TELKOMNIKA, Vol.13, No.3, September 2015, pp. 880~888
ISSN: 1693-6930, accredited A by DIKTI, Decree No: 58/DIKTI/Kep/2013
DOI: 10.12928/TELKOMNIKA.v13i3.1976

Performance Analysis of Different Modulation Techniques for Free-Space Optical Communication System

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Abstract

Free space optical system is a hot topic, which has gaining more and more attention. But, when the signal transmitted in the channel, the performance could be severely degraded due to the atmosphere turbulent. The purpose of this paper is to find a most suitable modulation method for FSO system under FSO channel. The performance of power efficiencies, bandwidth efficiency, BER and SNR for the four modulation schemes have studied and compared in this paper include 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 show that BPSK and QPSK schemes are better compared to other schemes in BER performance and power requirements. When take intensity scintillation under Gamma-Gamma turbulence channel into consideration and the average BER is derived with Meijer-G function, BER performances of BPSK and QPSK scheme approximate the same. Compared with BPSK, BER performance for QPSK is 3dB lower. From the simulation results, modulation for BPSK is robust resist turbulence. As a result, BPSK scheme is suitable for free-space optical communication system.

Keywords: *free-space optical communication, bit error rate, modulation scheme, signal–noise rate, gamma-gamma turbulence channel*

1. Introduction

In recent years, FSO communication has achieved considerable attentions due to its outstanding bandwidth, capacity and high data rate. However, when the laser beam carried information transmitting in the space, it is greatly influenced by atmospheric turbulencewhich is called scintillation. The behavior of turbulence is non-predictive, produces random fluctuation to the received optical irradiance that can cause serious distortion of the received front of wave, thus greatly reducing the receiver sensitivity and detection efficiency result in performance of the FSO system severely decreased [1]. In order to improve this problem,a variety of methods have been used to combat the effect for turbulence, 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 consideration. Previous studies have shown thatmodulation scheme is an effective means to resist atmospheric turbulence.In this paper, performance for four modulation schemes compared in order to find the most suitable schemes for FSO system.

There are many modulation methods in FSO system,such asamplitude modulation, frequency modulation and phase modulation. In the former research,the intensity modulation technique that is On-Off-keying (OOK) modulation scheme is widely used because of its bandwidth efficiency and it is easy to modulation and demodulation. However,the ability to resist atmospheric turbulence for OOK modulation is particularly weak. Compared with traditional intensity modulation/direct detection (IM/DD), phase modulationdue to its higher sensitivity and excellent properties that better suited for FSO system, wavefront compensation technology does not required but the atmospheric turbulence can be better suppressed [2]. In this paper, several modulation include On-Off keying(OOK), Binary Phase Shift Keying (BPSK), Differential Phase Shift Keying (DPSK), and Quadrature Phase Shift Keying (QPSK) described

Received March 6, 2015; Revised June 19, 2015; Accepted July 4, 2015

respectively. In addition, performance such as 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 fluctuation. Under the simulation results, performance for the four modulation schemes are compare, combined with the theoretical analysis results, a suitable modulation scheme that best for free space optical communication system is carried out.

The rest of the paper is organized as follows. Section 2 the FSO system model and channel model has introduced in this paper. In Section 3, the performance of the four modulation schemes are discussed without regard to the atmosphere turbulent. In Section 4,the BER performance for the four modulation schemes under Gamma-Gamma channel is compared and the Meijer-G function is used to simplify the analysis. Finally, the performance are simulated and compared according to the theory model.

2. Modelof FSO Systemand Channel

2.1. System Model

A typical FSO system is consisted of laser source, transmitter, receiver and information sink. The receiving end is mainly includeoptical antennas, photo-detector, demodulator and processor [3]. The block diagram of FSO system is shown in Figure 1.

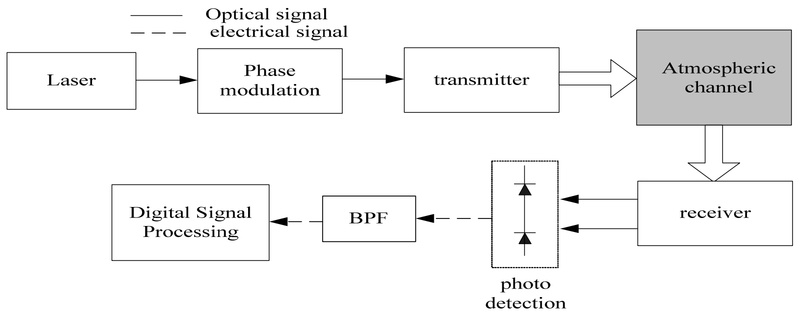

Figure 1. Block diagram of FSO system

Transmitting signal modulated by phase modulator and then transmitted by light beam into the FSO channel. Generally, the channel refers to the atmospheric channel and the space channel. As the signal travel through the space channel, properties of FSO system will be deteriorated because of atmosphere turbulent, such as absorption, scattering and scintillations. Assuming that the channel without memoryand with additive white Gaussian noise (AWGN). At the receiver, the received signal is assumed to be distorted by the noise and detected by the PD then the detected photocurrent is extracted by the BPF and the received signal is $Y=\eta hx+N$. Where, η is the efficiency of photo-electric conversion, h represents the channel state that distributed by Gamma-Gamma model, x is the transmitted signal, N is the Additive white Gaussian noise that zero mean and variance is $N_0/2$.

2.2. Channel Model Distributed by Gamma-Gamma

When the optical signal transmittedin the channel it will be affected by various interference, like rain, clouds, fog and atmospheric turbulence, which is 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 disturbance in space optical communication. Generally, there are four models to describe the intensity distribution. Because, this paper mainly focuses on the parallel link in the FSO system, therefore, we take Gamma-gamma model that both fit for strong turbulence and weak turbulence to describe atmospheric channel, and its parameters most suitable for the actual parameters. The beam intensity fluctuation probability density of Gamma-gamma model is given by [4, 5].

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

Where, I>0, it is intensity of signal light, $\Gamma(\cdot)$ 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:

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

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

3. Basic Modulation Schemes

As we all know, there are different kinds of phase modulation schemes are fit for FSO communication system. 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 [5].

3.1. OOK Modulation

Because of On-off key (OOK) scheme is the simplest modulation form of binary amplitude shift keying (2ASK), it is widely used in FSO communication system. For NRZ-OOK,the signal is defined as $s_{00k}(t)=A\left[\sum_{n=-\infty}^{\infty}a_n g_T(t-nT_b)\right]\cos w_c t$. Here, the value of a_n is 0 or 1, g_T represents no-return-to-zero pulse,Tb is the symbol interval. Take no turbulence into consideration, conditional bit error ratio ($p_{e\text{-}OOK}$) for the NRZ-OOK coded optical data can be expressed as a function of the Signal-to-Noise Ratio (SNR) as follows $p_{e-OOK}=\frac{1}{2}erfc\left(\frac{1}{2\sqrt{2}}\sqrt{SNR}\right)=Q(\frac{1}{2}\sqrt{SNR})$.

In NRZ-OOK, the required bandwidth is equal to bit rate ,that is $B_{OOK}=R_b$. According to communication theory, the bandwidth efficiency is defined as the ratio between the bit rate R_b can be transmitted and required bandwidth B. Therefore, the bandwidth efficiency of OOK is $\eta_{ook}=\frac{R_b}{B}=1$. Power requirementis one of the indicators that need to be considered. According to BER expression, the required power is defined as $P=\frac{1}{\gamma}\sqrt{\sigma_N^2 SNR}$. Here, γ is the responsivity of the PD, σ_N^2 is 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. BPSK Modulation

In phase modulation technique,the information is expressed in terms of the carrier. When binary digital signal to control the phase of a sinusoidal carrier that called Binary Phase Shift Keying (BPSK). It is a two stage phase shift keying where the phase of the carrier is set to 0 or π according the value of the modulating signal. If a symbol '1' is transmitted, the modulated signal is exactly as the carrier with phase 0, as the same, phase π standing for '0'.

The BPSK modulation is the simplest form of PSK and it more robust to resist noise than OOK [6-8].

As for BPSK,each bit of the modulating signal causes a transmitting symbol with T_s duration that equal with the bit duration T_b. That is, the required bandwidth for BPSK is equal to the bit rate. $B_{BPSK}=R_b$.This is consistent with the OOK. According to the definition of the bandwidth efficiency, the bandwidth efficiency for BPSK can be expressed as $\eta_{BPSk} = \frac{R_b}{B} = 1$, that is the theoretical bandwidth efficiency for BPSK is unit. And the conditional BER equation of BPSK is $p_{e-BPSK} = \frac{1}{2} erfc\left(\sqrt{SNR}\right)$. 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 require as much as $2\sqrt{2}$ times power than BPSK to obtain a particular BER performance.

3.3. DPSK Modulation

DPSK is a relative phase modulation model, the information which is transmitted represented by the phase difference between the adjacent symbols. When $\Delta\varphi$ equals 0, this means two adjacent symbol signals that before and after are the same. And so, the phenomenon of inverted π can be avoided with DPSK modulation scheme. As synchronous demodulation, compared to BPSK modulation, the phase and frequency of the carrier need not to know, but, the local carrier is necessary. The BER for DPSK can be calculated as follows $p_{e-DPSK} = \frac{1}{2} erfc\left(\frac{\sqrt{SNR}}{\sqrt{2}}\right)$.

When using differential decoding, the information bit “1” will be transmitted by shift the phase of modulated signal 180° relative to the previous phase of the modulate signal. And bit '0' will be transmitted without shift the phase of modulated signal relative to the previous of modulated signal. The required bandwidth for DPSK is equal to the bit rate $B_{DPSK}=R_b$ [9]. 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, $\eta_{DPSk} = 1$. For the convenience of analysis, 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. QPSK Modulation

Different from BPSK and DPSK, the QPSK scheme using two bits are grouped together to form signals. When signals transmitted, there are four particular phases. The spectral efficiency can be further enhanced by QPSK modulation. Since the QPSK can be regarded as the composition of two orthogonal signals of BPSK. Therefore, each bit occupies T_b seconds, the signals corresponding to the bits last for $T_s=2T_b$. This means that the required bandwidth for QPSK is double to BPSK modulation, that is, $B_{QPSK}=0.5R_b$.And the theoretical bandwidth efficiency for QPSK is $\eta_{QPSk} = \frac{R_b}{0.5R_b} = 2$. But, the practically the bandwidth efficiency is $1.4 \sim 1.6$bps/Hz. Since the QPSK is a four-state phase shifting keying in which two bits are grouped together and the carrier is phase modulated, each bit has half of the original received intensity. Therefore, BER for QPSK can considered as two orthogonal of BPSK combined. BER for QPSK can be described as $BER_{QPSK} = erfc\left(\sqrt{SNR}\right) = 2BER_{BPSK}$. Because of the average power requirement of BPSK requires a factor of $2\sqrt{2}$ more power than NRZ-OOK, consequently, the average power requirement by the QPSK normalized to NRZ-OOK can be express as:

$$\frac{P_{QPSK}}{P_{NRZ-OOK}} = \frac{1}{2\sqrt{2}} \frac{erfc^{-1}(BER)}{erfc^{-1}(2BER)} \quad (3)$$

From Equation (10), we assumed that inverse error of BER for QPSK modulation is equal to 2 as BPSK modulation. Therefore, the average power requirement by the QPSK is the same as BPSK, or it only a few amount power more than 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 than 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 the doubled compared to others. With respect to the performance of BER, BPSK and QPSK perform better. From the equation of the average power requirement for BPSK, DPSK and QPSK schemes normalized to NRZ-OOK respectively, it is clear that the DPSK requires 1.5dB more power than BPSK to obtain the particular BER performance, and the require power for BPSK and QPSK are the same. So the BPSK and QPSK schemes are the less power efficient modulation.

4. BER under Atmospheric Turbulence

Apparently, the BER performance of OOK is severely influenced because of the intensity scintillation in the FSO channel. Therefore, taking the detector noise and channel turbulence into account, the bit error rate on the receiving terminal of OOK can be calculated by $P_e = p(0)p(e|0) + p(1)p(e|1)$ [9, 10]. Where, p(0) and p(1)are the probability of transmitting 1 and 0 respectively. p(e|0) and p(e|1)are the conditional probability in the case of sending 0 and 1. The average bit error rate (BER)can be described as $P_e = \int_0^\infty f(I)Q(\frac{hI}{\sqrt{2N_0}})dI$. Where, N_0 represents noise, owing to $erfc(x) = 2Q(\sqrt{2}x)$, Q()is the Gaussian-Q function, substituting (1) and $erfc(\cdot)$ the average BER is represented as:

$$\overline{P}_e(I) = \int_0^\infty \frac{1}{2} erfc(\frac{1}{2}\frac{hI}{\sqrt{N_0}}) \frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} I^{(\frac{\alpha+\beta}{2}-1)} K_{\alpha-\beta}(2\sqrt{\alpha\beta I})dI \quad (4)$$

According to the Meijer-G functions, the $K_v(\cdot)$ and $erfc(\cdot)$ will be expressed as follows [12]:

$$erfc(x) = \frac{1}{\sqrt{\pi}} G_{1,2}^{2,0}\left[x \,\middle|\, \begin{matrix} 1 \\ 0, \frac{1}{2} \end{matrix} \right] \quad K_v(x) = \frac{1}{2} G_{0,2}^{2,0}\left[\frac{x^2}{4} \,\middle|\, \begin{matrix} - \\ \frac{v}{2}, -\frac{v}{2} \end{matrix} \right] \quad (5)$$

For the convenience of the analysis, define $\frac{h}{\sqrt{N_0}} = \delta$ making (5) into (4) the average bit error rate can be simplified as:

$$\bar{P}_{e-ook} = \frac{1}{2\sqrt{\pi}\Gamma(\alpha)\Gamma(\beta)} G_{3,2}^{2,2}\left[\frac{1}{2\sqrt{2}\alpha\beta}\delta \,\middle|\, \begin{matrix} 1-\beta, 1-\alpha, 1 \\ 0, 1-\frac{\alpha+\beta}{2}, \frac{1}{2} \end{matrix} \right] \quad (6)$$

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:

$$\overline{P_e}(I) = \int_0^\infty \frac{1}{2} erfc(\sqrt{SNR}) f(I)dI = \int_0^\infty \frac{1}{2} erfc(\frac{hI}{\sqrt{N_0}}) \frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} I^{(\frac{\alpha+\beta}{2}-1)} K_{\alpha-\beta}(2\sqrt{\alpha\beta I})dI \quad (7)$$

All the same, define $\frac{h}{\sqrt{N_0}} = \delta$, by using the formula (5) to simplified the expression (7) is:

$$\bar{P}_{e-BPSK} = \frac{(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{2\sqrt{\pi}\Gamma(\alpha)\Gamma(\beta)}\delta^{-\frac{\alpha+\beta}{2}} G_{2,3}^{2,2}\left[\frac{\alpha\beta}{\delta}\Bigg|\begin{matrix}1-\frac{\alpha+\beta}{2}, \frac{1-\alpha-\beta}{2}\\ \frac{\alpha-\beta}{2}, -\frac{\alpha+\beta}{2}, \frac{\beta-\alpha}{2}\end{matrix}\right] \quad (8)$$

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

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

$$\bar{P}_{e-QPSK} = \frac{(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\sqrt{\pi}\Gamma(\alpha)\Gamma(\beta)}\delta^{-\frac{\alpha+\beta}{2}} G_{2,3}^{2,2}\left[\frac{\alpha\beta}{\delta}\Bigg|\begin{matrix}1-\frac{\alpha+\beta}{2}, \frac{1-\alpha-\beta}{2}\\ \frac{\alpha-\beta}{2}, -\frac{\alpha+\beta}{2}, \frac{\beta-\alpha}{2}\end{matrix}\right] \quad (9)$$

5. Simulation and Results

Following the comparison presented above, in this section, four modulation model will be simulated to verify the analytical results by experiments. Considering the intensity scintillationand without intensity scintillation when talk about the BER performance. While discuss the bandwidth efficiency and the requirement power for the signal transmitted, the channel fading and turbulence haven't take into consideration [13]. Assumed the main simulation parameters of FSO used in the experiment as Table1.

Table1. Simulation parameters

Parameter	value
Modulation mode	NRZ-OOK,BPSK,DPSK ,QPSK
Wavelength λ	1550nm
Efficiency η	0.8
Maximum optical power	10mW
Beam divergence θ	$10mrad$
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

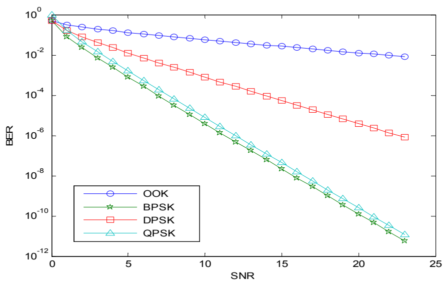

Figure 2. Comparison of the four modulation schemes for BER

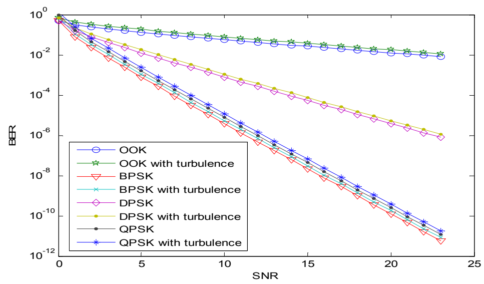

Figure 3. Four modulation schemes for BER with turbulence

Simulation of BER performance for NRZ-OOK, BPSK, DPSK and QPSK is given in Figure 2. In order to make a comparison, the atmospheric turbulence is not into consideration. With the SNR increased the BER for the modulation schemes shows decreased from the simulation results. Conclusion that the BER performance for BPSK is lower than others can be obtained compared with 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 display a better performance. On the other hand, it is clear that BPSK requires the less SNR than other schemes at the particular BER from Figure 2. That is, the BPSK requires lest power. The BER=10^{-10} for instance, SNR for BPSK is 13.10 dB and for QPSK is 13.24 dB, for DPSK is 16.33, for OOK is 22.5 dB, it illustrates that the BPSK is 0.14 dB, 3.23 dB and 9.4 dB better than QPSK, DPSK and OOK modulation respectively. From the simulation results, it can be inferred that when the value of BER is 10^{-15} achieved, difference of SNR between BPSK and QPSK is small. When the value for BER<10^{-15}, it can conclude that the performance of BER for BPSK and QPSK is approximately the same. Experimental results and theoretical analysis results are consistent. But, the structure of BPSK modulation is simpler than QPSK. Therefore, the BPSK modulation schemes is better for FSO. Taking the atmospheric fluctuation into consideration, the simulation results as shown in Figure 3 [14].

Under moderate turbulence, it is clear that the performance of the four modulation schemes display a distinct decrease in BER. In this paper, only the atmospheric fluctuation taken into consideration. Compared Figure 2 with Figure 3, we can seen that the performance of BER lead to 8.2dB, 1.4dB, 5.8dB, 1.8dB deterioration for OOK, BPSK, DPSK and QPSK respectively. Conclusion that the performances of the four modulation are dramatically aggravated by the fluctuation. Although, under the atmospheric turbulence can be drawn, the performance of BPSK still better than other schemes and QPSK scheme is approximately consistent with BPSK [15]. Therefore, the performance for BPSK and QPSK modulation scheme are most outstanding than OOK and DPSK scheme in against the fluctuation. Furthermore, compared with OOK,BER for DPSK is about 3dB better. The relationship between transmitting power and BER can be shown from the Figure 4.

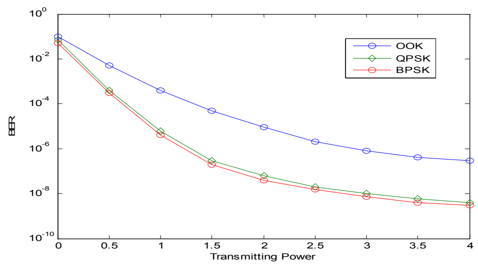

Figure 4. Relationship between BER and transmitting power

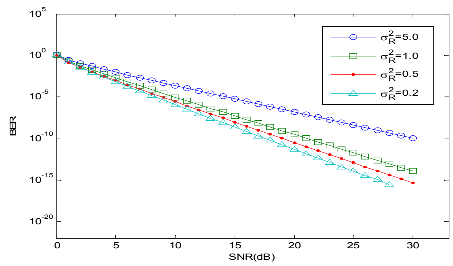

Figure 5. BER performance of BPSK in different scintillation situation

Based on the comparison among OOK, QPSK and BPSK schemes, it is obvious that the transmitting power for BPSK is the lowest. When the transmitting power is 4mW, OOK is 18dB higher and QPSK is 3dB higher than BPSK. Hence, only considering the transmitting power, modulation of BPSK is suitable for FSO system. In this part, BPSK scheme for average BER under different levels of turbulence is simulated. Assuming the transmitting rate is fixed to 1Gbit/s, the deviation of the received signal frequency is about 100MHz. Under weak turbulence, strong turbulence and moderate turbulence,simulation results are shown in Figure 5. From Figure 5 we can seen that in the weak atmosphere turbulent, the system has low BER and when the atmosphere turbulent is high, the BER is high also. When the σ_R^2 is 0.2, 0.5, 1.0, 5.0, if keep the BER at 10^{-10}, the SNR that we need about are 17.5dB, 18.7dB, 21.8dB, 28.6dB respectively. That means if we want decrease the SNR, effective measure should be taken to compensate the power of the signal when transmit under the turbulence channel [16]. From the simulation results, the conclusion that BPSK has a better performance under the weak turbulent can be derived. That is to say the BPSK scheme effectively resist weak turbulent. Theoretical analysis for the bandwidth efficiency of the four modulation schemes above, we can seen that the bandwidth efficiency for the four modulation all areconstant. The simulation results are drawn in Figure 6 that as the same as we discussed. Simulation result reveals that the bandwidth efficiency for OOK, BPSK and DPSK scheme are about 1 respectively, but for QPSK is equal to 2. This suggest that the QPSK modulation scheme can make full use of the system bandwidth utilization and the transmission rate can be improved.

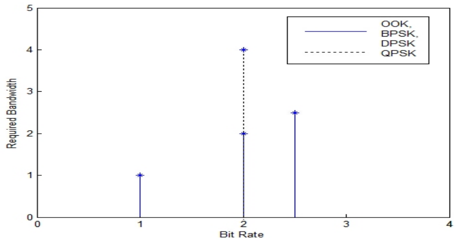

Figure 6.Simulation results of bandwidth efficiency

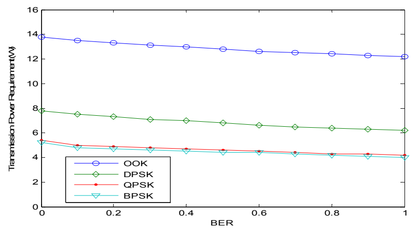

Figure 7. Simulation for transmission power requirement

Simulation of the power requirement for OOK, BPSK, DPSK and QPSK modulation schemes are shown in Figure 7. Just as we discussed above, the BPSK and QPSK scheme requires approximately the same power. But when the same BER performance for the DPSK and OOK scheme achieved, the DPSK requires less power than OOK, about 1.5dB lower. From Figure 7 it is clear that the BPSK and the QPSK need the lowest power, and about 4.52 dB lower than the OOK and 1.5dB lower than DPSK. Hence, the BPSK and QPSK are more suitable for free space communication based on requirement power.

6. Conclusion

The purpose of this paper is to present the comparison for the four modulation schemes, from the theoretical analysis and experimental results we can seen 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. When take the atmospheric fluctuation into the Gamma-Gamma distributed channel, the average BER performance of the four modulations shows direct decline respectively. From the simulation it can be seen that in the weak and strong turbulent, the BPSK and QPSK formats still have almost the same BER performance. Simulation under different turbulence conditions for BPSK modulation, the experimental shows that it has good characteristics to resistance turbulence. For the bandwidth efficiency of OOK, BPSK and QPSK are closed to uint, only the QPSK is the twice times than others. Also the require power for QPSK is the same as BPSK format, and they need the lowest power compared others. Therefore, BPSK and QPSK show outstanding performance. Compared with QPSK, there is 3dB lower for BPSK of BER performance. Furthermore, the modulation and demodulation for BPSK is simpler than QPSK, and the transmission bandwidth is halved compared with BPSK under the same BER. Consequently, BPSK scheme is thought to be the most suitable modulation and demodulation scheme for FSO communications system.

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