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Performance Analysis of Terrestrial Free Space Optical (FSO) Communication Link Using M-QAM Modulation Technique

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Abstract— Free Space Optical (FSO) communication refers to use atmosphere as transmitting link between two or more communicating nodes separated by certain distance. A lot of work has been done to suggest measures to improve FSO link performance which is seriously affected due to atmospheric turbulence. In this paper, performance analysis of M-QAM has been done under the turbulent atmospheric conditions. The Bit Error Rate (BER) for M-QAM has been analyzed for different values of M. Further the BER of M-QAM has been analyzed for different wavelengths and Link Ranges (distance between transmitter and receiver) and it has been found that 8-QAM gives best BER performance under turbulent atmospheric conditions.

Index Terms—FSO, BER, M-QAM, Wavelength, Atmospheric Turbulence, Link Range.

1 Introduction

Free Space Optical (FSO) communication involves the transmission of optical signals through free space or air. A main requirement for operating an FSO system is unobstructed line-of-sight between the two networking locations. FSO systems operate in the infrared (IR) spectral range. FSO systems use wavelengths close to the visible spectrum around 850 and 1550 nm, which corresponds to frequencies around 200 THz[1]. The unguided channels could be any,or a combination of space, sea-water, or atmosphere. In this paper, the emphasis is on the terrestrial FSO link.

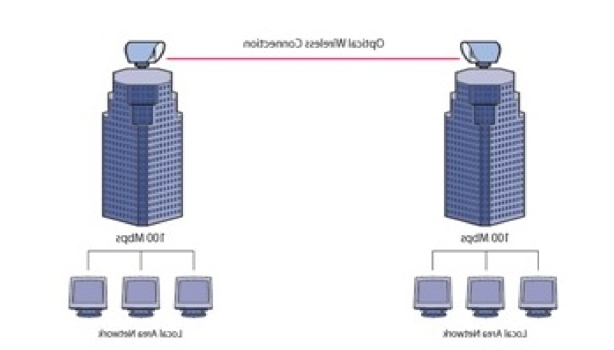

Fig. 1 Schematic of FSO

FSO has now emerged as a commercially viable technology to radio frequency (RF) used for reliable and rapid deployment of data, voice and video within the access networks. RF based wireless networks can offer data rates from tens of Mbps (point-to-multipoint) up to several hundred Mbps (point-to-point)[2]. However, there is a major limitation which these RF systems face and that is due to spectrum congestion. The frequency spectrum is getting congested day by day due to increasing bandwidth requirements of present and emerging communication systems. The most efficient solution to this problem is the use of FSO system which guarantees abundant bandwidth. Using an optical carrier, we can get data bandwidth upto 200 THz where as in RF the usable frequency bandwidth is comparatively lower by a factor of 10^5. We need not to purchase any spectrum license for FSO link. FSO system is quick to deploy and redeploy and the cost of FSO system is lower than RF system[3].

The greatest challenge that FSO faces is the atmospheric turbulence, resulting in signal scattering, absorption and fluctuation[4]. These effects become adverse for a link range exceeding 1 km. Another factor responsible for FSO performance degradation is the atmospheric scintillation. The scintillation effect results in signal fading, due to constructive and destructive interference of the optical beam traversing the atmosphere. For FSO links spanning 500 meters or less, typical scintillation fade margins are 2 to 5 dB, which is less than the margins for atmospheric attenuation, making scintillation insignificant for short range FSO systems. However, in clear air when the atmospheric channel attenuation is less than 1 dB/km and most especially when the link range is in excess of 1 km, scintillation impairs the FSO link availability, attainable error performance and the available link margin significantly. However, in clear atmosphere, with a typical attenuation coefficient of 0.43 dB/km, a longer range FSO (1 km) is easily achievable.

In this paper we are investigating the BER performance of M-ary QAM modulation technique for a FSO link under tur-

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bulent atmospheric conditions. This paper is organised as follows: In section 2, atmospheric turbulence has been described. In section 3, M-QAM modulation technique and its bit error rate expression for a turbulent FSO link has been discussed. Section 4 includes results and discussions which is followed by conclusion in section 5.

2 ATMOSPHERIC TURBULENCE

Solar radiation absorbed by the Earth's surface causes air around the earth surface to be warmer than that at higher altitude. This layer of warmer air becomes less dense and rises to mix turbulently with the surrounding cooler air causing the air temperature to fluctuate randomly. Inhomogeneities caused by turbulence can be viewed as discrete cells, or eddies of different temperature, acting like refractive prisms of different sizes and indices of refraction. The interaction between the laser beam and the turbulent medium results in random phase and amplitude variations (scintillation) of the information-bearing optical beam which ultimately results in performance degradation of FSO links. Atmospheric turbulence results in random fluctuation of the atmospheric refractive index, n along the path of the optical field/radiation traversing the atmosphere. This refractive index fluctuation is the direct end product of random variations in atmospheric temperature from point to point[5]. These random temperature changes are function of the atmospheric pressure, altitude and wind speed. The smallest and the largest of the turbulence eddies are termed the inner scale, l_o, and the outer scale, L_o, of turbulence respectively. l_o is typically of the order of a few millimetres while L_o is typically of the order of several metres [6,7]. These weak lens-like eddies shown graphically in Fig. 2 result in a randomised interference effect between different regions of the propagating beam causing the wavefront to be distorted in the process.

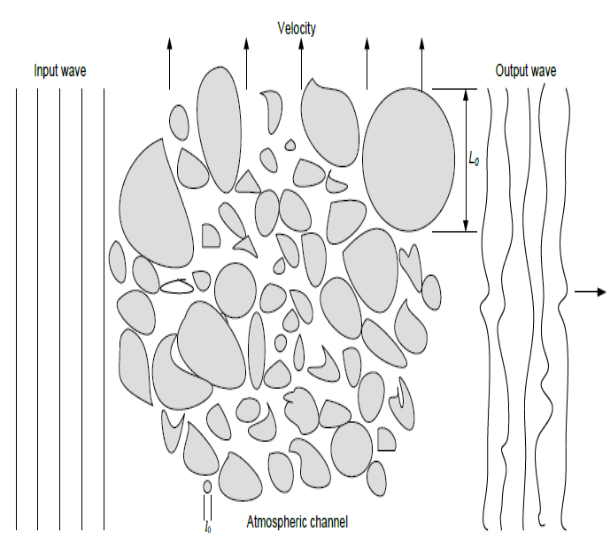

Fig. 2 Atmospheric Channel with turbulent eddies

In atmospheric turbulence, an important parameter for charactерising the amount of refractive index fluctuation is the index of refraction structure parameter, C_n^2, introduced by Kolmogorov [8]. The value of C_n^2 varies with altitude and a commonly used model to describe it is the Hufnagel-Valley (H-V) model given below as:

$$C_n^2(\text{h})=0.00594(v/27)^2(10^{-5}h)^{10}\exp(-h/1000)+2.7\times10^{-16}\exp(-h/1500)+\hat{A}\exp(-h/100) \quad (1)$$

where $\hat{A}$ is taken as the nominal value of C_n^2 (0) at the ground in $m^{-2/3}$, v is the velocity of wind in m/s and h is the altitude in meters.The value of the index of refraction structure parameter varies with altitude, but for a horizontally propagating field it is usually assumed constant and typically it ranges from 10^{-12} $m^{-2/3}$ for strong turbulence to 10^{-17} $m^{-2/3}$ for weak turbulence and its typical average value is considered to be 10^{-15} $m^{-2/3}$[9].
Another important factor is the rytov approximation which gives relationship between index refraction structure parameter C_n^2 and relative variance of optical intensity σ_I^2 as follows:

$$\sigma_I^2 = 0.5\ C_n^2 k^{7/6} L^{11/6} \quad (2)$$

Where k is the boltzman's constant, k is the wavenumber and L is the link range (distance between transmitter and receiver).

3 M-ARY QAM MODULATION

QAM modulation is a method of combining two amplitude-modulated signals into a single channel, thereby doubling the effective bandwidth. In QAM, there are two carriers, each having the same frequency but differing in phase by 90 degrees (one quarter of cycle). Mathematically,one of the signals can be represented by a sine wave, and the other by a cosine wave. The two modulated carriers are combined at the source of transmission and then the resulting modualted carrier is used to modulate the irradiance of an optical signal. At the destination, the carriers are separated, the data is extracted from each, and then the data is combined into the original modulating signal. In QAM, we use two double sideband (DSB) signals using carriers of same frequency but in phase quadrature as shown in Fig. 3.The two baseband signals used are $m_1(t)$ and $m_2(t)$ and the corresponding QAM signal is given by:

$$\Phi_{QAM}(t)=m_1(t)\cos\omega_c(t) + m_2(t)\sin\omega_c(t) \quad (3)$$

Both the modulated signals occupy same band but the two signals can be separated at the receiver by synchronous detection using two local carriers in phase quadrature. So the multiplier output $x_1(t)$ of receiver is given by:

$$\begin{aligned} x_1(t) &= 2\,\Phi_{QAM}(t)\cos\omega_c(t) \\ &= 2[m_1(t)\cos\omega_c(t) + m_2(t)\sin\omega_c(t)]\cos\omega_c(t) \\ &= m_1(t) + m_1(t)\cos 2\omega_c(t) + m_2(t)\sin 2\omega_c(t) \end{aligned} \quad (4)$$

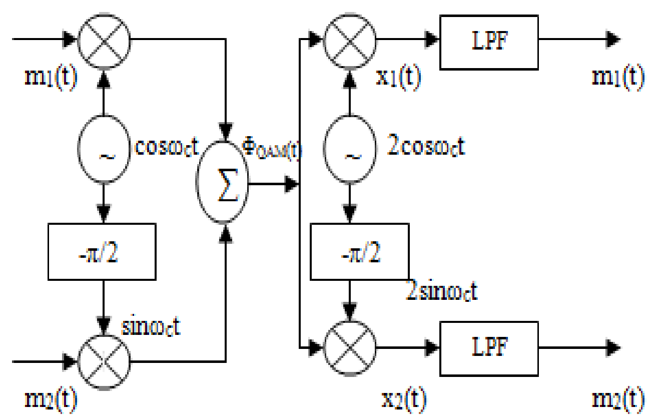

Fig. 3 Quadrature Amplitude Multiplexing

The last two terms are suppressed by the low pass filter (LPF) and we get desired output signal $m_1(t)$. Similarly we can get the signal $m_2(t)$. This is called Quadrature Amplitude Multiplexing. Thus two baseband signals, each of bandwidth B Hz, can be transmitted simaltaneously over a bandwidth 2B by using QAM Modulation. Now we consider data symbols which comprise log_2M data symbols which have been mapped to one of the M phases on each carrier signal m(t). So the conditional BER expression for M-QAM is given by[10]:

$$P_e=\frac{2(1-1/\sqrt{M})}{\log_2 M}Q\sqrt{\frac{3\log_2 M\times(SNR)}{2(M-1)}} \quad (5)$$

The unconditional BER for FSO link, P_e, is obtained by averaging the conditional bit error rate over the atmospheric turbulence stastics which is given by:

$$P_e=\frac{2(1-1/\sqrt{M})}{\log_2 M}\int_0^\infty Q\sqrt{\frac{3\log_2 M\times(SNR)}{2(M-1)}}\,p(I)\,dI \quad (6)$$

$$P_e=\frac{2(1-1/\sqrt{M})}{\log_2 M}\int_0^\infty Q\sqrt{\frac{3\log_2 M\times(SNR)}{2(M-1)}}\frac{1}{I\sqrt{2\pi\sigma_I^2}}\times \exp\left\{-\frac{[\ln I/I_0+\sigma_I^2/2]^2}{2\sigma_I^2}\right\}dI \quad (7)$$

Where $p(I)=\frac{1}{I\sqrt{2\pi\sigma_I^2}}\exp\left\{-\frac{[\ln I/I_0+\sigma_I^2/2]^2}{2\sigma_I^2}\right\}$, I is the field irradiance in the turbulent atmosphere, I_o is the mean received irradiance without atmospheric turbulence and σ_I^2 is irradiance variance.

4 RESULTS AND DISCUSSIONS

The system described above has been simulated using matlab.The simulation parameters used are given in Table 1.

Fig. 4 shows the BER performance of M-QAM for different values of M.The BER has been plotted againt SNR. It has been observed that BER of 8-QAM is more than 10^{-10} for a SNR of 35 dB while BER of 64-QAM is around 10^{-7} for the same value of SNR. So it is clear that the BER of M-QAM degrades with the increasing value of M.

TABLE 1
SIMULATION PARAMETERS

Parameters	Values
Bit Rate	155Mbps
Link Range	1 Km
Responsivity	1
Modulation Index	1
Temperature	300 K
Optical Filter Bandwidth	1e-3μm
Field of view	0.6 radian
Refractive Index Structure Parameter	0.75e-14 $m^{-2/3}$
Load Resistance	50 Ω
Boltzman's Constant	1.38e-23J/K
Electronic Charge	1.6e-19 C

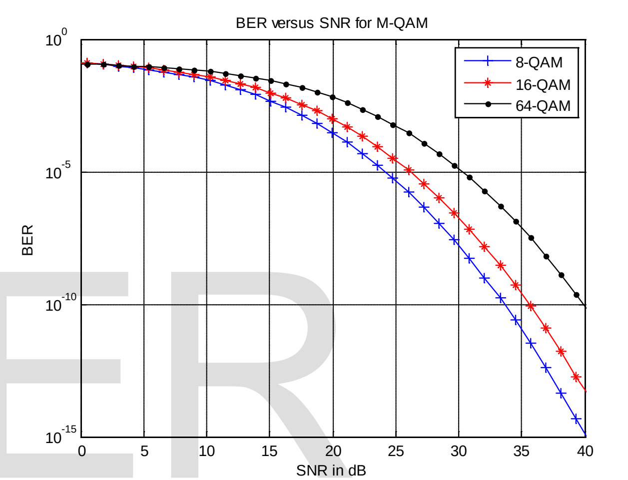

Fig. 4 BER versus SNR for M-QAM

Fig. 5 shows the BER performance of 8-QAM for different values of wavelengths.The BER has been plotted for 850 nm, 1350 nm and 1550 nm wavelengths being used for FSO comunication. The BER of 8-QAM using 1550 nm wavelength is around 10^{-11} for a SNR of 35 dB but the BER using 850 nm wavelength is 10^{-10}.It is clear that higher wavelengths used for FSO link gives better BER performance.

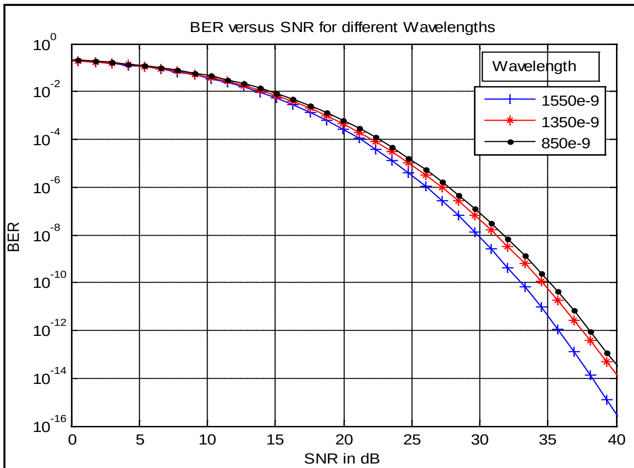

Fig. 5 BER versus SNR for 8-QAM

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Fig. 6 shows BER performce of 8-QAM for different link ranges.The BER for 8-QAM has been plotted for 1 Km, 1.5 Km and 2 Km link ranges for a FSO system. It is clear that with the increasing link range, the BER performance degrades due to increasing atmospheric attenuation. For 1 Km link range, the value of BER is around 10^{-10} for a SNR of 35 dB and for 2 Km link range the BER value is between 10^{-4} and 10^{-5} for the same value of SNR.So the BER performance is very good for 1 Km link range but it degrades with increasing link range and it gets worst for 2 Km link range.

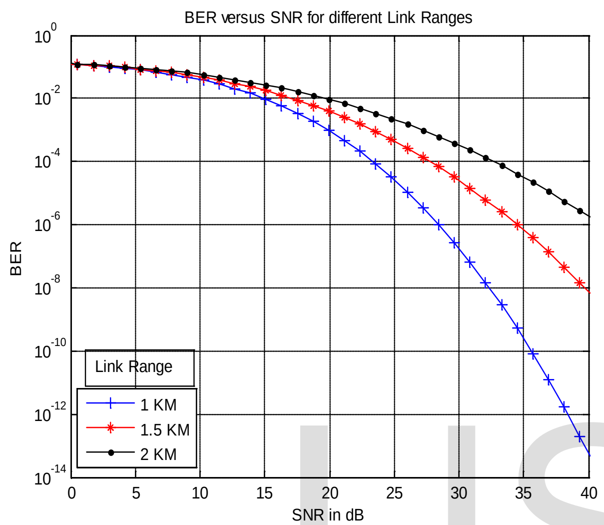

Fig. 6 BER versus SNR of 8-QAM

5 CONCLUSIONS

In this paper,the BER performance of M-ary QAM has been analyzed for different values of M. Then the research has been extended to analyze the BER performance of M-QAM using different wavelengths and link ranges. It has been found that the BER perforamance degrades with the increasing value of M. The BER performance is improved by using higher wavelengths(1550 nm). Link range affects the BER perforamce of FSO system. As the link range is increased, the system performance degrades.

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