Average BER of maritime visible light communication system in atmospheric turbulent channel *

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***Abstract*—The atmospheric turbulence makes signal intensity fluctuation randomly and reduce performance of Visible light communication (VLC) system in maritime environment. To establish an effective VLC network in the actual marine environment, an effective channel transmission model needs to be established and used to study the performance of the maritime VLC link. Based on the Pierson-Moskowitz spectrum , the geometric model of links between lighthouse and ship is established. Considering the aperture averaging effect, Log-normal distribution is employed to deduce the mathematical expression of average bit error rate (BER). The effects of sea wave height, transmission distance, atmospheric turbulence intensity, receiver aperture size and wavelength on the average BER is analyzed. The work presented here is devoted to propose a new model for the evaluation of maritime VLC system performance and providing reference for practical application.**

Keywords—atmospheric turbulence, average bit error rate, maritime visible light communication

I. INTRODUCTION

Visible light communication (VLC) technology has important application prospects in the military and commercial fields, especially in LiFi , intelligent transportation and lamp signal, as it has many advantages such as no spectrum authentication, anti-electromagnetic interference and anti-multipath fading[1-2]. The signal transmitted by the maritime VLC system will be affected by the atmospheric turbulence, which will cause the signal intensity to change randomly and affect the system performance. Therefore, the application of VLC technology in shore-to-ship and ship-to-ship lamp signal systems needs to consider the influence of atmospheric turbulence. The modeling and performance analysis of atmospheric turbulence channels for maritime VLC systems needs to be further studied.

The probability density distribution of the scintillation intensity in the atmospheric turbulence channel generally adopts the Log-normal distribution model or the Gamma-Gamma distribution model. The scintillation intensity experimental data fit well with the Log-normal distribution model when large aperture receiver be used with aperture smoothing effects [3], Gamma-Gamma distribution model is not suitable for considering aperture smoothing effect [4].

In this paper a VLC system model between lighthouse and ship is established and a closed expression for the average BER of the system is deduced. The effect of the sea wave height, refractive-index structure parameter, link distance, average signal-to-noise ratio (SNR) and receiver aperture size on the system performance has been analyzed.

II. MARITIME VISIBLE OPTICAL COMMUNICATION SYSTEM AND CHANNEL MODEL

VLC system using the On-Off Keying (OOK) scheme has that serves the coast lamp signal system. The received signal y is suffers from a fluctuation in signal intensity due to atmospheric turbulence and additive noise, so it can be modeled as (1) without background light intensity [5],

$$y = Ix + n \tag{1}$$

where x is the transmitted modulated signal, I is the signal fading due to atmospheric turbulence, and n is the Gaussian white noise with mean zero and variance σ_0^2 .Visible light signal intensity random fluctuations induced by atmospheric turbulence meet the lognormal distribution:

$$f(I) = \frac{1}{I\sqrt{2\pi\sigma_{\ln I}^2}} \exp\left[-\frac{\left[\ln(I) + 0.5\sigma_{\ln I}^2\right]^2}{2\sigma_{\ln I}^2}\right] \tag{2}$$

where $\sigma_{\ln I}^2$ the logarithmic irradiance variance, which satisfies $\sigma_{\ln I}^2 = \ln\left(\sigma_I^2 + 1\right)$, σ_I^2 is scintillation index. The scintillation index of the spherical wave in the turbulent atmosphere satisfies [6]:

$$\begin{aligned}\sigma_I^2 = \exp\Bigg[&\frac{0.49\sigma_0^2}{\left(1+0.18d^2+0.56\sigma_0^{12/5}\right)^{7/6}} \\ &+\frac{0.51\sigma_0^2\left(1+0.69\sigma_0^{12/5}\right)^{-5/6}}{\left(1+0.9d^2+0.62d^2\sigma_0^{12/5}\right)^{5/6}}\Bigg]-1\end{aligned} \tag{3}$$

Project supported by the Key Industrial Innovation Chain Project in Industrial Domain (Grant No. 2017ZDCXL-GY-06-02), Open Research Fund of State Key Laboratory of Pulsed Power Laser Technology (Grant No. SKL2016KF05), and Huawei Innovation Research Program (Grant No. HO2017050001AG).

where $\sigma_0^2 = 0.5C_n^2 k^{7/6} L^{11/6}$, $d = [kD_s^2/(4L)]^{1/2}$, C_n^2 is refractive-index structure parameter, λ is the operating wavelength, k=2π/λ is the wave number, L is the path length of the information transmission, and D_s is the receiver aperture.

Fig.1 shows the geometric model of the VLC system proposed in this paper, where D is the horizontal distance between the lighthouse and the ship, H is the height of the lighthouse, h_1 is the height of the ship, h_2 is the undulating height of the waves, and θ is the zenith angle. The model considers the influence of waves on the communication system in the offshore environment. The transmitter is set up at the lighthouse to act as a base station, the ship or ocean beacon is equipped with a receiver and connected to the terrestrial network through a VLC link. Each maritime transceiver consists of a high-power LED array and a photodetector [7].

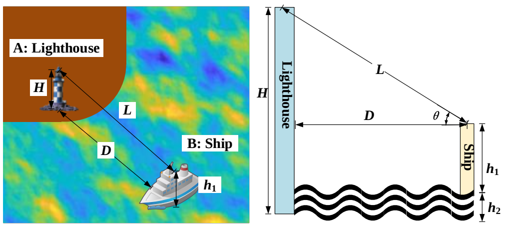

Fig. 1. Geometric model of marine visible light communication system.

From Fig.1 , the information transmission path distance L of the in the channel is

$$L = \sqrt{D^2 + \left(H - h_1 - h_2\right)^2} \tag{4}$$

It is worth noting that due to the randomness of the waves, the value of the sea wave height h_2 in the model will fluctuate within a certain range, which leads to a inconsistent transmission path even if the horizontal distance D is constant. Taking into account the smoothness and ergodicity of the waves, the waves model can be simulated using the Pierson-Moskowitz (PM) wave spectrum, and its expression is

$$S(\omega) = \frac{\alpha g^2}{\omega^5} exp\left[-\beta\left(\frac{g}{U\omega}\right)^4\right] \tag{5}$$

where parameter α=0.0081,β=0.74,g is gravity acceleration and g=9.8m/s, U is the wind speed at the height of 19.5m.

In the OOK scheme, the average BER can be expressed as:

$$BER = \int_0^\infty f_I(I) Q\left(\sqrt{SNR I}\right) dI \tag{6}$$

where SNR is the average signal to noise ratio and Q(x) is the Gaussian-Q function in the form:

$$Q(x) = \frac{1}{\pi}\int_0^{2\pi} \exp\left(-\frac{x^2}{2\sin^2\theta}\right) d\theta, \quad x > 0. \tag{7}$$

Let $x = \left[\ln(I) + \sigma_{\ln I}^2/2\right] / \left[2\sigma_{\ln I}^2\right]^{1/2}$, by using Gauss-Hermite orthogonal integral approximation, $\int_0^\infty \exp\left(-x^2\right) f(x) dx \approx \sum_{i=1}^n w_i f(x_i)$, the average BER can be accurately approximated as [8]:

$$\begin{aligned} BER &= \frac{1}{\pi}\int_0^{2\pi} \frac{1}{\sqrt{\pi}} w_i \\ &\quad \times \sum_{i=1}^n \exp\left(\frac{-SNR^2 \exp\left[2\left(\sqrt{2}\sigma_{\ln I} x_i - \sigma_{\ln I}^2/2\right)\right]}{2\sin^2\theta}\right) d\theta \\ &= \frac{1}{\pi}\sum_{i=1}^n Q\left[SNR \exp\left(\sqrt{2}\sigma_{\ln I} x_i - \sigma_{\ln I}^2/2\right)\right] \end{aligned} \tag{8}$$

where x_i is the root of the Hermite polynomial.

III. SIMULATION AND ANALYSIS

Simulation analysis is perform based on the closed expression derived above in order to analyze the performance of the system. Unless otherwise specified in followed, the position of the lighthouse is located at (0,0), λ=632.8nm, SNR=10, C_n^2 =1×10^{-13}m$^{-2/3}$, D=500m, H=50m, h_1=5 m.

Fig.2 and Fig.3 shows that the average BER variation of VLC systems in the 250m×250m with wind speeds of 9.6m/s and 22.5m/s, respectively. Compare Fig.2.1 and Fig.3.1 observe that the average BER of the system between the lighthouse and the ship increases with the increase in the link distance. In Fig.2.2, Fig.2.3, Fig.3.2 and Fig.3.3, the average BER variation in different 10m×10m regions is further analyzed. The average BER is affected by the wave fluctuations, and the average BER change is as random and complex as the wave height. With the increase of wind speed, the situation on the surface of the sea has become worse and the average BER fluctuations have become more severe.

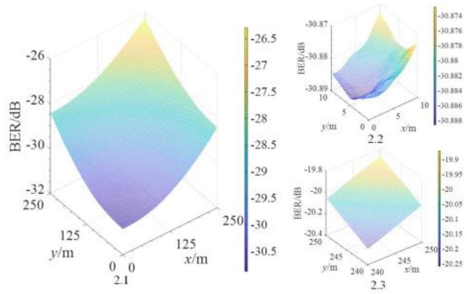

Fig. 2. The influence of average *BER* with wave fluctuation in 9.6 m/s wind speed:Fig.3.1 0-250 m range;Fig.3.2 0-10 m range;Fig.3.3 240-250 m range.

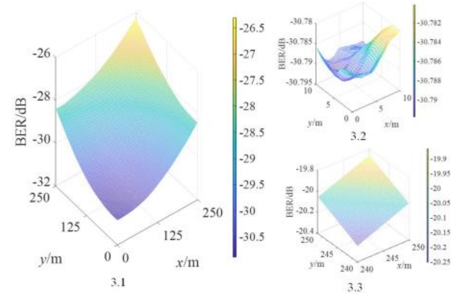

Fig. 3. The influence of average *BER* with wave fluctuation in 22.5m/s wind speed:Fig.3.1 0-250 m range;Fig.3.2 0-10 m range;Fig.3.3 240-250 m range.

In Fig.4, the influence of the detector aperture size on the system needs to be considered on the maritime VLC link. Let D_s=0.01m,0.02m,0.03m, the average BER of the system decreases with the increase of the receiver aperture because increasing the aperture size of the receiver makes the aperture smoothing effect stronger so that weakens the effect of atmospheric turbulence on the performance of the link.

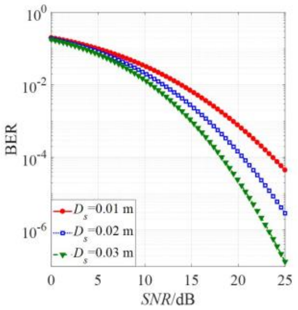

Fig. 4. Average *BER* versus the average *SNR* for various values of the receiver aperture size.

In Fig.5, the influence of the atmospheric turbulence intensity and wavelength of the visible light signal on the average BER is analyzed with refractive-index structure parameter range from 1×10^{-14}m$^{-2/3}$ to 5×10^{-13}m$^{-2/3}$ and *SNR*=20dB. Fig.5 shows that the average BER begins to increase rapidly to the maximum value and then enters into the saturated attenuation region with the increase of atmospheric turbulence intensity. This situation can be explained by the classical theory of turbulence [9]: Atmospheric turbulence is formed by the interaction of eddies of different sizes and it can be divided into the outer scale of turbulence and the inner scale of turbulence. The Rytov variance increases as the refractive index structure constant increases, the light intensity scintillation increases rapidly and then enters the saturated region, but the conditions and the performance of the two scintillators entering the scintillation saturation region are not the same. The average BER decreases with the increase of wavelength in the visible light band, when the wavelength is 450nm, the average BER reaches the maximum at about $C_n^2 = 2.5\times10^{-13} m^{-2/3}$ and the average BER increases to about 3×10^{-3}. It is difficult to communication by visible light between lighthouse and ship, so it can be seen that the turbulence intensity and visible light signal wavelength have a significant impact on the performance, consideration should be given to reducing its impact in actual communication applications.

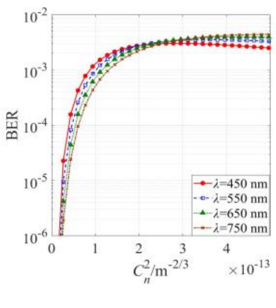

Fig. 5. Average *BER* versus the turbulence strength for various values of wavelength.

IV. CONCLUSION

In this paper, the mathematical expression of the average BER of the maritime lighthouse-to-ship VLC system is deduced, and the visible light communication system link performance is analyzed with sea wave fluctuation, transmission distance, receiver aperture size, atmospheric turbulence intensity and wavelength of light. Results show that the performance of the VLC system between lighthouse and ship is affected by the fluctuation of the sea waves, and the average BER changes with randomness and complexity like the sea waves. As the wind speed increases, the marine environment becomes worse and the average BER is undulate. The average BER of maritime VLC system increases with the increasing of transmission distance and atmospheric turbulence intensity, and the decreasing of receiver aperture sizeand wavelength. The results of this paper can provide some references for the design and performance estimation of actual marine visible light communication systems.

REFERENCES

[1] A Jovicic, J Li, T Richardson, and Q Research, “Visible light communication: opportunities, challenges and the path to market,” IEEE Communications Magazine, 2013, 51(12):26-32.

[2] O Ergul, E Dinc,and O B Akan “Communicate to illuminate: State-of-the-art and research challenges for visible light communications,” Physical Communication, 2015,17:72-85.

[3] G Parry and P N Pusey “K distributions in atmospheric propagation of laser light,” Journal of the Optical Society of America, 1979 , 69 (69) :796-798.

[4] F S Vetelino, C Young, L Andrews, and J Recolons “Aperture averaging effects on the probability density of irradiance fluctuations in moderate-to-strong turbulence,” Applied Optics, 2007 , 46 (11) :2099.

[5] Z Ghassemlooy, W Popoola, and S Rajbhandari “Optical Wireless Communications System and Channel Modelling with MATLAB,” Florida:CRC Press,2012, pp.138-146.

[6] R L Phillips and L C Andrews Laser Beam Propagation through Random Media ,Washington:SPIE Press, 2005, pp.415-420.

[7] H Kim, A Sewaiwar , and Y H Chung “High-Performance Time-Code Diversity Scheme for Shore-to-Sea Maritime Visible-Light Communication,” Journal of the Optical Society of Korea, 2015 , 19 (5):514-520.

[8] M J Cheng, L X Guo, and Y X Zhang “Scintillation and aperture averaging for Gaussian beams through non-Kolmogorov maritime atmospheric turbulence channels,” Optics Express ,2015 , 23 (25):32606.

[9] M J Cheng, Y X Zhang, J Gao, F Wang, and F Zhao “Average capacity for optical wireless communication systems over exponentiated Weibull distribution non-Kolmogorov turbulent channels,” Applied Optics, 2014 , 53 (18) :4011-7.