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Performance Analysis of a Subcarrier Multiplexed Qpsk Modulated Free Space Optical Mimo Transmission Link through Atmospheric Turbulence

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Abstract

Free space optical (FSO) communication shows potential technology for communication. But the main weakness is atmospheric turbulence which causes major transmission destruction for an open air optical communication system. In this paper, the performance of free space optical (FSO) is analyzed using subcarrier multiplexed QPSK intensity modulated OFS link with optical intensity modulation and direct detection for a single input single output (SISO) system considering strong atmospheric turbulence. To overcome the effect of atmospheric turbulence, multiple input multiple output (MIMO) communication system is introduced here. The performance results are evaluated and are shown in terms of BER and it is clearly found that performance is considerably improved for a multiple input multiple output (MIMO) system.

Keywords: Free space optical (FSO), Single input single output (SISO), Single input multiple output (SIMO), Multiple input single output (MISO), Multiple input multiple output (MIMO), Quadrature phase shift keying (QPSK)

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INTRODUCTION

"Free space" means air, outer space, vacuum, or something similar. free space optics (FSO) is also an optical communication technology that uses light propagating in free space to send information between two points. The technology is useful where physical connections by means of fiber optic cables are unfeasible due to higher costs or other considerations. Nowadays, free space optical (FSO) communication is a very promising technology for communication. But the main weakness is atmospheric turbulence which causes major transmission impairment for an open air optical communication system. In FSO communication, the transmitter and the receiver are separated by the propagation channel, which is the atmosphere. free-space optical (FSO) links involve the transmission, absorption and scattering of light by the Earth's atmosphere. The atmosphere interacts with transmitted light due to the composition of the atmosphere. Under normal conditions, the atmosphere consists of a mixture of different molecules and small suspended particles called aerosols. This interaction produces a wide variety of optical incidents like selective attenuation of radiation that propagates in the atmosphere, absorption at specific optical wavelengths by the atmospheric molecules and scintillation due to the variation of the air's refractive index under the effect of temperature variation.

It is previously found that two primary challenges for FSO communication are pointing error and fading due to scattering and scintillation [1, 3]. FSO communication is not much affected by snow and rain, but is rigorously affected by the atmospheric turbulence and fog [2, 4]. Free space laser communication systems based on a single laser source and single detector suffer the effect of atmospheric turbulence much [1]. The communication system based on the use of multiple laser multiple detector (MLMD) architecture can considerably diminish the effect of this problem [1, 5]. Already different modulation schemes are examined for the FSO system through atmospheric turbulence [1, 2, 4, 6 and 8]. In this paper, analysis has been carried out for a multiplexed subcarrier QPSK modulated optical intensity modulated free space link over a turbulent atmospheric channel.

ATMOSPHERIC TURBULENCE MODELS

Atmospheric turbulence is well studied and various models exist to describe it. Generally, three types of atmospheric models are used. They are:

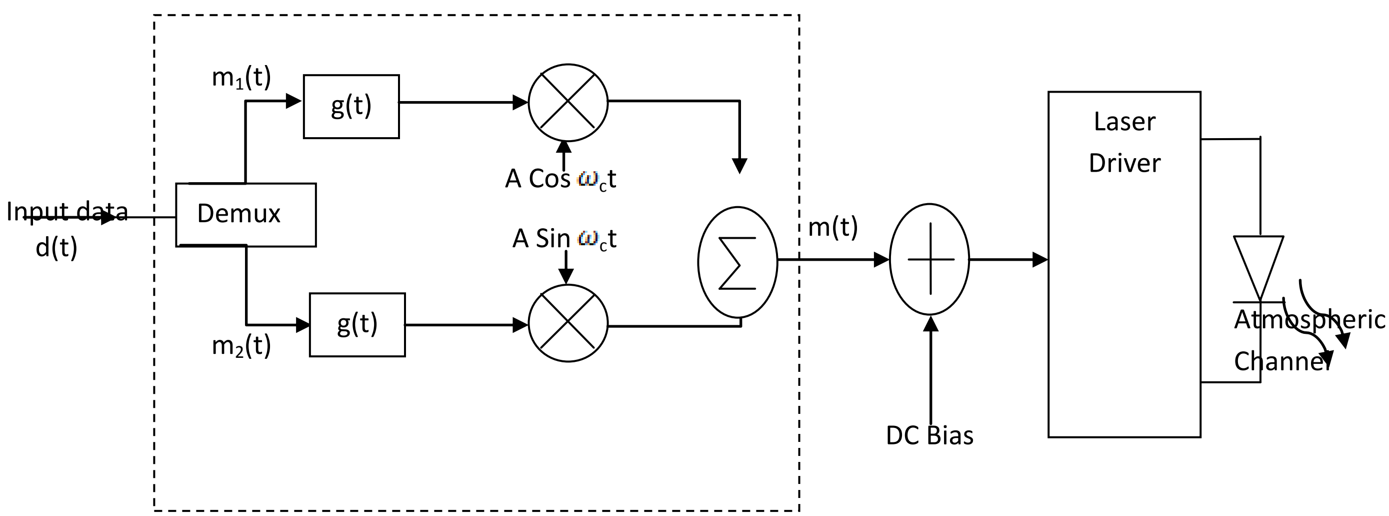
(1) Log normal distribution model
(2) Gamma-gamma model
(3) Negative exponential model

It is observed that log normal distribution is suitable for weak turbulence regime. The atmospheric turbulence across weak to strong regime is represented using the gamma-gamma distribution [2]. During strong turbulence, negative exponential model is suitable [2].

In this paper, strong turbulence is considered and that is why the negative exponential model is considered while taking the effect of atmospheric turbulence. The probability density function (pdf) for the negative exponential model is

$$P(I) = \frac{1}{I_o} exp\left(\frac{-I}{I_o}\right) \qquad (1)$$

where, $I_o > 0$ and I_o is said as the noise turbulence variance which is often normalized to unity.



QPSK Modulator

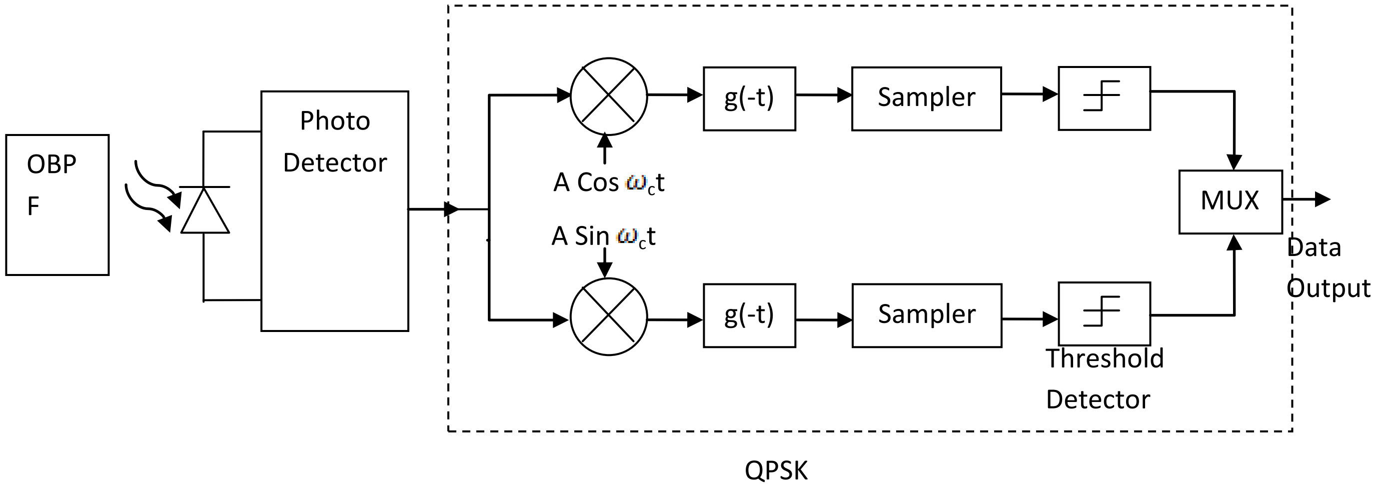


Fig. 1 Block Diagram of QPSK Subcarrier Intensity Modulated FSO Link.

QPSK SUBCARRIER INTENSITY MODULATION

In optical subcarrier intensity modulated links, an RF subcarrier signal is pre-modulated with the source data d(t) and then it is used to modulate the intensity of the optical carrier by a continuous wave laser diode as shown in Figure 1. Prior to modulating the laser irradiance, the input signal is modulated onto the RF subcarrier signal using QPSK in which four dibits are represented by four different phases 90 degree apart from one another. In the QPSK modulator, the transmitted signal m(t) can be expressed as:

$$m(t) = A_c g(t)\varepsilon[m_1(t)\cos(\omega_c t+\theta) + m_2(t)\sin(\omega_c t+\theta)] \quad (2)$$

where, A_c is the channel carrier amplitude, ε is the channel modulation index, ω_c is the channel angular frequency and g(t) is the rectangular pulse shaping function. This modulated signal is added to the dc bias current of a semiconductor laser in order to directly intensity modulate it. The transmitted optical signal by the laser is

$$S(t)=\sqrt{P_o[1+m(t)]} \quad (3)$$

where P_o is the output power at the bias level for the semiconductor laser. The radiated optical signal is proportional to m(t).

At the receiver end, the incoming optical radiation is passed through an optical band pass filter (OBPF) before being converted into an electrical signal by the photo detector. The OBPF is used to limit the amount of background radiation noise detected by the photo detector. The total power received at the input of the photo diode detector can be written as

$$P_r = P_o[1+m(t)] \quad (4)$$

Now this optical signal is converted into the corresponding electrical signal through direct detection by using the photo diode detector. At the receiver end, the received photo current is [2]

$$i_r = RI(1 + m(t)) + n(t) \quad (5)$$

Where R is photo detector responsivity and I is optical intensity, n(t) is additive white Gaussian noise (AWGN) which consists of thermal noise and background radiation shot noise.

Now Eq. (5) can be written as

$$i_r = RI(1 + A_c g(t)\varepsilon[m_1(t)\cos(\omega_c t+\theta) + m_2(t)\sin(\omega_c t+\theta)]) + n(t) = RI + RI\, A_c g(t)\varepsilon[m_1(t)\cos(\omega_c t+\theta) + m_2(t)\sin(\omega_c t+\theta)] + n(t) \quad (6)$$

RI is a DC component which is filtered out by the QPSK demodulator. So, to get the received photo current, Eq.. (6) can be written as

$$i_r = RI.\, A_c g(t)\varepsilon[m_1(t)\cos(\omega_c t+\theta) + m_2(t)\sin(\omega_c t+\theta)] + n(t) \quad (7)$$

The shot noise is

$$\sigma^2_{shot} = 2qB.i_{sho} \quad (8)$$

and the background noise is-

$$\sigma^2_{bg} = 2qB_{el.}i_{bg} \quad (9)$$

Here, B_{el} is post-detection electrical filter bandwidth and i_{bg} is the background current $=R.I_{Bg}$, considering I_{Bg} is the background radiation irradiance. The total noise power is

$$\sigma^2 = \sigma^2_{bg} + \sigma^2_{th} = 2qB_{el.}\, R.I_{Bg} + 4kTB_{el}/R_L \quad (10)$$

Now the post-detection SNR of the photo detector is

$$SNR = \frac{(IR\varepsilon)^2 Pm}{2\, B_{el}.(qR.I_{Bg} + 2kT/R_L)} \quad (11)$$

where P_m is the subcarrier signal power which is

$$P_m = \frac{1}{T}\int_T m_x^2(t)\,dt \quad (12)$$

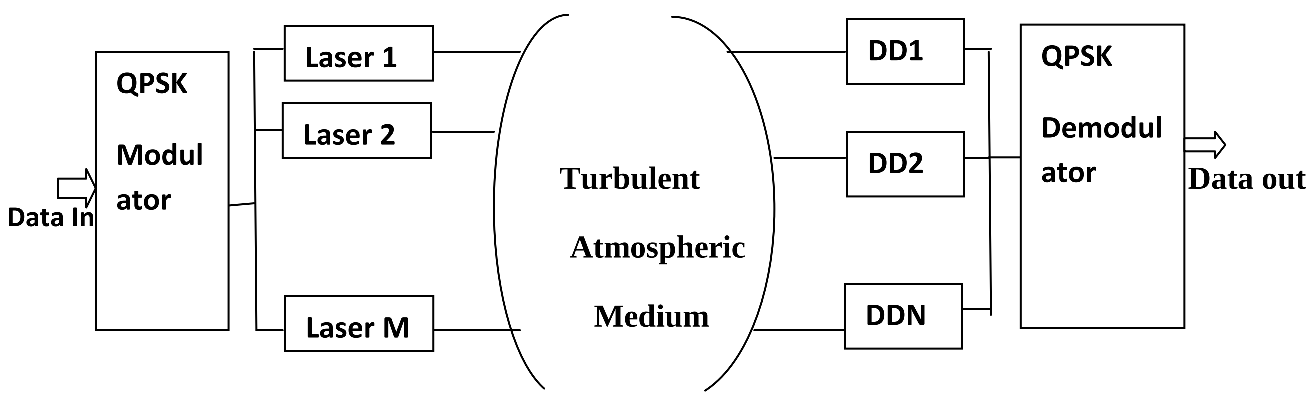


Fig. 2 Free Space Optical MIMO System Model.

where $m_x = A_c g(t)[m_1(t)\cos(\omega_c t+\theta) + m_2(t)\sin(\omega_c t+\theta)]$

Without diversity for a single transmitter and single detector, the BER for the QPSK detector without atmospheric turbulence will be as follows

$$BER = \int_0^\infty Q\left(\frac{IRA\varepsilon}{\sqrt{2}\sigma}\right)dI \quad (13)$$

Without diversity for a single transmitter and single detector, the BER for the QPSK detector considering atmospheric turbulence will be

$$BER = \int_0^\infty Q\left(\frac{IRA\varepsilon}{\sqrt{2}\sigma}\right)P(I)dI \quad (14)$$

where, P(I) indicates the pdf of atmospheric turbulence model. In this thesis, negative exponential model is used considering that the turbulence is strong.

So, the unconditional BER (considering atmospheric turbulence) will be

$$\text{BER} = \int_0^\infty Q\left(\frac{IRA\varepsilon}{\sqrt{2}\sigma}\right) \cdot \frac{1}{I_0} \exp\left(\frac{-I}{I_0}\right) dI \qquad (15)$$

FSO COMMUNICATION WITH SPATI AL DIVERSITY

To further develop the error performance of an FSO link, the turbulence induced irradiance fluctuation is mitigated by employing multiple transmitters and multiple receivers shown in Figure 2. Diversity recovers the transmission

L diversity channel at the receiving side will be [9]

$$P_{b(1,L)} = (0.5(1-\mu))^L \sum_{l=0}^{L-1} \binom{L-1+l}{l} [0.5(1+\mu)]^l \qquad (16)$$

For the other transmitting antenna, same thing will happen. So, the probability of bit error for N transmitting antenna will be

performance by making use of more than one independently faded version of the transmitted signal. This significantly improves transmission accuracy by creating higher instantaneous SNR for strong turbulence of the atmosphere. In this paper, maximal ratio combining technique has been considered at the detector end for the diversity combining.

In maximal ratio combining for MIMO system, if there are N transmitting antenna and L receiving antenna, signal from the first transmitting antenna will go to L receiving antenna. So the diversity channel will be L for the first transmitting antenna. The probability of bit error after combining

$$P_{b(N,L)} = \left\{(0.5(1-\mu))^L \sum_{l=0}^{L-1} \binom{L-1+l}{l} [0.5(1+\mu)]^l\right\}^N \qquad (17)$$

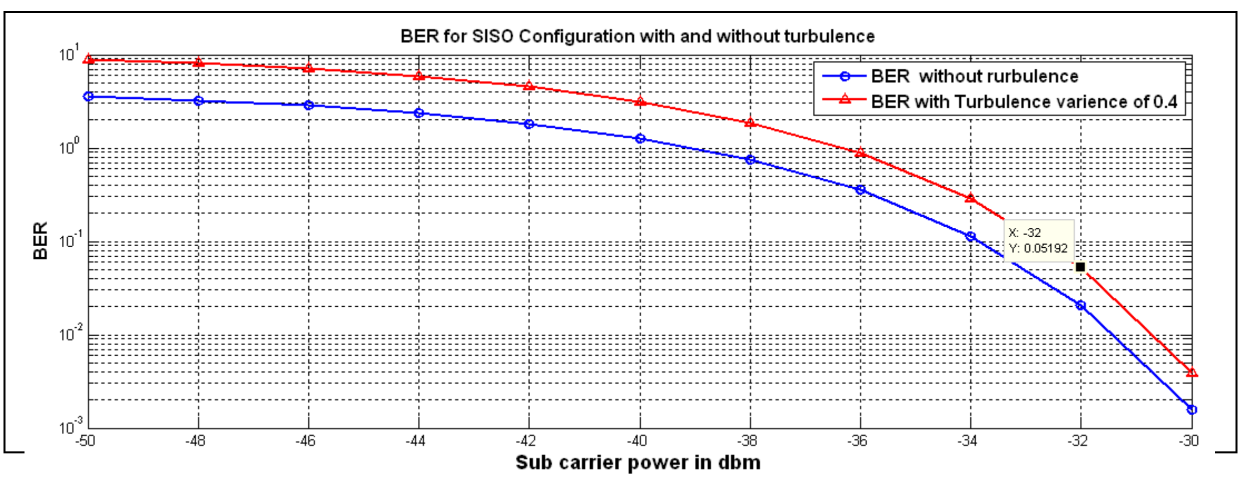


Fig. 3 BER vs. Subcarrier Power of an FSO Link with and without Turbulence.

For a particular subcarrier power of −32 dbm, BER without atmospheric turbulence is 2 × 10 − 2 and the BER with the turbulence variance of 0.4 is 5.2×10^{-2}.

where,

$$\mu = \sqrt{\frac{\Gamma_c}{1+\Gamma_c}} \quad (18)$$

Γ_c is the average SNR per bit of each channel. Using subcarrier multiplexed QPSK modulation scheme, the considered SNR is

$$\Gamma_c = \frac{(IR\varepsilon)^2 Pm}{2\, B_{el}.(qR.I_{Bg} + 2kT/R_L)} \quad (19)$$

RESULTS AND DISCUSSIONS

more BER. Figure 3 shows the effect of BER versus subcarrier power in the presence of atmospheric turbulence.

Figure 4 shows BER versus subcarrier power with variable transmitters and one receiver at a bit rate of 1 Gbps considering turbulence variance 1.0.

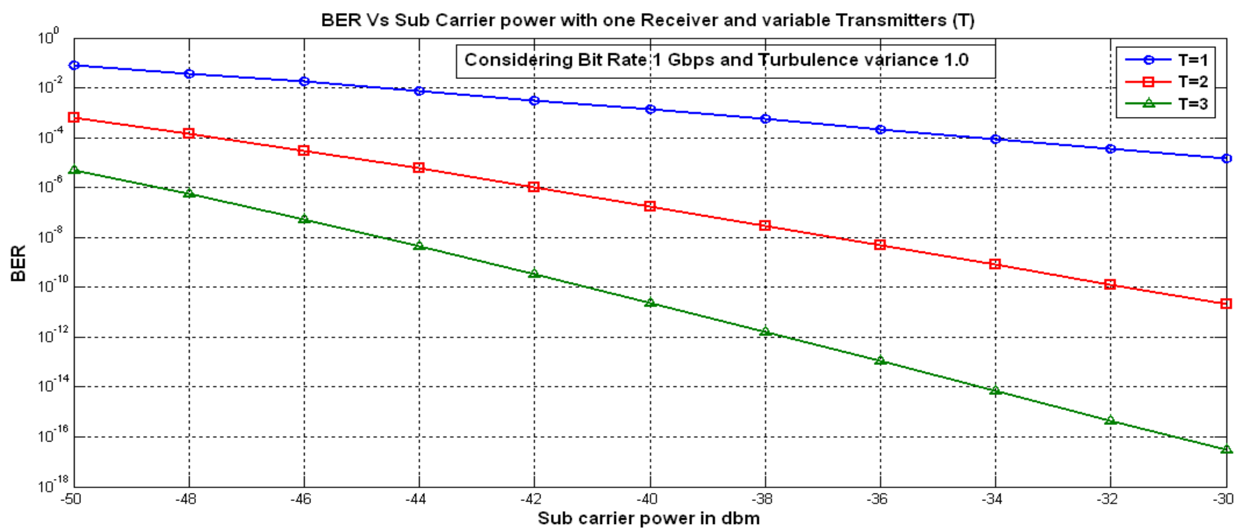


Fig. 4 BER vs. Subcarrier Power of an FSO Link with Variable Transmitters and One Receiver at a Bit Rate of 1 Gbps and turbulence variance of 1.0.

In Figure 4, it is clearly seen that the BER is reduced with the increase of the number of transmitters for a bit rate of 1 Gbps. For a particular power of −30 dbm, if one transmitter and one receiver are used, then the BER is 1.418×10^{-5}. If the number of transmitting antennae is increased to two and three, then the BER is reduced to 2.034×10^{-11} and 2.916×10^{-17} respectively.

Figure. 5 shows BER versus subcarrier power with one transmitter and variable receivers at a bit rate of 1 Gbps considering turbulence variance 1.0.

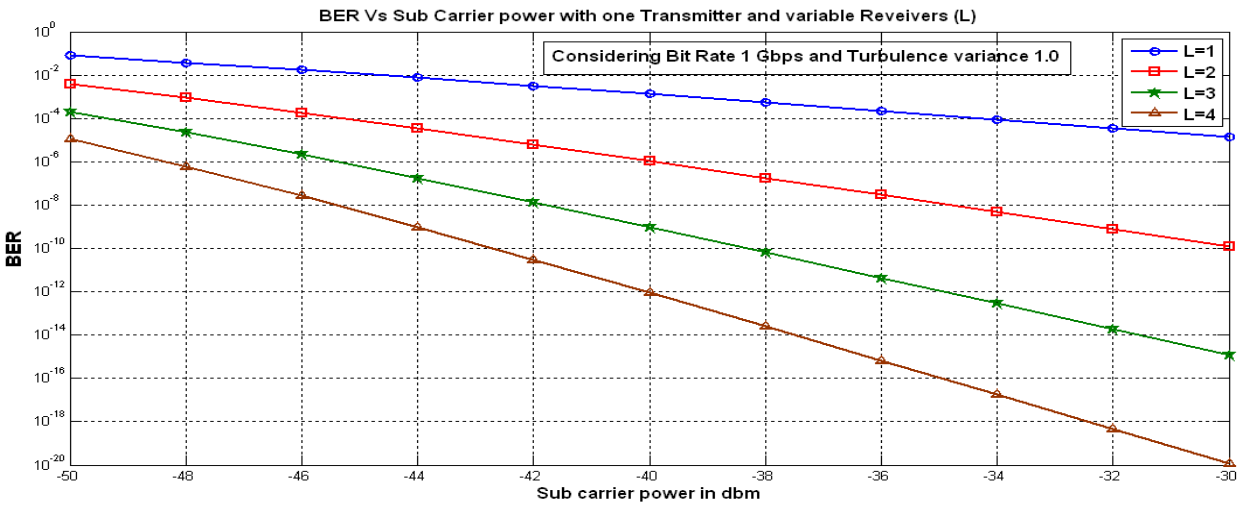


Fig. 5 BER vs. Subcarrier Power of an FSO Link with One Transmitter and Variable Receivers at a Bit Rate of 1 Gbps and Turbulence Variance of 1.0.

In Figure 5, it is also observed that the BER is reduced with the increase of the number of receivers for a bit rate of 1 Gbps. For a particular power of -30 dbm, if one transmitter and one receiver are used, then the BER is 1.418×10^{-5}. If the number of receiving antennae is increased to two, three and four, then the BER is reduced to 1.22×10^{-10}, 1.166×10^{-15} and 1.173×10^{-20}, respectivel

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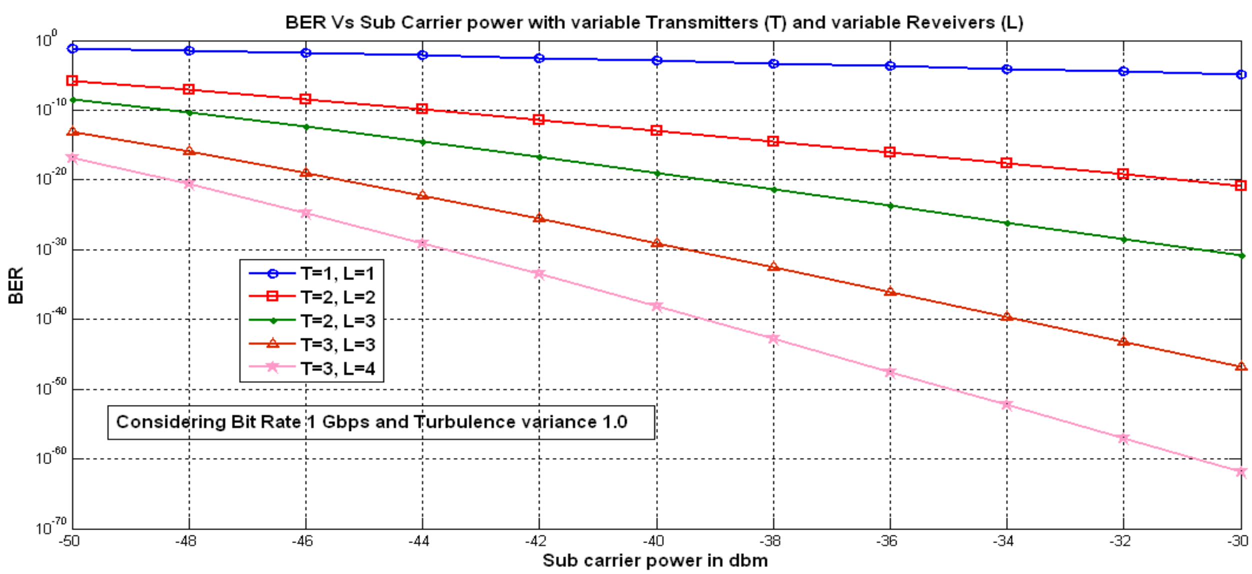

Fig. 6 BER vs. Subcarrier power of an FSO Link for a MIMO System at a Bit Rate of 1 Gbps and turbulence variance of 1.0.

For a MIMO system, the amount of BER is appreciably reduced which is observed in Figure 6. MIMO system can significantly improve the BER performance over single input single output (SISO) system. In wireless communication, as the power is severely limited by the battery capacity, the MIMO system can significantly reduce the transmitted power. Table I gives a very clear idea for particular subcarriers power of -30 dbm how the MIMO technology is improving the FSO signal through atmospheric turbulence. In Table I, it is clearly observed that for the MIMO system the BER is quite negligible for a subcarrier power of − 30 dbm. So, the subcarrier power can be reduced for achieving favorable BER with the help of spatial diversity.

Table I Performance Analysis of an FSO Link for Different Transmitting and Receiving Diversity in Terms of BER Considering Subcarrier Power of − 30 dbm in Different Atmospheric Conditions.

Atmospheric Condition	Applied Technology	No. of Transmitter	No. of Receiver	Bit Error Rate (BER)
Without Turbulence	SISO	1	1	1.55×10^{-3}
With Turbulence	SISO	1	1	3.9×10^{-3}
With Turbulence	MISO	2	1	2.03×10^{-11}
With Turbulence	MISO	3	1	2.92×10^{-14}
With Turbulence	SIMO	1	2	1.22×10^{-10}
With Turbulence	SIMO	1	3	1.166×10^{-15}
With Turbulence	MIMO	2	2	1.5×10^{-21}
With Turbulence	MIMO	2	3	1.381×10^{-31}
With Turbulence	MIMO	3	3	1.632×10^{-47}
With Turbulence	MIMO	3	4	1.65×10^{-62}

CONCLUSIONS

MIMO system can significantly improve the BER performance and provide diversity gain over single input single output (SISO) system. It is also observed that MIMO technology not only improves the transmitted signal quality, but also it can save signal power in comparison with the single input single output (SISO) system. However, MIMO technology requires morecost for the extra arrangements in the transmission and receiving end.

In the free space optical communication, the length of communication channel is very much limited due to atmospheric turbulence in different atmospheric conditions. Still lots of research work need to be carried out to increase the length of FSO channel. Here the effect of cloud is not considered. So, this work also can be extended considering the effect of cloud.

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