intensity modulated direct detection channels using OOK modulation, which is widely employed in practical systems. The received signal suffers from a fluctuation in signal intensity due to atmospheric turbulence and misalignment, as well as additive noise, and can be well modeled as

$$Y=hR_x+n \quad (1)$$

Where I is the transmitted intensity, h is the channel state, Y is the resulting electrical signal, and n is signal independent additive white Gaussian noise with variance $σ_n^2$.

In Fig 1 (b) a Q-ary PPM scheme transmits L=log2Q bits per symbol, providing high power efficiency. In the transmitter, the signals are described by the binary data bits are converted into a stream of pulses corresponding to QPPM symbol described below, and sent to the laser. The signals are described by the waveforms

$$S_0(t)=A=\sqrt{2P},\ 0 \le t \le T_s/4 \quad \text{‘00’}$$
$$S_1(t)=A=\sqrt{2P},\ T_s \le t \le T_s/2 \quad \text{‘01’}$$
$$S_2(t)=A=\sqrt{2P},\ T_s/2 \le t \le 3T_s/4 \quad \text{‘10’}$$
$$S_3(t)=A=\sqrt{2P},\ 3T_s/4 \le t \le T_s \quad \text{‘11’} \quad (3)$$

2. Channel Modeling with Gamma-Gamma Model

The gamma-gamma turbulence model is based on the modulation process where the fluctuation of light radiation traversing turbulent atmosphere is assume to consist of small scale (scattering) and large scale (refraction) effects. The gamma-gamma model for the probability density function (pdf) of received irradiance fluctuation which is based on the assumption that both the large and small scale effects are governed by the gamma distribution is therefore given by (X. Zhu *et al*; 2002),

$$F(I) = (2(\alpha\beta)^{(\alpha+\beta)/2} / \Gamma(\alpha)\Gamma(\beta))\, I^{((\alpha+\beta)/2)-1}\, k_{(\alpha+\beta)}(2\sqrt{\alpha\beta I}),\ I > 0 \quad (4)$$

Where 'I' is the signal intensity, α and β are parameters of the p.d.f, Γ is the gamma function and $K_{(\alpha-\beta)}$ is the modified Bessel function of the second kind of order (α-β). Here, Γ (α) and Γ (β) are the effective number of small scale and large scale eddies of the scattering environment. The Atmospheric turbulence is given as:

$$(\alpha) = 1/\exp(0.49\sigma_R^2 / (1+1.11\,\sigma_R^{12/5})^{7/6}) - 1 \quad (5)$$
$$(\beta) = 1/\exp(0.51\sigma_R^2 / (1+0.69\,\sigma_R^{12/5})^{5/6}) - 1 \quad (6)$$

Based on the atmosphere turbulence model adopted here and assuming strong turbulence, we can obtain the approximate analytic expression for the covariance of the log-amplitude fluctuation of plane and spherical waves which is also known as Rytov variance, given by,

$$\sigma_R^2 = 1.23C\, n^2\, k^{7/6} L^{11/6} \quad (7)$$

Where Cn^2 is the wave number spectrum structure parameter that depends upon the altitude.

3. Theoretical Analysis

a) Analysis of BER Using OOK Modulation Format

In this modulation format, the received electrical signal can be written as: -

$$r(t) = I(t) + \sum_{i=-\infty}^{\infty} I(t)a\, g(t-iT) + n(t) \quad (8)$$

Where a is the level of the i-th symbol and a ε - 1, 1}, the transmission probabilities of bit - 1 and 1 are P_0 and P_1, respectively; get(t) is the rectangle pulse shape function and T is the symbol time. When there is no turbulence and only A WGN is present, the BER can be written as (W. O. Popoola *et al*; 2007),

$$P_{e(ook)} = ½\, \mathrm{erfc}(\sqrt{E_b} / 2\sigma_n^2) \quad (9)$$

Where $E_b = a_i^2 = 1$ is the normalized bit energy, erfc= $2/\sqrt{\pi} \int_x^{\infty} \exp\left(-\frac{t*t}{2}\right) dt$ .Finally the BER is written as

$$P_{e(ook)} = ½\, \mathrm{erfc}((1/2\sqrt{2})\sqrt{\Gamma_0}) \quad (10)$$

In decibels, the signal-to-noise ratio (SNR) can be defined as: -

$$SNR\ (db) = 10\log(E_b / \sigma_n^2) \quad (11)$$

The PDF of the converted electrical signal when bit 0 or 1 is sent by (x>0):

$$P(r\ 0) = (1/\sqrt{2}\sigma_n\pi)\exp(-(r^2/2\,\sigma_n^2)) \quad (12)$$

b) Analysis of BER Using Q-ary PPM Modulation Format

At the receiver the received signal r(t) after optical/electrical conversion is:

$$r(t) = Sh(t)\, I_0 + n(t) \quad (13)$$

where I_0=the average transmitted light intensity and
I $=hI_0$ =the corresponding received intensity in an ON PPM slot.
h =the channel fading coefficient
n =receiver noise.

In block encoding, bits are transmitted in blocks instead of one at a time. Optical block encoding is achieved by converting each word of l bits into one of $L=2^1$ optical fields for transmission. One of the most commonly used optical block encoding schemes is PPM, where an input word is converted into the position of a rectangular pulse within a frame. The frame with duration Tf is divided into L slots and only one of these slots contains a pulse. This scheme can also be denoted as L PPM, in order to emphasize the choice of L. The transmit pulse shape for L-PPM is given by

$$P_m(t) = \begin{cases} 1, & for\ t = \left(\frac{(m-1)T}{L}, \frac{mT}{L}\right) \\ 0, & elsewhere \end{cases} \quad (14)$$

Where m= {1,2, ... ,L} Since L possible pulse positions code for $\log_2 L$ bits of information, the bit rate is R_b=/og2L/f. The optimum L-PPM receiver consists of a filter bank, each integrating the photo current in one pulse interval. The demodulated pulse is taken to originate from the slot in which the most current level was found. If the demodulated pulse position is the correct pulse position, log2L bits are decoded correctly. Otherwise, we assume that all L -1 wrong position are equally likely to occur. Therefore bit errors usually occur in groups. For Gaussian noise, the BER can be written as (J.R. Barry; 1994, E.A. Lee *et al*; 1994),

$$p_{e(ppm)} = ½\, \mathrm{erfc}((1/2\sqrt{2})\sqrt{L/2}\log_2 L^{\Gamma}{}_0) \quad (15)$$

Substituting L = 2 yields the BER for Manchester signals, which is identical to the BER of OOK modulation.

3. Diversity Combining Techniques

a) Selection Combining

The selective diversity combining techniques is based on the principle of selecting the best signal among all of the signals received from different nodes, at the receiver end. As each element is an independent sample of the fading process, the element with the greatest SNR is chosen from all the branches. In selection combining therefore

$$w_k = \begin{cases} 1, & \gamma k = \max\{\gamma n\} \\ 0, & otherwise \end{cases} \quad (16)$$

Since the element chosen is the one with the maximum SNR, the output SNR of the selection diversity scheme is $\gamma = \max_n \{n\}$. Such a scheme would need only a measurement of signal power, phase shifters or variable gains are not required (14). To analyze such a system we look at the probability of outage, BER, and resulting improvement in SNR. The probability of outage is the probability that the output SNR falls below a threshold γs, i.e., the SNR of all elements is below the threshold. Therefore the SNR of each branch in selection combining is given by,

$$\gamma k = \max\{\gamma n\} \quad (17)$$

The probability of outage is the probability that the output SNR falls below a threshold, i.e., the SNR of all elements is below the threshold.

$$P_{out}(\gamma s) = (1-e^{-(\gamma n/\Gamma)})^N \quad (18)$$

The overall error rate is obtained by integrating the conditional error rate at a given SNR (Ahmed A. Farid *et al*; 2012). The overall error rate is given as,

$$P_e = \int_0^\infty \left(\frac{BER}{\gamma}\right) f_\Gamma(\gamma) d\gamma = \int_0^\infty erfc\left(\sqrt{2\gamma}\right) \frac{N}{\Gamma} e^{-\gamma/\Gamma[1-e^{-\frac{\gamma}{\Gamma}}]^{N-1}} d\gamma \quad (19)$$

This equation can be determined as a series for N >1.

b) Equal Gain Combining

In equal gain combining, all the received signals are summed coherently. In this technique, the weights are varied with respect to the fading signals, where the magnitude fluctuates in the order of several 10s of dB. The equal gain combiner avoids this problem by setting unit gain at each element. In the equal gain combiner, the noise and instantaneous SNR are given by,

$$P_n = W^H W \sigma^2 = N\sigma^2 \quad (20)$$

In this analysis, it shows that despite being significantly simpler to implement, SNR is improved that is comparable to that of the optimal maximal ratio combiner. The SNR of both equal gain combiner and maximal ration combiner increases linearly with N. The probability of error for equal gain combining is given as,

$$P_e = ½(1-(\sqrt{\Gamma}\,(\Gamma+2))/(\Gamma+1)) \quad (21)$$

There is no closed form solution for the BER for general N, but several researchers have investigated the BER performance in several kinds of fading channels.

C) Maximum Ratio Combining

In the above formulation of selection diversity, we chose the element with the best SNR. This is clearly not the optimal solution as fully (N − 1) elements of the array are ignored. Maximal Ratio Combining (MRC) obtains the weights that maximize the output SNR, i.e., it is optimal in terms of SNR. The SNR improves by a factor of N. This is significantly better than the factor of (lnN) improvement in the selection diversity. Note the BER reduces exponentially as a function of N. The rate of fall of (the exponent) is the diversity order. This is consistent with the fact that in a SISO system.

$$P_e = 1/\,SNR \quad (22)$$

For large SNR in a diversity system, therefore, we expect the BER to be a linear function of the SNR (Jinlong Zhang *et al*). The slope of the plot indicates the diversity order. The BER, in a system with diversity order two, would fall off by a factor of for every 10dB gain in SNR.

d) Threshold Combining

In threshold combining, received signals from the first branch are randomly selected in sequential order in which the signal to noise ratio (SNR) is greater than the threshold. Selection combining transmits data continuously and it requires the dedicated receiver on each branch to continuously monitor the signal to noise ratio (SNR) but threshold combining does not need the receiver at all the branches. Threshold combining is simpler when compared with the selection combining method. In threshold combining, once a branch is chosen, the SNR on that branch remains above the desired threshold, the combiner outputs that received signal. If the SNR on the selected branch falls below the threshold, the combiner switches to another branch. The simplest method is to switch randomly to another branch. From (N. Letzepis *et al*; 2009), to pursue the thresholding at the input the following equation is given as,

$$\gamma n' = \begin{cases} 0, & 0 < \gamma n < \gamma T \\ \gamma n, & \gamma n \geq \gamma T \end{cases} \quad (23)$$

Branch switching is performed periodically with period T_s which is an amount of time longer than channel coherence time T_c.

4. Simulation Results

Table 1 Parameters for System Analysis

Parameter	Symbol	Value
Wavelength	λ	1550 nm
Receiver radius	A	6 cm
Link distance	L	1550m
Refractive index structure parameter	C_n^2	1.5*10-15
Beam waist radius	W_0	2cm
Inter spacing between transmitter	D	20cm
Phase front radius	F_0	-10cm

The software used for simulation is MATLAB and the simulations are carried out in Rayleigh fading channel. A MIMO system consists of M=N transmitters and receivers with identical arrangements. The outage probability and the BER are analyzed for different diversity combining techniques. Thus the performance gain is achieved by increasing the number of nodes N in the receiver side. The simulation parameters used for the Free Space Optics – MIMO system is given in Table 1.

The bit error rate and outage probability is analyzed for different diversity combining techniques for FSO-MIMO system, which improves the performance of the system. For indoor usages, small FSO nodes the receiver radius is 1-6 cm and for outdoor usages, the receiver radius is 10-25 cm is used for larger sizes of FSO nodes. Since for indoor applications, the receiver radius 5 cm is used.

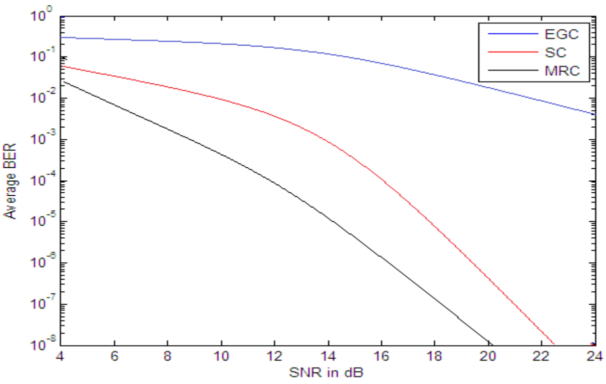

Fig.1 MRC, SC and EGC Bit Error Rate performance

Fig. 1 shows that the BER performance of different diversity combining techniques. As the signal to noise ratio increases, bit error rate is decreased. By comparing equal gain combining (EGC) with selection combining (SC) and maximum ratio combining (MRC), simulations show that maximum ratio combining gives the lowest bit error rate and it improves the performance of the system.
Fig. 2 shows that the outage probability versus SNR for diversity combining techniques. Maximum ratio combining has lowest outage probability when compared with the selection combining and equal gain combining.

Fig. 3 shows that the BER performance of different diversity combining techniques. As the signal to noise ratio increases, the error in the transmitted data decreases.

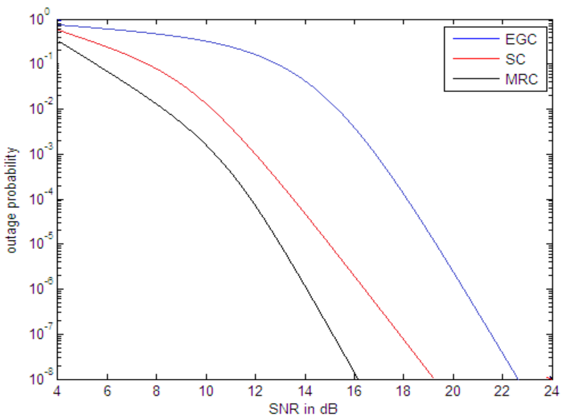

Fig.2 Outage probability Vs SNR for diversity combining techniques

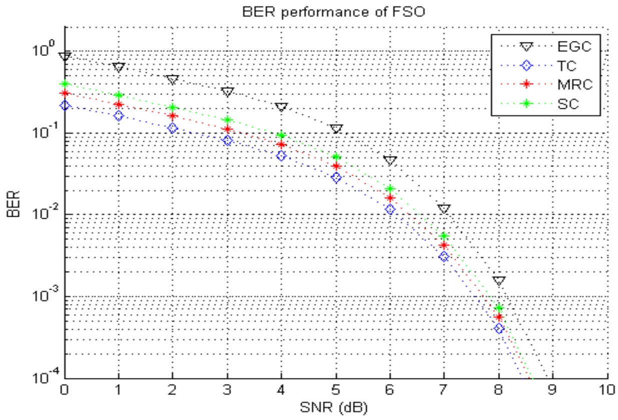

Fig.3BER performance of FSO-MIMO system with different diversity combining techniques

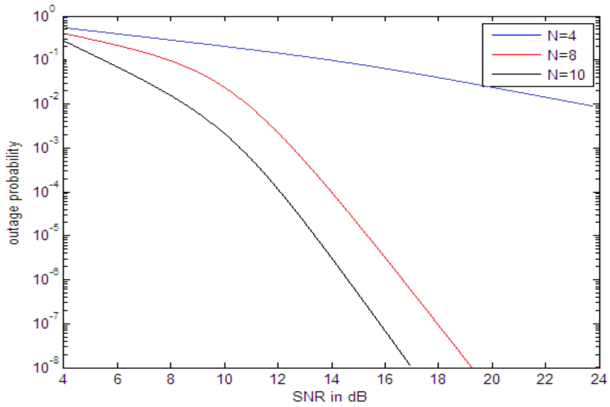

Fig.4 Outage probability of Threshold combining depending upon the Number of nodes

Threshold combining gives the better bit error rate when compared to the Equal gain combining, Maximum ratio combining and Selection combining techniques. Fig. 4 shows that the outage probability of threshold combining depending on the number of nodes N. As the number of nodes increases, the outage probability is decreased. This increases the performance of the system.

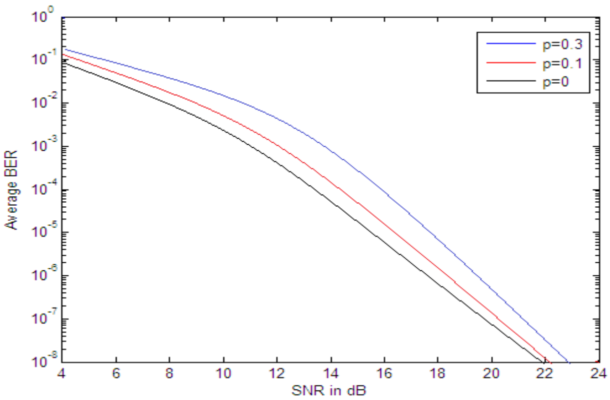

Fig.5 BER for threshold combining with different atmospheric parameter

Fig. 5 shows the bit error rate performance for threshold combining using different atmospheric parameter (p). If the atmospheric turbulence parameter decreases, bit error rate is decreased.

Conclusion

A model for FSO-MIMO channels impaired in the presence of atmospheric fading, the diversity gain depends only on the atmospheric parameters and is independent of both the number of transceivers and atmospheric fading parameters. In this paper, bit error rate and the outage probability is analyzed for different diversity combining techniques which increases the performance of the system. The results confirm that the performance of the threshold combining is better when compared with the EGC, SC and MRC techniques. By increasing the number of transmitter antennas and receiver antennas, diversity gain is increased and the performance of the system is increased. In order to reduce fading an alternative approach is used to investigate the cooperative diversity technique as a solution for combating turbulence-induced fading over Free-Space Optical (FSO) links.

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