Research on Transmission Performance of Laser Communication System in Atmospheric Turbulent Channel

Xiaohu Liu [a]
School of Intelligent Science & Information Engineering, Xi'an Peihua University, Xi'an 710032 China.
[a]liuxiaohu2017@126.com

Abstract. In order to solve the problem of system interference caused by noise interference of laser communication system, according to the theory of finite aperture receiving intensity fluctuation, the signal-to-noise ratio model based on the influence of atmospheric fluctuation on atmospheric turbulence and no turbulence is established respectively, and the BER model of laser communication system under turbulent conditions is given. Through calculation and analysis, the intensity fluctuation and the receiver aperture at the receiving end are the main factors causing the fluctuation of the performance of the atmospheric turbulent optical communication system. The model can effectively evaluate the BER performance of laser communication systems under atmospheric turbulence conditions and provide reference for relevant theoretical research.

Keywords: Laser Communication; Atmospheric Turbulence; SNR; BER.

1. Introduction

Due to its unique properties, lasers have been widely used in laser ranging, laser guidance and laser radar. Due to the short wavelength of the laser [3-4], the absorption and scattering of its signal is strong, so the atmospheric penetration ability is poor, and its performance is very sensitive to climate. Therefore, in the long-distance information transmission process in the atmospheric channel [3-4], atmospheric attenuation, atmospheric turbulence and background radiation cause spatial loss of the laser signal, and the bit error rate of the communication link is generated. Due to the atmospheric turbulence effect, the laser signal flickers during the propagation process [5], causing severe interference of the optical communication signal and reducing the transmission performance of the communication link. Based on the atmospheric turbulence channel, an optical communication system is established. The influence of receiver aperture and intensity fluctuation on optical communication is discussed. The signal-to-noise ratio and bit error rate model under the channel are given.

2. Laser Atmospheric Transmission Principle and Establishment of Optical Communication System

Atmospheric attenuation effects and atmospheric turbulence effects are the two main effects of atmospheric channels [6-8], which seriously interfere with laser transmission performance. In order to make the research targeted, the laser communication system of the paper does not consider the influence of atmospheric attenuation, and uses the Gaussian beam as the laser. The receiving end structure of the optical communication system is shown in Fig.1.

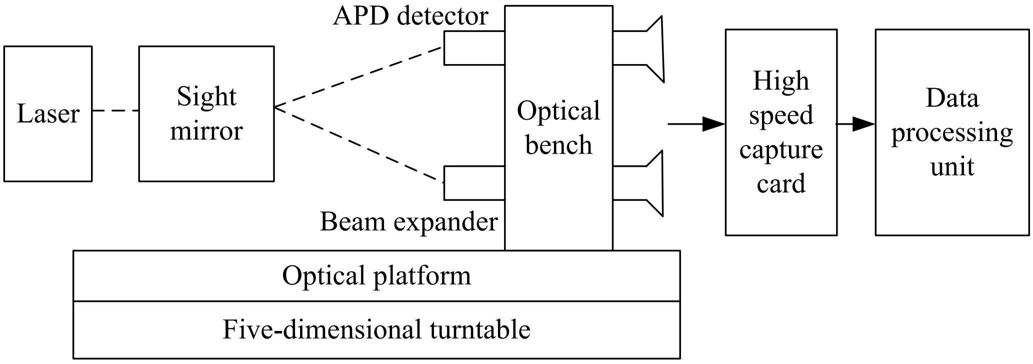

Figure 1. Optical communication system receiving end structure.

3. Laser Transmission in the Atmospheric Turbulence Channel

Assuming δ_I^2 is the intensity fluctuation variance, which can be expressed by:

$$\delta_I^2 = \frac{\langle [I - \langle I \rangle]^2 \rangle}{\langle I \rangle^2} \tag{1}$$

Where I is the light intensity and $\langle * \rangle$ is the statistical average. Let B be the aperture averaging factor, which can be expressed by the following formula:

$$B = \frac{\delta_I^2(D)}{\delta_I^2(0)} \tag{2}$$

Let l_0 and L_0 be the turbulent internal scale and the turbulent outer scale, respectively, C_n^2 is the atmospheric refractive index structure constant, and δ_{nx}^2 and δ_{ny}^2 are the large-scale fluctuation variance and the small-scale fluctuation variance, respectively. Then, the variance of the received light intensity fluctuation when the Gaussian beam propagates is:

$$\begin{aligned}\delta_I^2(L_0, D, l_0, C_n^2) = \exp\left[\delta_{nx}^2(D, l_0, C_n^2)\right. \\ \left. - \delta_n^2(L_0, D, l_0, C_n^2) + \delta_{ny}^2(D, l_0, C_n^2)\right] - 1\end{aligned} \tag{3}$$

4. Signal-To-Noise Ratio Model of Atmospheric Turbulence Channel and Calculation Formula of Bit Error Rate

Due to the communication distance of the optical communication system, considering the aperture average effect, the intensity fluctuation is generally regarded as weak fluctuation, obeying the logarithm a normal distribution whose probability density function is:

$$P(I) = \frac{1}{\sqrt{2\pi}\,\delta_I I} \exp\left(-\frac{\left(\ln\left(I/\langle I \rangle\right) + 1/2\,\delta_I^2\right)^2}{2\delta_I^2}\right) \tag{4}$$

In the formula, the variance of the laser intensity fluctuation is represented by δ_I^2. It can be seen from the formula that the factors affecting the probability density function are I, δ_I^2 and $\langle I \rangle$.

When neglecting the beam broadening effect caused by atmospheric turbulence, the current output of the detector in each time slot without being affected by atmospheric turbulence and the output current affected by atmospheric turbulence are:

$$i_0 = I_B r_i \tag{5}$$

$$i_1(L_S) = \langle I \rangle L_S r_i + I_B r_i \tag{6}$$

Where r_i is the detector current responsivity, determined by the detector itself. At this point, the optimal threshold expression is:

$$I_{BT} = \frac{1}{2}(i_0 + i_1) \tag{7}$$

When not affected by atmospheric turbulence, the detector has output noise, mainly including signal light shot noise I_{sn}^2, dark current optical noise I_{dn}^2 and system inherent thermal noise I_{Tn}^2. However, when the "1" code is transmitted, the atmospheric turbulence noise variance is introduced, and the variance can be expressed as:
When sending a "0" code

$$\sigma_0^2(L_S) = 2eBMFr_i(i_b + i_d) \tag{8}$$

When sending a "1" code

$$\sigma_1^2(L_S) = 2eBMFr_i\left[\langle I \rangle L_S + i_b + i_d\right] \tag{9}$$

Then derive the signal-to-noise ratio (SNR) and threshold SNR of the atmospheric turbulence channel system:
When sending a "1" code

$$SNR_1(L_S) = \frac{i_1(L_S)}{\sigma_1(L_S)} = \frac{\langle I \rangle L_S r_i + I_b r_i}{\sqrt{2eBMF\left[\langle I \rangle L_S r_i + i_b r_i + i_d r_i\right]}} \tag{10}$$

When sending a "0" code

$$SNR_0(L_S) = \frac{i_0(L_S)}{\sigma_0(L_S)} = \frac{\langle I \rangle L_S r_i + I_b r_i}{\sqrt{2eBMF\left[\langle I \rangle L_S r_i + i_b r_i + i_d r_i\right]}} \tag{11}$$

Under atmospheric turbulence conditions, when a "1" code is transmitted, the current mean and noise variance in each time slot can be considered as a function of S as an independent variable. Let E_{RT} be the average bit error rate of the system under atmospheric turbulence conditions. It is necessary to average the intensity fluctuation probability density function. E_{RT} can be expressed by the following formula:

$$E_{RT} = \frac{1}{4}\left\{\int_0^\infty P(I) erfc\left[\frac{SNR_1(L_S) - SNR_{T1}(L_S)}{\sqrt{2}}\right] dL_S + erfc\left[\frac{SNR_{T0}(L_S) - SNR_0(L_S)}{\sqrt{2}}\right]\right\} \tag{12}$$

Where $SNR_0(L_S)$ is the signal-to-noise ratio when the "0" code is transmitted, and $SNR_1(L_S)$ is the signal-to-noise ratio when the "1" code is transmitted.

5. Experiment and Calculation Analysis

In order to analyze the relationship between the optimal decision threshold and the turbulence intensity under turbulent conditions, different light intensity flicker values are obtained by changing the turbulence intensity change, and the corresponding optimal threshold is obtained by numerical calculation. The result is shown in Fig.2.

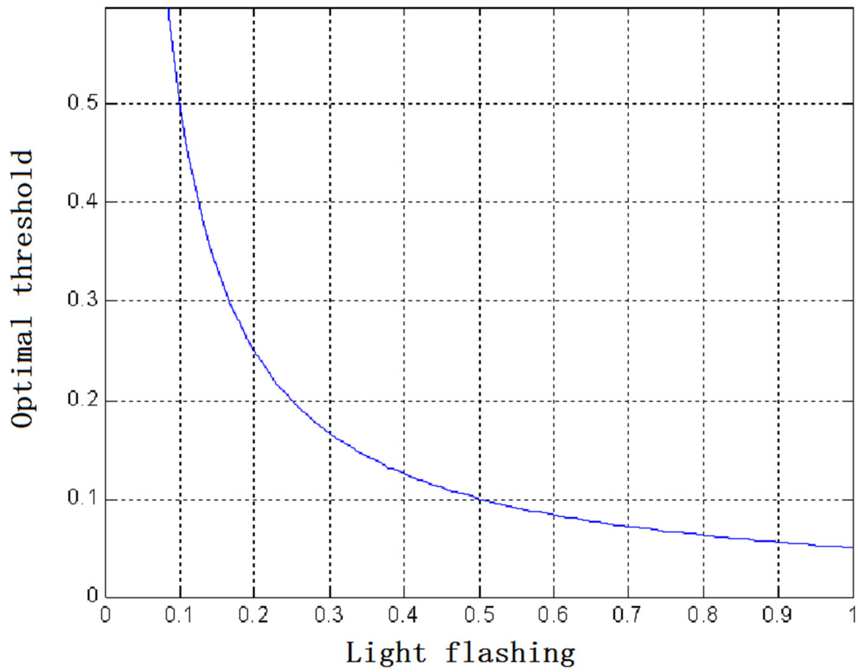

Figure 2. Relationship between light intensity flicker and optimal threshold

According to the Fig.1, it can be inferred that the gap between the noise variances is further increased as the scintillation index increases, and the symmetry of the missed alarm probability and the false alarm probability is weakened, so that the optimal threshold gradually deviates from 0.5. In an actual optical communication system, the decision threshold should be appropriately adjusted according to the change in turbulence intensity to obtain better system performance.

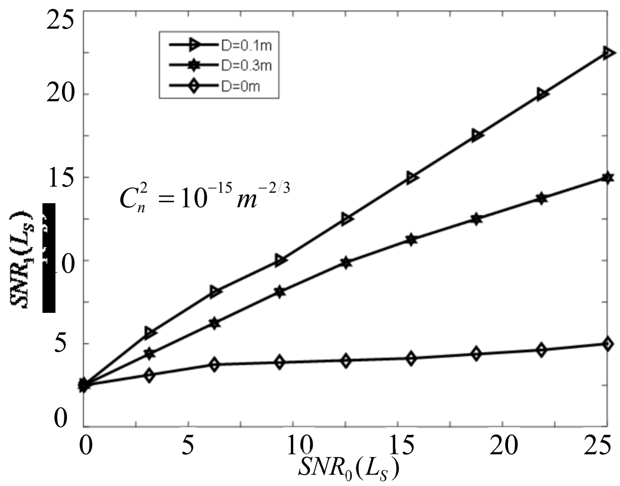

Figure 3(a). $C_n^2 = 10^{-15} m^{-2/3}$, the relationship between $SNR_0(L_S)$ and $SNR_1(L_S)$ at different receiving apertures

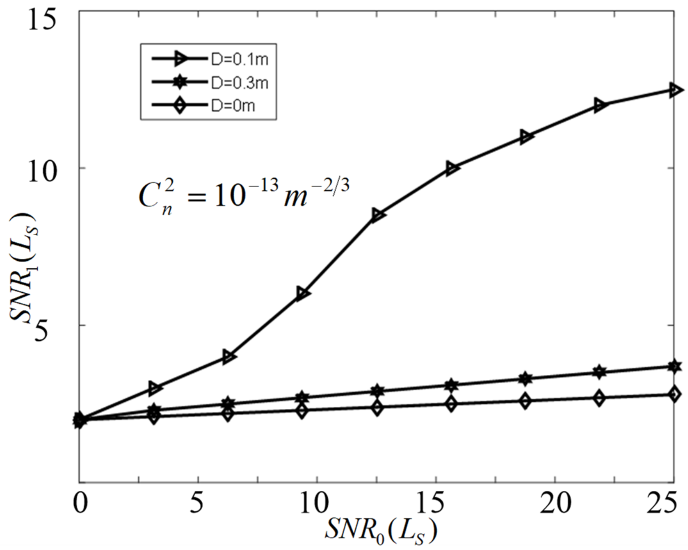

Figure 3(b). $C_n^2 = 10^{-13} m^{-2/3}$, the relationship between $SNR_0(L_S)$ and $SNR_1(L_S)$ at different receiving apertures

It can be seen from Fig. 3 that the value of the atmospheric refractive index structure constant affects the turbulence intensity, thereby affecting the signal-to-noise ratio of the laser communication system. The results show that the aperture size improves the signal-to-noise ratio of the laser communication system more obviously.

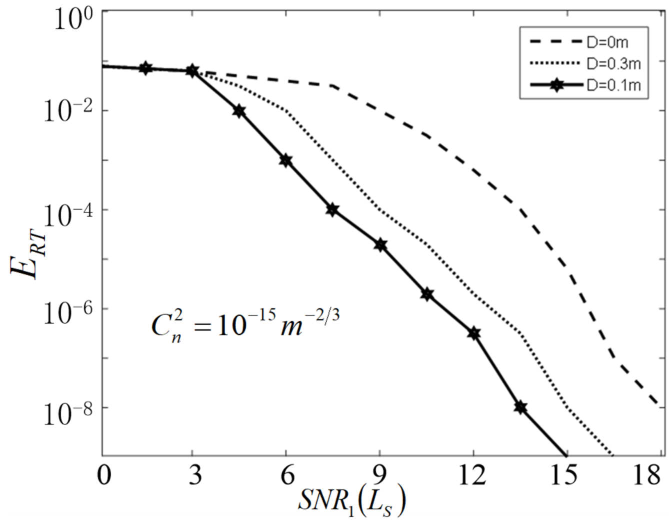

Figure 4. Relationship between turbulence intensity and signal-to-noise ratio and bit error rate

Fig.4 shows, in the case of the same signal-to-noise ratio, as the receiving aperture diameter D increases, the error rate of the optical communication system decreases. When the bit error rate is the same, the signal-to-noise ratio decreases as the receiving aperture diameter D increases.

6. Conclusion

The paper analyzes the communication principle and basic requirements of laser communication system under long-distance conditions, studies the influencing factors of atmospheric turbulence channel affecting laser communication system, and establishes the signal-to-noise ratio model and BER model based on optical communication angle and different light intensity. The undulation condition focuses on the relationship between the optimal threshold and the intensity flicker. Under the condition of atmospheric turbulence, the problem of light intensity flicker appears constantly. The intensity and phase of the receiving end wave are randomly fluctuated in time and space. The results show that the receiving aperture of the receiver is the main factor affecting the transmission performance of the optical communication system of the atmospheric choke channel. The theoretical calculation model of the paper can provide theoretical calculation basis for the communication performance of the remote lidar system. The calculation method can effectively improve the stability and reliability of laser transmission.

Acknowledgments

This work has been supported by Project of the School-Level Research of Xi'an Peihua University (No. PHKT18017).

References

[1]. J. C. Ricklin, S. M. Hammel, F. D. Eataon. Et al. Atmospheric channel effects on free-space laser communication [J]. J. Opt.Fiber Commun, 2006,3(2):111-158.

[2]. A. K. majumdar. Free-space laser communication performance in the Atmospheric channel [J]. J.Opt.Fiber Commun. 2005,2(4):345-396.

[3]. M.H. Mahdieh, M. Pournoury.Atmospheric turbulence and numerical evaluation of bit error rate (BER) in free-space communication [J]. Opt.&Laser Technol. 2010,42(1):55-60.

[4]. E.Ferdinandov, B.pachedjieva, B.Bonev. Joint Influence of heterogeneous stochastic factors on bit error rate of ground-to-ground free-space laser communication system [J].Opt. Commun.2007, 270(2):121-127.

[5]. M. Uysal, J. Li. Error rate performance of coded free-space optical links over Gamma-Gamma turbulence channels [J]. IEEE International conference on communications. 2004(6):3331-3335.

[6]. Xiangqian Meng, Shunxing Hu and Yingjian Wang, etc. Research on Detection of Aerosol Scattering Phase Function and Atmospheric Visibility Based on Charge Coupled Devices [J]. Journal of Optics, 2012, 32(9):137-143.

[7]. Chunyi Chen, Huaming Yang and Huilin Jiang, etc. Large aperture receiving performance analysis and aperture size selection in atmospheric optical communication [J]. Chinese laser, 2009, 36(11):2957-2960.

[8]. Changqi Yang, Yihan Jiang and Changhui Rao. Influence of aperture averaging on BER of free-space optical communication [J]. Journal of Optics, 2007, 27(2): 212-218.