Transmission Analysis of a Ternary Diversity Reception Based on OFDM FSO System over Correlated Log-normal Fading Channel

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Abstract— With the increasing requirements for larger bandwidth and higher data rate transfer of information, free space optical (FSO) communication has received growing attention in recent years. Atmospheric turbulence factors may give the most serious influence to the performance of the FSO system. In this paper, orthogonal frequency division multiplexing (OFDM) is chosen for the purpose of against channel dispersion and time varying environment. Spatial diversity is another efficient way to mitigate the effects of scintillation. We investigate the performance of OFDM FSO system of a ternary receiver with EGC reception combining scheme in log-normal distribution atmospheric turbulence channel. We analyze the probability distribution function (PDF) of the received light intensity in ternary diversity reception. Based on the simulation results, we present a comparison of the transmission performance among ternary receiver, dual receiver and single receiver system over correlated log-normal weak turbulence fading channel. The results would be useful for design and evaluation of optical wireless communication system.

1. INTRODUCTION

Free space optics (FSO) communication has received increasing attention in recent years, since it fulfill the requirement of higher transmission speed and wider bandwidth in modern communication system. Compared with the RF communication system, the FSO communication system has lighter, smaller and more energy efficient devices. In some special area, where the optical fiber networks are not available to be established, the FSO system can be a suitable alternative option [1, 3].

The atmospheric turbulence situation has a great influence on the performance of FSO communication system. As atmospheric channel changes randomly, the laser irradiance in receiving plane would have a spatial and temporal fluctuation known as scintillation. The optical scintillation could cause an unacceptable channel fading in FSO communication [2]. Classical studies of atmospheric turbulence were focus on fluctuations in the velocity field of a viscous fluid, which can be simplified as a stochastic field model. Log-normal distribution perform excellent match in describing the weak atmospheric turbulence [3].

Orthogonal frequency division multiplexing (OFDM) is a kind of multi-carrier modulation which the data information is carried over many lower rate subcarriers. It has been widely used in wireless communication and adopted in a lot of high speed communication standards: ITU-T G. hn; IEEE 802.11a, g, n, ac; IEEE 802.15.3a; IEEE 802.16e; IEEE 802.20 and so on. One of the advantages of OFDM is that it is a suitable technology against channel dispersion and time varying environment [1].

Spatial diversity is another way to mitigate the channel fading of FSO communication system. With the larger size of the reception, the system performance would get better [3, 8]. However, the increasing lens radius would lead to the cost and the weight of the reception terminal increase exponentially. It is kind of a trend to replace one big lens to several smaller receivers [4]. Most of the previous research on FSO communication system with multiple receivers concerned each reception being independent with others, which meant the distance between two individuals was long enough [5]. It would make serious difficulties in the design of FSO system [2].

In this paper, a ternary reception OFDM FSO system is proposed to mitigate the channel fading over log-normal distribution atmospheric turbulence. In order to have an insight into the performance of the system, we compare the ternary reception system with single reception and dual reception systems on the average bit-error-ratio (BER), average signal-to-noise ratio (SNR) and outage probability (OP).

The remainder of this paper organized as follows, in Section 2, we give a brief introduction of the ternary reception OFDM FSO system. In Section 3, we analyze the received light intensity probability distribution function (PDF) over log-normal distribution atmospheric turbulence. In Section 4, we investigate the transmission performance of the system. In Section 5, we present the conclusion.

2. TERNARY RECEPTION SYSTEM ARCHITECTURE

In order to mitigate the light intensity fluctuation in FSO communication, increasing the diameter of the aperture known as Aperture Average is a feasible solution [8]. But the increasing size of lens would lead to a sharp increasing of the cost. Hence we consider replacing one big lens to several small lenses is more efficient.

In this paper, we consider a ternary receiver. As showed in Fig. 1, D is the diameter of each lens. Consider two separate lenses lens$_i$ and lens$_j$, d_{ij} presents the central distance between lens$_i$ and lens$_j$. Fig. 2 shows a brief architecture of ternary diversity reception OFDM FSO system. The electrical signal is modulated by OFDM Modulator and converted to optical signal by laser-diode. The optical signal propagates through turbulence and would be received by the ternary receiver. After converted back electrical signal, the signals from three detectors would be demodulated by OFDM Demodulator and combined under equal gain combining (EGC) scheme.

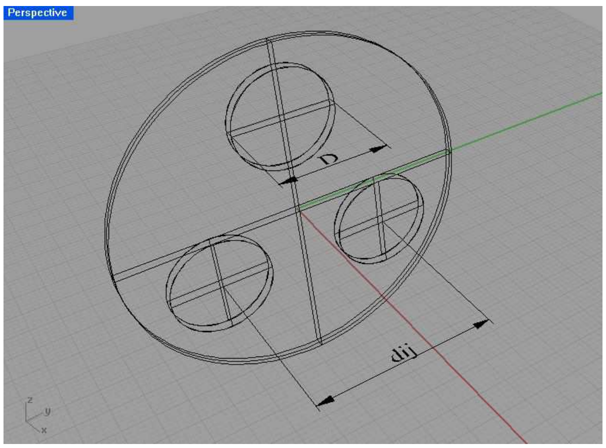

Figure 1. Ternary receiver.

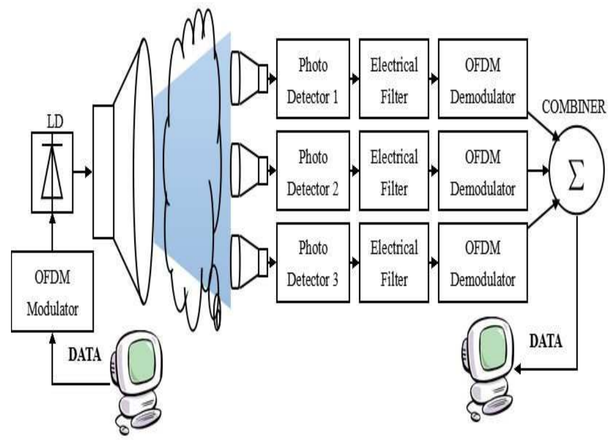

Figure 2. System architecture.

3. LIGHT INTENSITY PROBABILITY DISTRIBUTION

In the theory used to derive the atmospheric turbulence, optical field propagation can be seen as a random process. The received light intensity of lens$_i$ and lens$_j$ have average value I_i and I_j. Correlation coefficient γ_{ij} of lens$_i$ to lens$_j$ is presented by function (1):

$$\gamma_{ij}(d_{ij}, D) = \frac{B_{I,ij}(I_i, I_j, d_{ij}, D)}{\sqrt{\sigma_i^2 \sigma_j^2}} \tag{1}$$

$B_{I,ij}(I_i, I_j, d_{ij}, D)$ is covariance of lens$_i$ to lens$_j$, which is presented by function (2). The σ_i^2 and σ_j^2 are the variances of lens$_i$ and lens$_j$, which can be calculated by function (3) [3].

$$B_{I,ij}(I_i, I_j, d_{ij}, D) = \frac{\langle I_i I_j \rangle}{\langle I_i \rangle \langle I_j \rangle} - 1 \tag{2}$$

$$\sigma_i^2(D) = B_{I,ij}(I_i, 0, D) = \frac{\langle I_i^2 \rangle}{\langle I_i \rangle^2} - 1 \tag{3}$$

The symbol $\langle\cdot\rangle$ stands for the ensemble average value. Based on Rytov Theory, I_i, I_j, σ_i^2 and σ_j^2 are the variables versus atmospheric turbulence situation, which can be described by Rytov Variance σ_R^2. Hence the correlation coefficient is a function of the receivers setting and turbulence condition, as showed in Fig. 3. We can see that with increasing of the central distance d_{ij}, correlation coefficient γ_{ij} is drawing close to 0. And when turbulence is getting stronger, γ_{ij} is getting higher.

According to the extended Rytov theory, we can use the log-amplitude X to indicate the light intensity I by the function $I = I_0 \exp(2X - 2X_0)$. As the optical field propagation through atmospheric turbulence is random process, the received light intensity should be presented by a probability distribution function (PDF) [6, 7].

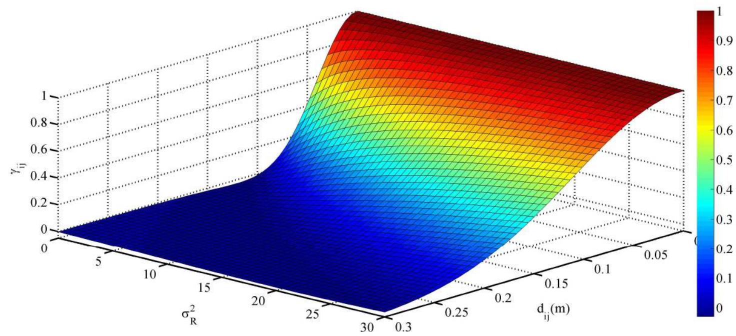

Figure 3. Channel correlation coefficient under different separation distance and turbulence condition.

Log-normal distribution is widely used in describing the turbulence situation. A single receiver log-normal PDF of received light intensity is:

$$f_1(I) = \frac{1}{2I}\frac{1}{\sqrt{2\pi\sigma_X^2}}\exp\left\{-\frac{[\ln(I)-\ln(I_0)]^2}{8\sigma_X^2}\right\} \tag{4}$$

where I_0 denotes the ensemble average received light intensity and σ_X^2 denotes the variance of X. In this paper, we consider the situation of weak turbulence ($\sigma_R^2 = 0.14$) and the three receivers setting as an equilateral triangle with same diameters. We can extend PDF to the situation of ternary reception as function (5):

$$f_{3I}(I) = \frac{1}{16\pi I^3}\cdot\frac{1}{\sqrt{2\pi\sigma_X^6(1-3\gamma^2+2\gamma^3)}}\cdot\exp\left\{-\frac{1}{8(1-3\gamma^2+2\gamma^3)}\cdot\left[3\sigma_X^4(1-2\gamma+\gamma^2)\ln^2\left(\frac{I}{I_0}\right)\right]\right\} \tag{5}$$

4. PERFORMANCE OF TERNARY RECEPTION OFDM FSO SYSTEM

In this paper, we use OFDM signal for its advantages against channel dispersion and time varying environment. The OFDM signal with N subcarriers, after up-conversion can be written as below, where ω_n is the nth subcarrier angular frequency, φ_n is the nth subcarrier initial phase, A_n is nth subcarrier complex data symbol.

$$S_{OFDM}(t) = \sum_{0}^{N-1} S_n(t) = \sum_{0}^{N-1} A_n \exp(j\omega_n t + \varphi_n), \quad 0 \le t \le T_s \tag{6}$$

We assumed the total noise power is a sum of thermal noise, shot noise and relative intensity noise process:

$$N_0(I_1, I_2, I_3) = \frac{4K_B T_{abs} F}{R_L}B_e + 2qI_{ph}(I_1, I_2, I_3)B_e + (RIN)I_{ph}^2(I_1, I_2, I_3)B_e \tag{7}$$

I_{ph} is DC of total received current, K_B is Boltzmann's constant, T_{abs} is absolute temperature, F is the noise figure of the receiver electronics, R_L is PD load resistor, q is electron charge and B_e is the Electrical filter bandwidth. The ensemble average SNR and ensemble average BER can be calculated as:

$$\langle SNR\rangle = \int_0^\infty\int_0^\infty\int_0^\infty SNR(I_1, I_2, I_3)\cdot f_I(I_1, I_2, I_3)dI_1 dI_2 dI_3 \tag{8}$$

$$\langle BER\rangle = \int_0^\infty\int_0^\infty\int_0^\infty BER(I_1, I_2, I_3)\cdot f_I(I_1, I_2, I_3)dI_1 dI_2 dI_3 \tag{9}$$

In Fig. 4, we set the lens diameters of single, dual and ternary reception are 12 cm, 8.49 cm and 6.93 cm, so that the total reception area of three schemes are the same. We can see that ternary reception system with low correlation coefficient ($\gamma = 0$) perform better.

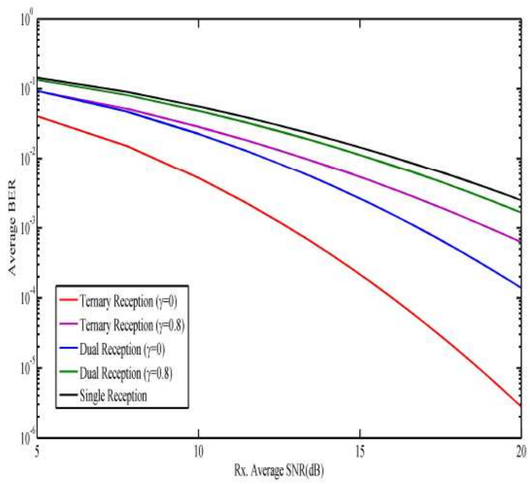

Figure 4. Under different reception.

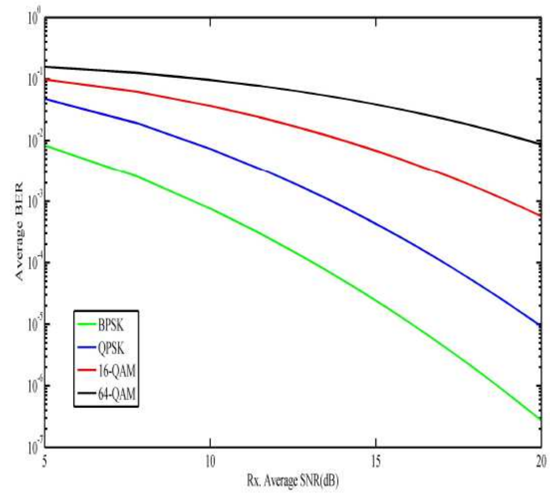

Figure 5. Under different modulation.

Figure 5 shows the transmission performance of ternary reception system with different modulation schemes. It is clear that the higher constellation size modulation require more received powers to reduce BER of the system. Consider a threshold SNR_{th}. Only when the SNR of the system is better than the SNR_{th}, the quality of communication is acceptable. Otherwise, we can see the communication is failed. Define the probability of the SNR falling worse than the SNR_{th} as the outage probability P_{outage}. It can be written as:

$$P_{outage}(SNR_{th}) = P[SNR < SNR_{th}] \tag{10}$$

Figure 6 shows that, in certain threshold SNR_{th}, ternary reception system has lower outage probability.

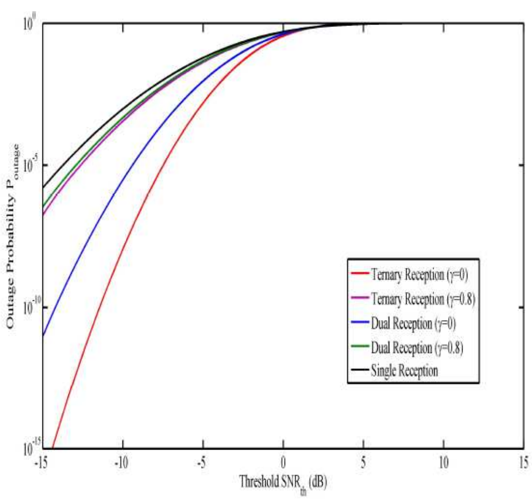

Figure 6. Outage probability.

Parameter	Value
Operating wavelength (λ)	1550 nm
Relative intensity noise (RIN)	-130 dB/Hz
PD load resistor (R_L)	50 Ω
Absolute temperature (T_{abs})	300 K
Transmission distance (L)	2 km
Electron charge (q)	1.602×10^{-19}C
Noise figure (F)	2 dB
Electrical filter bandwidth (B_e)	2 GHz
Number of carrier (N_s)	256
Optical modulation index (m_n)	1%

Table 1.

5. CONCLUSION

In this paper, we propose a ternary diversity reception OFDM FSO system. Considering the effects of correlation coefficient, we analyze the probability distribution function of received light intensity and investigate the transmission performance of the system in log-normal distribution atmospheric turbulence. In terms of the numerical results about comparisons with other reception schemes (single reception, dual reception) on average SNR, average BER and outage probability, we can see that ternary diversity reception OFDM FSO system has an apparent advantage on mitigating atmospheric turbulence channel fading.

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