Review Of Various Modulation Techniques For Optical Wireless Communication System

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Abstract: Optical wireless systems are gaining more and more attention. When the signal is transmitted in the channel, the performance could be severely degraded due to the atmosphere turbulent. The purpose of this paper is to analyse the most suitable modulation technique for FSO systems under FSO channel. The analysis of power efficiencies, bandwidth efficiency, BER and SNR for the four modulation schemes have studied and compared namely On-Off keying (OOK), Binary Phase Shift Keying (BPSK), Differential Phase Shift Keying (DPSK) and Quadrature Phase Shift Keying (QPSK) without atmospheric turbulence. Numerical experiments resulting in BPSK and QPSK schemes are better compared to other schemes in BER performance and power requirements. When taking intensity scintillation under Gamma-Gamma turbulence channel, BER performances of BPSK and QPSK scheme approximate the same. BPSK is robust to resist turbulence. As a result, the BPSK scheme is suitable for free-space optical communication systems.

IndexTerms **- Optical Wireless System, FSO Systems, FSO Channels, On-Off Keying, Binary Phase Shift Keying, Differential Phase Shift Keying, Quadrature Phase Shift Keying, BER performance, Gamma-Gamma turbulence channel.**

I. INTRODUCTION

FSO communication has excellent bandwidth, capacity and high data rate. However, when the laser beam carries information and is transmitted in the space, it is greatly affected by atmospheric turbulence which is called scintillation. The behavior of turbulence is random, producing random differences that can cause serious distortion of the received wave, thus resulting in poor performance of the FSO system [2]. So as to reduce these distortions, a variety of methods have been used, such as reducing the receiving aperture, an adaptive optics system for wavefront correction, the multiple input multiple output (MIMO) technology is adapted and an effective modulation scheme is considered. Previous studies have shown that the modulation scheme is an effective means to resist atmospheric turbulence [1].

There are many modulation methods in the FSO system, such as amplitude modulation, frequency modulation and phase modulation. In previous research, On-Off-keying (OOK) modulation scheme is widely used because of its bandwidth efficiency and it is convenient to modulate and demodulate. However, OOK modulation cannot overcome atmospheric turbulence. Compared with traditional intensity modulation/direct detection (IM/DD), phase modulation due to its higher sensitivity and excellent properties that are better suited for FSO systems, wavefront compensation technology does not required but the atmospheric turbulence can be better suppressed [3]. In this paper, several modulations include On-Off keying (OOK), Binary Phase Shift Keying (BPSK), Differential Phase Shift Keying (DPSK), and Quadrature Phase Shift Keying (QPSK) described respectively. In addition, power efficiency, bandwidth efficiency, bit error rate (BER) and signal to noise rate (SNR) for the four modulation schemes are compared under the FSO channel with and without the atmospheric turbulence. In simulation results, performance for the four modulation schemes are compared. The rest of the paper is distributed as such.

In Section II, the FSO system model and channel model has been introduced in this paper.

In Section III, the performance of the four modulation schemes are discussed without considering the atmosphere turbulence.

In Section IV, the BER performance for the four modulation schemes under the Gamma-Gamma channel is compared. Finally, the various modulation techniques are simulated and compared.

II. FSO SYSTEM MODEL AND CHANNEL MODEL

2.1 System Model

The FSO System Consists of a laser source, transmitter, receiver and an information sink. The receiving end mainly includes optical antennas, photo-detector, demodulator and processor [4]. A FSO system is shown below in Figure 1[1].

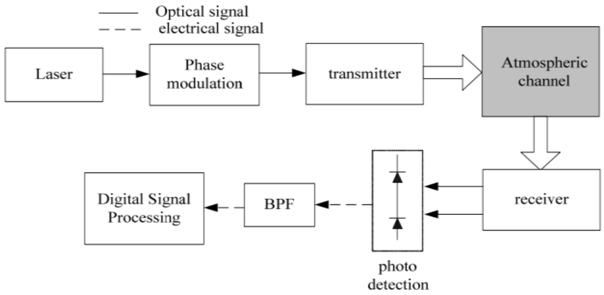

Fig.1. Block diagram of FSO System [1]

After the transmitted signal crosses the transmitter, it passes through the atmospheric channel. This results in change in the properties of the FSO System because of atmospheric turbulences, such as absorption, scattering and scintillations. At the receiver, the received signal is assumed to be distorted by the noise and detected by the photodetector then the detected photocurrent is extracted by the band pass filter and the received signal is Y=nhx+N. Where n is the efficiency of photo-electric conversion, h represents the channel state, x is the transmitted signal, N is the noise.

2.2 Channel Model distributed by Gamma-Gamma

Various interference affects the signals while passing through channels, like rain, clouds, fog and atmospheric turbulence, which can easily lead to intensity scintillation, beam wander, scattering, refracting, phase variations, wavefront aberrations and turbulence. Therefore, the phase-coherent modulation and demodulation techniques are used to degrade the impact of atmospheric disturbances. As this paper mainly focuses on the parallel link in the FSO system, therefore, we take Gamma-gamma model that is suitable for strong turbulence and weak turbulence to describe atmospheric channels, and its parameters most suitable for the actual parameters. The beam intensity fluctuation probability density of the Gamma-gamma model is given by [5, 6].

$$f(I) = \frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} I^{(\frac{\alpha+\beta}{2}-1)} K_{\alpha-\beta}(2\sqrt{\alpha\beta I})$$

Where, l > 0, it is intensity of signal light, r(·) is the Gamma function, K represents the solution of Bayesian equation, α and β are parameters that represent the large–scale and small-scale optical wave intensity fluctuation, which are given as:

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

Where, $\sigma^2{}_R$ represents the scintillation index which is consider as a Rytov parameter, the mathematical model is given by $\sigma^2{}_R$ $=1.23C^2{}_n\, k^{7/6}L^{11/6}$. Here, $k=2\pi/\lambda$, λ is wavelength, L is the communication distance, $C^2{}_n$ is the refractive index structure parameter that is determined by wind speed and altitude according to the H-V turbulence model. When $\sigma^2{}_R<1$, it means the light intensity fluctuation is weak and when the $\sigma^2{}_R>1$ it means the strong intensity fluctuation. Since the Gamma-Gamma model covers all the possible turbulence, so in this paper the performance of BER under the Gamma-Gamma model is used.

III. BASIC MODULATION SCHEMES

As we all know, there are different kinds of phase modulation schemes that fit for FSO communication systems. In this section, we will discuss the SNR, the bandwidth efficiency and power efficiency under different modulation schemes, but the atmospheric turbulence not take into consideration.

3.1 On-Off Keying

OOK modulation technique is the direct detection technique which is widely used in optical communication [7]. It transmits bit 0's and 1's. when bit 0 is transmitted it remains in off state and when bit 1 is transmitted it remains in on a state. This modulation can be done by using RZ and NRZ waveforms. The probability of error from the optical photodiode can be found from the following equations:

$$BER-NRZOOK = \frac{1}{2} erfc\left(\frac{1}{2\sqrt{2}}\sqrt{SNR}\right)$$

$$BER-RZ\ OOK = 0.5 erfc\left(0.5\sqrt{SNR}\right)$$

In NRZ-OOK, the required bandwidth is equal to bit rate, that is BOOK=Rb. According to BER expression, the required power is defined as:

$$P = \frac{1}{\gamma}\sqrt{\sigma_N^2 SNR}$$

Here, Ɣ is the responsibility of the PD,2Nis the total noise power. To get the particular BER while transmitting OOK through an ideal channel, the normalized average power requirement is:

$$P_{OOK} = \frac{1}{\gamma}\sqrt{\sigma_N^2 SNR}$$

3.2 Binary Phase Shift Keying

The BPSK modulation technique is the coherent detection technique. In optical communication, the carrier is always taken as the laser [8]. The demodulation can be done by two methods homodyne and heterodyne detection. The phase shift occurs in BPSK modulation is 0 degree and 180degrees. The BER of this technique is given by the equation:

$$BER = 1/2erfc(\sqrt{SNR}$$

For BPSK, each bit of the modulating signal causes a transmitting symbol with Ts duration that equal with the bit duration Tb. That is, the required bandwidth for BPSK is equal to the bit rate. BBPSK=Rb.

The power requirements can readily be derived from the BER expressions. In the case of equal BER, using the normalized average power requirements of BPSK to NRZ-OOK, the power requirement for BPSK can be written as:

$$\frac{P_{BPSK}}{P_{NRZ-OOK}} = \frac{1}{2\sqrt{2}}$$

Theoretically, the NRZ-OOK requires as much as $2\sqrt{2}$times power than BPSK to obtain a particular BER performance.

3.3 Differential Phase Shift Keying

The DPSK modulation technique is the direct detection technique which is used for short distance communication [9]. The signal High 1 or Low 0 decided the phase of the previous bits transmitted. If the data bit is low i.e., 0 the bit does not reverse it continues there is no phase change when the data is high i.e., 1 the bit gets reversed there is a phase change. The probability of error for the DPSK modulation from the optical photodiode can be given by the following equation:

$$BER = 0.5erfc(\frac{\sqrt{SNR}}{\sqrt{2}})$$

The required bandwidth for DPSK is equal to the bit rate BDPSK=Rb [10]. The spectrum efficiency of DPSK is relatively higher, dispersion tolerance, nonlinear tolerance and PMD tolerance can be improved. When getting the same bit error rate, the receiver sensitivity is 3dB higher than OOK modulation. In terms of resist noise, it is better than OOK. The bandwidth efficiency is equal to BPSK and OOK, that is,

$$\eta_{DPSk} = 1$$

the average power requirement of DPSK normalized to OOK can be expressed as:

$$\frac{P_{DPSK}}{P_{NRZ-OOK}} = \frac{1}{2}$$

Under the same BER condition, the average power of NRZ-OOK is twice than DPSK.

3.4 Quadrature Phase Shift Keying

QPSK signals are Gray coded and differential encoding is applied to resolve the phase ambiguity. For DSP based coherent detection, we adopt the widely used scheme of block feed-forward carrier phase recovery with Viterbi & Viterbi algorithm. After digital carrier phase recovery, the kth QPSK symbol received is $r(k) = r_{Re} + jr_{1m}(k=1,2,3.,.N)$[13].

Simulating a QPSK system is equivalent to simulating two BPSK systems in parallel. So there is no difference in bit error rate(BER). Since the QPSK can be regarded as the composition of two orthogonal signals of BPSK. Therefore, each bit occupies Tb seconds, the signals corresponding to the bits last for Ts=2Tb. This means that the required bandwidth for QPSK is double to BPSK modulation, that is, $B_{QPSK}=0.5B_{BPSK}$. BER for QPSK can be described as:

$$\mathbf{BER_{QPSK}=erfc\ (\sqrt{SNR})=2BER_{BPSK}.}$$

From theoretical analysis above, it shows that the bandwidth efficiency for OOK, BPSK and DPSK modulation schemes are the same, only the QPSK twice as much as other schemes. Also, from the discussion above, it is clear that the required bandwidth for QPSK is the lowest than other modulation schemes, however, the data rate is doubled compared to others.

IV. BER UNDER ATMOSPHERIC TURBULENCE

The average bit error rate (BER) is an accepted metric to assess the reliability of the OWC systems subjected to turbulence induced fading. This can be obtained by statistical averaging of conditional BER over the probability density function (PDF) of atmospheric turbulence. The conditional BER, for different modulation schemes in an OWC system can be represented in terms of Gaussian Q-function, i. e., Q(x) [14]. As a result, the BER of OWC systems in weak turbulence is evaluated by an integral involving the product of Q-function and PDF of log-normal distribution. The conditional BER (Pec) [15] for an OWC can be expressed as:

$$P=Q(\sqrt{\phi o \gamma})$$

where Q(.) is the Gaussian Q-function and ϕ0 is a constant which is 1=2 for OOK and 1 for SIM-BPSK. Fig 2 [20] shows typical values of log (BER) versus different turbulent conditions characterized by log Cn2 for two initial laser beam radius 0.03 and 0.09 m. The laser wavelength is assumed l ¼ 850 nm and the calculations were performed for a distance of z ¼ 1000 m. From this figure it can be seen that the BER has very small values at turbulence with weak refractive index fluctuation, and rises dramatically with the Cn2. According to this figure, the BER becomes very large at turbulence with stronger refractive index fluctuation i.e., Cn2> 5x10-13 m-2/3. Figure shows that the initial beam aperture is also very important in the results. As the figure illustrates, for similar atmospheric turbulence conditions, the larger the beam size is the smaller the BER is obtained. However, at turbulence with medium refractive index fluctuation, the influence of the beam size on BER becomes insignificant and the difference between the two beams becomes smaller. It must be noted that in commercial FSO systems a typical value of BER<10-10 is acceptable for reasonably good performance.

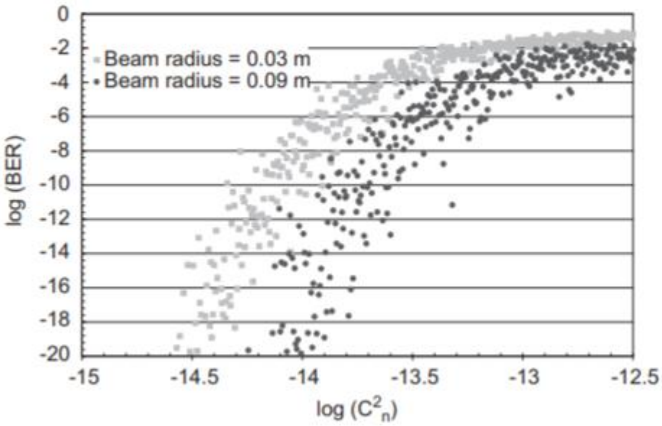

Fig.2. Typical values of BER versus different turbulent conditions characterized by Cn2 for two initial laser beam radius 0.03 and 0.09 m and laser wavelength l ¼ 850 nm for a receiver at distance z ¼ 1000 m. [20]

The average bit error rate (BER) can be described as:

$$P_e=\int_0^\infty f(I)Q\left(\frac{hI}{\sqrt{2No}}\right)dI.$$

Where, N0 represents noise, owing to erfc(x)= 2Q($\sqrt{2}$x), Q() is the Gaussian-Q function, substituting erfc() the average BER is represented as:

$$\bar{P}_e(I)=\int_0^\infty \frac{1}{2}erfc\left(\frac{1}{2}\frac{hI}{\sqrt{N_0}}\right)\frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)}I^{(\frac{\alpha+\beta}{2}-1)}K_{\alpha-\beta}(2\sqrt{\alpha\beta I})dI$$

For the convenience of the analysis, define $\frac{h}{\sqrt{No}}=\delta$thus, the average bit error rate can be simplified as:

$$\bar{P}_{e-ook}=\frac{1}{2\sqrt{\pi}\Gamma(\alpha)\Gamma(\beta)}G^{2,2}_{3,2}\left[\frac{1}{2\sqrt{2}\alpha\beta}\delta\ \middle|\ \begin{matrix}1-\beta,1-\alpha,1\\ 0,1-\frac{\alpha+\beta}{2},\frac{1}{2}\end{matrix}\right]$$

If the FSO system using BPSK modulation scheme, under the atmosphere turbulence and detector noise, and assuming that the balanced detection is used, the average BER of the system is represent as:

$$\bar{P}_e(I)=\int_0^\infty \frac{1}{2}erfc(\sqrt{SNR})f(I)dI=\int_0^\infty \frac{1}{2}erfc\left(\frac{hI}{\sqrt{N_0}}\right)\frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)}I^{(\frac{\alpha+\beta}{2}-1)}K_{\alpha-\beta}(2\sqrt{\alpha\beta I})dI$$

All the same, define $\frac{h}{\sqrt{No}}=\delta$,

$$\bar{P}_{e-BPSK}=\frac{(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{2\sqrt{\pi}\Gamma(\alpha)\Gamma(\beta)}\delta^{-\frac{\alpha+\beta}{2}}G^{2,2}_{2,3}\left[\frac{\alpha\beta}{\delta}\ \middle|\ \begin{matrix}1-\frac{\alpha+\beta}{2},\frac{1-\alpha-\beta}{2}\\ \frac{\alpha-\beta}{2},-\frac{\alpha+\beta}{2},\frac{\beta-\alpha}{2}\end{matrix}\right]$$

Similarly, average BER for DPSK and QPSK can be derived:

$$\bar{P}_{e-DPSK}=\frac{(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{2\sqrt{\pi}\Gamma(\alpha)\Gamma(\beta)}\delta^{-\frac{\alpha+\beta}{2}}G^{2,2}_{2,3}\left[\frac{\alpha\beta}{\sqrt{2}\delta}\ \middle|\ \begin{matrix}1-\frac{\alpha+\beta}{2},\frac{1-\alpha-\beta}{2}\\ \frac{\alpha-\beta}{2},-\frac{\alpha+\beta}{2},\frac{\beta-\alpha}{2}\end{matrix}\right]$$

$$\bar{P}_{e-QPSK}=\frac{(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\sqrt{\pi}\Gamma(\alpha)\Gamma(\beta)}\delta^{-\frac{\alpha+\beta}{2}}G^{2,2}_{2,3}\left[\frac{\alpha\beta}{\delta}\ \middle|\ \begin{matrix}1-\frac{\alpha+\beta}{2},\frac{1-\alpha-\beta}{2}\\ \frac{\alpha-\beta}{2},-\frac{\alpha+\beta}{2},\frac{\beta-\alpha}{2}\end{matrix}\right]$$

V. Simulation and results

To verify the analytical result via experiments, with all the given comparisons mentioned, various models were simulated. Here only channel the bandwidth efficiency and the required power for the signal transmitted is discussed whereas the channel fading and turbulence haven't been taken into discussion [16]. The main parameters that are taken into account are in the following table:

Parameter	value
Modulation mode	NRZ-OOK,BPSK,DPSK ,QPSK
Wavelength λ	1550nm
Efficiency η	0.8
Maximum optical power	10mW
Beam divergence θ	$10 mrad$
Modulation bandwidth	100MHz
Responsivity of PIN	1A/W
Dark current	10nAmp
Time duration per slot	10ns
Spectral density	10Nw/m^2
Attenuation of FSO	20dB/km

Table. Simulation parameters [1]

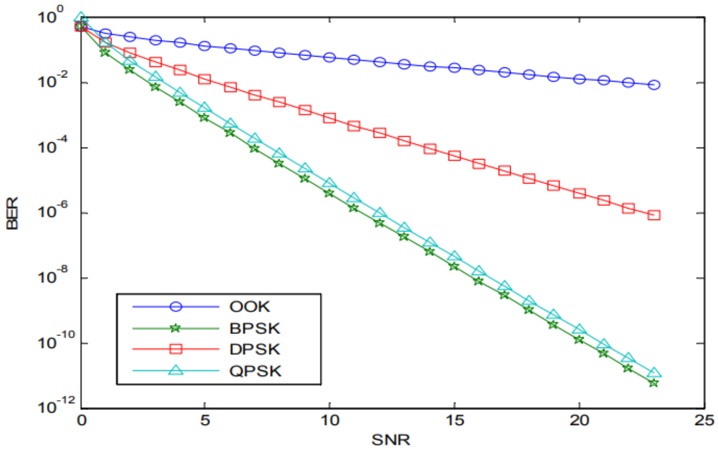

Fig.3. Comparison of the four modulation schemes for BER [1]

Simulation of BER performance for OOK, BPSK, DPSK and QPSK is given above and here in order to make comparison between them, the atmospheric turbulences are not taken into consideration. As SNR is increased the BER decreases due to their inverse relation. So here we can say that when BER performance is taken into account, BPSK is lower than other modulation schemes. When SNR is 10dB achieved, the BER performance of BPSK modulation is better than QPSK modulation by 0.4 dB, and 2.56 dB better than DPSK, 4.46 dB better than OOK. Hence, when under the same SNR, BPSK modulation displays a better performance. We can say that BPSK requires the least power.
From the simulations that are done, it can be deduced that when the value of BER is 10^{-15} achieved, difference of SNR between BPSK and QPSK is small and on the other hand, when the value of BER<10^{-15} their performances of both BPSK and QPSK are approximately the same. Thus, making the experimental and theoretical results consistent.

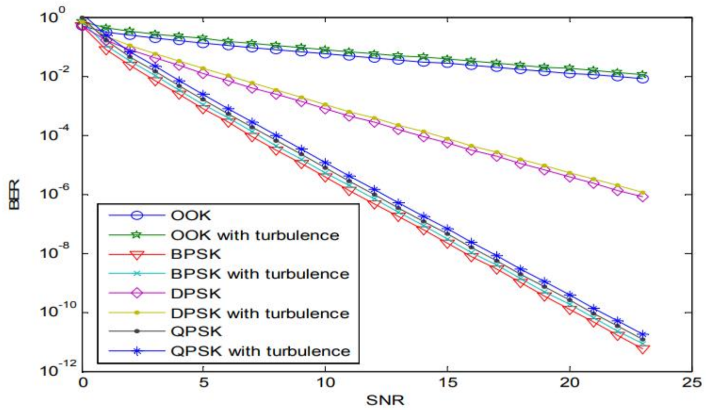

Fig.4. Four modulation schemes for BER with turbulence [1, 17]

Now, here moderate turbulences are taken into account and making it clear that the performance of the four modulation schemes display a recognizable decrease in BER.
On comparison of both the above figures, it can be seen that the performance of BER lead to 8.2dB, 1.4dB, 5.8dB, 1.8dB deterioration for OOK, BPSK, DPSK and QPSK respectively.
We can say that the performances of both these modulations are conclusively aggravated by the fluctuation. The performance of BPSK is still better than the others and QPSK is congruous with BPSK [18]. Hence, the performance for BPSK and QPSK modulation scheme are more outstanding than OOK and DPSK scheme in against the fluctuation. Relationship between transmitting power and BER is shown below:

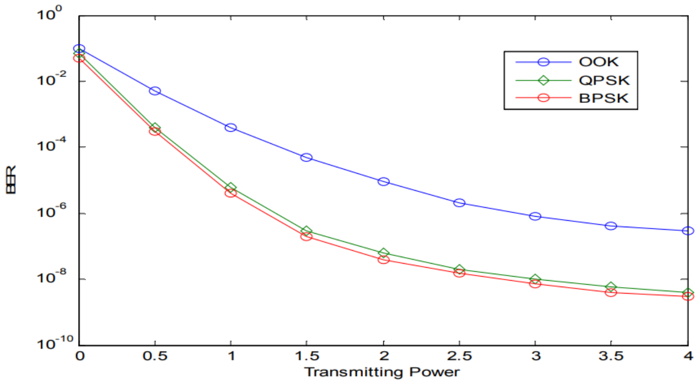

Fig.5. Relationship between BER and transmitting power [1]

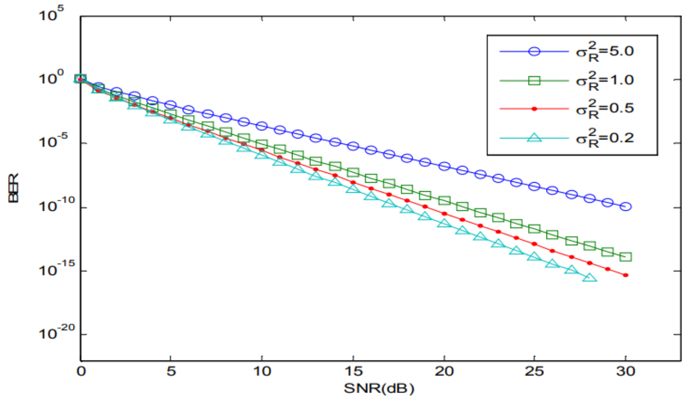

Fig.6. BER performance of BPSK in different scintillation situation [1]

While comparing the OOK, QPSK and BPSK schemes, it is evident that the transmitting power for BPSK is the lowest. Now if only the transmitting power is considered modulation of BPSK is suitable for the system. Here, , BPSK scheme for average BER under different levels of turbulence is simulated. Under three kinds of turbulence, weak, strong, and moderate, simulation results are shown in Figure 6. It can be seen that when in weak atmospheric turbulence, the BER is low and when the atmospheric turbulence is high, the BER is also high. By making some analysis form the above figure, if we want to decrease the signal-to-noise ratio, effective measure should be taken to compensate for the power of the signal when transmitted under the turbulence channel [19].

From the simulations, it can be derived that BPSK has a better performance under weak turbulence and this scheme constructively resists weak turbulences.

In the theoretical analysis for the bandwidth efficiency of the modulation schemes above, we can say that the bandwidth efficiency for all the modulations are constant. In Figure 7, the results are drawn, same as we discussed above. Results say that bandwidth efficiency for OOK, BPSK and DPSK scheme are about 1 respectively, but for QPSK is equal to 2.

This suggests that the QPSK modulation scheme can make full use of the system bandwidth utilization and the transmission rate can be improved [1].

Simulations of these modulations in terms of power efficiency are shown is Figure 8. Here also the BPSK and QPSK require almost the same power. But when the same BER performance for the DPSK and OOK scheme is achieved, the DPSK requires less power than OOK, about 1.5dB lower. It is clear that the BPSK and the QPSK need the lowest power, about 4.52 dB lower than the OOK and 1.5dB lower than DPSK.

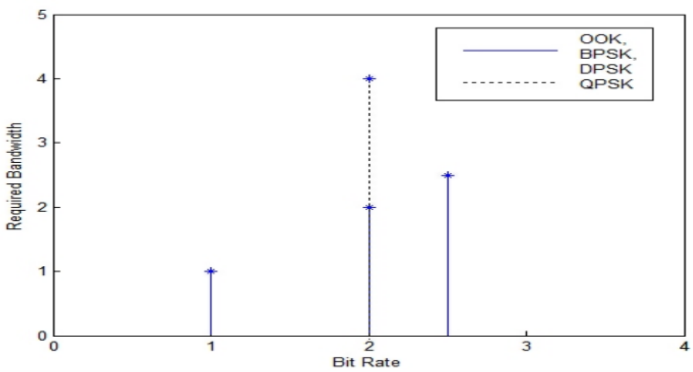

Fig.7. Simulation results of bandwidth efficiency [1]

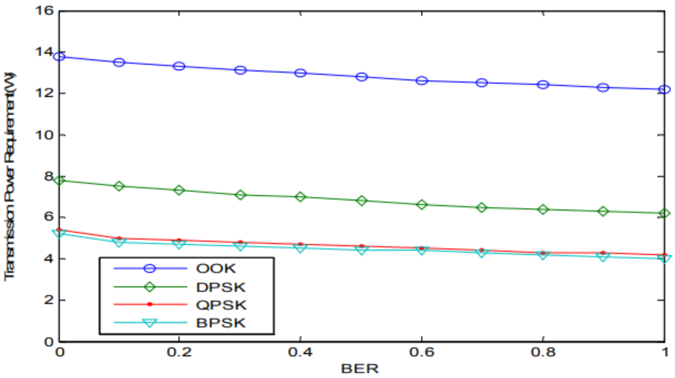

Fig.8. Simulation for transmission power requirement [1]

Hence, the BPSK and QPSK are more suitable for free space communication based on requirement power.

VI. CONCLUSION

Hence, the BPSK Here, the review of the above presented comparison for the modulations schemes was done successfully. Both theoretical and experimental results show that compared with OOK and DPSK modulation, the BPSK and QPSK shows a much better performance in terms of the BER without considering the atmospheric disturbances.

After taking atmospheric fluctuations in account the average BER performance of the modulations schemes show direct decrease respectively. From the outputs it can be seen that in the weak and strong turbulence, the BPSK and QPSK formats still have approximately the same BER performance. Experiment proves that BPSK has good characteristics to resist turbulence, under different turbulence conditions. In terms of bandwidth efficiency QPSK is the one which is twice as much as others. The power requirements of both QPSK and BPSK are lowest than others and also are found to be the same. QPSK and BPSK have shown superlative performances. Compared with QPSK, there is 3dB lower for BPSK of BER performance.

Besides, the modulation and demodulation for BPSK is simpler than QPSK, transmission bandwidth is halved compared with BPSK under the same BER.

In consequence, BPSK scheme is thought to be the most suitable modulation and demodulation for communication systems.

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