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Performance of Spatial Diversity for FSO Links with Pointing Errors over Malaga Turbulence

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I.INTRODUCTION

Free space optical (FSO) communication is easily affected by atmospheric turbulence and pointing errors. In order to overcome the comprehensive effect of atmospheric turbulence, multiple input multiple output technology is adopted. MIMO system has two main technologies: spatial multiplexing and spatial diversity. Spatial diversity include maximum ratio combining (MRC), equal gain combining(EGC) and selective combining(SC).

In this paper, under the combined influence of Malaga turbulence and misaligned fading, Meijer G is used to derive the average bit error rate(BER) of EGC, MRC and SC. The system performance under different number of receiving apertures, jitter deviation and waist radius is analyzed, The average BER performance of the three merging methods is compared.

II. SYSTEM MODEL

The FSO system considered here has F transmitting and L receiving apertures. Assuming the noise of the channel is additive white Gaussian noise , the system model for PSK modulation can be expressed as

$$y_l = x\gamma_1 \sum_{f=1}^{F} I_{fl} + v_l, \quad l = 1,2,\ldots,L \tag{1}$$

where x is the transmitted signal, y is the received signal. γ_1 is the detector responsivity, v_l is the Gaussian additive white noise with zero mean value and variance σ_v^2=N$_0$/2 . I_{fl} is the irradiance of the f-th transmitter and the l-th receiver, and $I_{fl} = I_a\, I_p$. Here, the channel state consists of two parts: I_a represents atmospheric turbulence fading and I_p represents pointing errors.

III. CHANNEL MODEL

The joint probability density function under atmospheric turbulence and pointing errors in MIMO system channel model can be expressed as:

$$f_{I_{fl}}(I_{fl}) = \frac{g^2 A}{2} I_{fl}^{-1} \sum_{k=1}^{\beta} a_k \left(\frac{\alpha\beta}{\gamma\beta+\Omega'}\right)^{-\frac{\alpha+k}{2}} G_{1,3}^{3,0}\left(\frac{\alpha\beta}{\gamma\beta+\Omega'}\cdot\frac{I_{fl}}{A_0}\middle|\begin{matrix} g^2+1 \\ g^2,\alpha,k\end{matrix}\right) \tag{2}$$

where α is a positive parameter, which is related to large-scale turbulence. β is a natural number which represents the amount of fading. $K_v(\cdot)$ is the second kind of modified Bessel function. Ω' is the average power of coherence. $A_0 = [erf(v)]2$, $v = \sqrt{\pi}a/(\sqrt{2}w_z)$ and $erf(\cdot)$ is the error function. $w_{zeq}^2 = w_z^2\sqrt{\pi}erf(v)/(2v\exp(-v^2))$ is the square of the equivalent beam width, w_z is beam waist. And $g = w_{zeq}/2\sigma_s$ represents the ratio of the equivalent beam radius w_{zeq} of the receiver to the standard deviation of pointing error displacement (or jitter standard deviation) σ_s .

IV. SPATIAL DIVERSITY

A. Equal Gain Combining

For EGC system, there is no need to weight the signals, and all weight coefficients are considered as 1. The diversity branch signals are combined after in-phase processing. The average BER expression is as follows

$$\begin{aligned} BER(M) =& \frac{g^2 A}{12\log_2 M}\prod_{f=1}^{F}\prod_{l=1}^{L}\sum_{k=1}^{\beta} a_k D\cdot G_{6,3}^{1,6}\left(\frac{16A_0^2 C}{(FLB)^2}\middle|\begin{matrix}\frac{1-g^2}{2},\frac{2-g^2}{2},\frac{1-\alpha}{2},\frac{2-\alpha}{2},\frac{1-k}{2},\frac{2-k}{2}\\ 0,-\frac{g^2}{2},\frac{1-g^2}{2}\end{matrix}\right) \\ &+\frac{g^2 A}{4\log_2 M}\prod_{f=1}^{F}\prod_{l=1}^{L}\sum_{k=1}^{\beta} a_k D\cdot G_{6,3}^{1,6}\left(\frac{64A_0^2 C}{3(FLB)^2}\middle|\begin{matrix}\frac{1-g^2}{2},\frac{2-g^2}{2},\frac{1-\alpha}{2},\frac{2-\alpha}{2},\frac{1-k}{2},\frac{2-k}{2}\\ 0,-\frac{g^2}{2},\frac{1-g^2}{2}\end{matrix}\right)\end{aligned} \tag{3}$$

where $B = \frac{\alpha\beta}{\gamma\beta+\Omega'}$, $C = \bar{r}sin^2(\frac{\pi}{M})$, $D = B^{-\frac{\alpha+\beta}{2}}\frac{2^{\alpha+k-2}}{2\pi}$, M is the modulation order, $\bar{r}$ is average electrical SNR. And when F=1,Eq.(3) can be described as the SIMO system average BER under EGC.

B. Maximum Ratio Combination

MRC combines the received independent and uncorrelated diversity signals from L different paths by selecting appropriate weighting coefficients. The expression of the system average BER under the MRC is:

$$\begin{aligned} BER(M) =& \frac{g^2 A}{12\log_2 M}\prod_{f=1}^{F}\prod_{l=1}^{L}\sum_{k=1}^{\beta} a_k D\cdot G_{6,3}^{1,6}\left(\frac{16A_0^2 C}{FLB^2}\middle|\begin{matrix}\frac{1-g^2}{2},\frac{2-g^2}{2},\frac{1-\alpha}{2},\frac{2-\alpha}{2},\frac{1-k}{2},\frac{2-k}{2}\\ 0,-\frac{g^2}{2},\frac{1-g^2}{2}\end{matrix}\right) \\ &+\frac{g^2 A}{4\log_2 M}\prod_{f=1}^{F}\prod_{l=1}^{L}\sum_{k=1}^{\beta} a_k D\cdot G_{6,3}^{1,6}\left(\frac{64A_0^2 C}{3FLB^2}\middle|\begin{matrix}\frac{1-g^2}{2},\frac{2-g^2}{2},\frac{1-\alpha}{2},\frac{2-\alpha}{2},\frac{1-k}{2},\frac{2-k}{2}\\ 0,-\frac{g^2}{2},\frac{1-g^2}{2}\end{matrix}\right)\end{aligned} \tag{4}$$

When F=1, it can be described as the SIMO system average BER under MRC.

C. Select Combining

Only the branch with the highest output strength or signal-to-noise ratio(SNR) of the received diversity signal is selected for selective merging, and other diversity branch signals are discarded. Therefore, the weighted coefficient of SC is only 1 for one branch and 0 for the other branches. Then the expression of the average BER is

$$BER(M) = \frac{L}{\log_2 M}\int_0^{\infty} f_{I_l}(I_{SC})F_{I_l}(I_{SC})^{L-1} erfc\left(\sin\frac{\pi}{M}\sqrt{\frac{\bar{r}}{L}}I_{SC}\right)dI_{SC} \tag{5}$$

where $F_{I_l}(I_j) = \frac{g^2 A}{2}\sum_{k=1}^{\beta} a_k\left(\frac{\alpha\beta}{\gamma\beta+\Omega'}\right)^{-\frac{\alpha+k}{2}} G_{2,4}^{3,1}\left(\frac{\alpha\beta}{\gamma\beta+\Omega'}\times\frac{I_j}{A_0}\middle|\begin{matrix}1,g^2+1\\ g^2,\alpha,k,0\end{matrix}\right)$

V . RESULTS

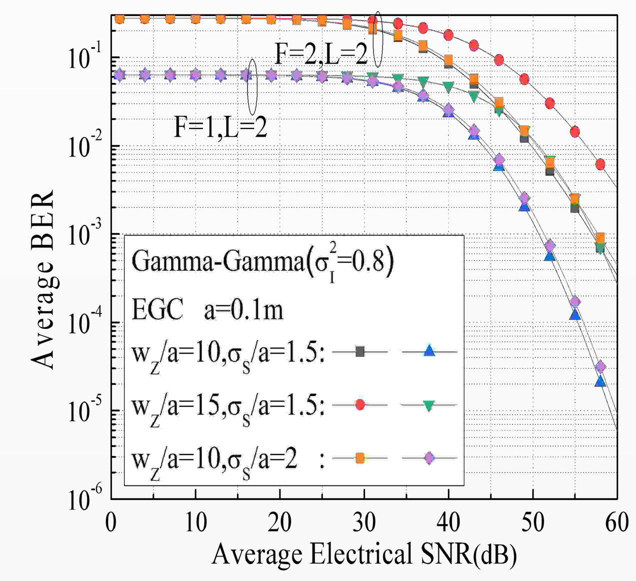

Fig.1 Effect of and on average BER(EGC)

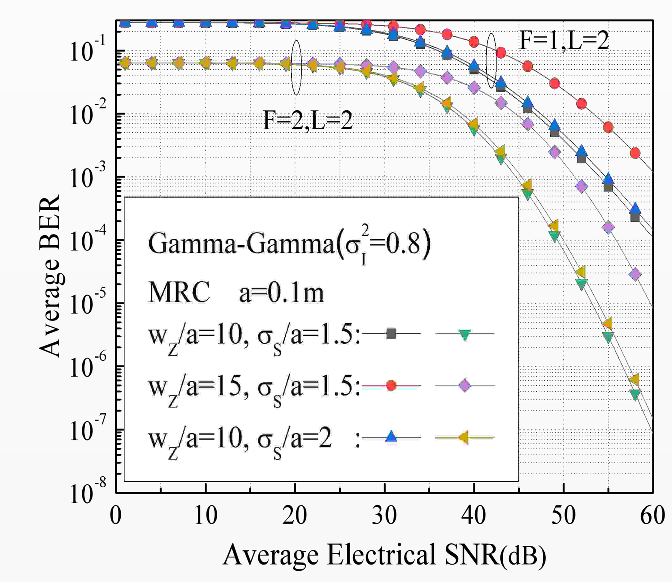

Fig.2 Effect of and on average BER(MRC)

In Fig.1 and Fig.2, it can be seen that the average BER performance degradates with the increasing of the ratio w_z/a and σ_s/a .As can be seen from Figure, increasing the transmitting/receiving aperture can effectively suppress the influence of jitter deviation or beam waist radius on BER. It is also found that the effect of jitter deviation on the performance degradation of average BER is greater than the waist radius of beam.

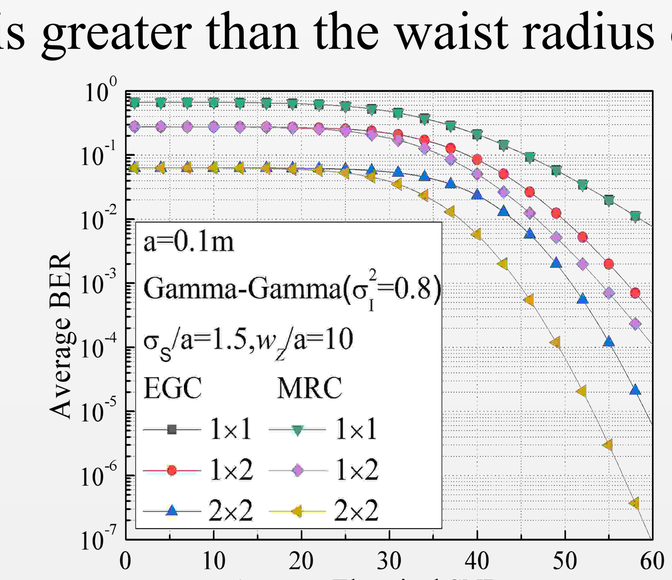

Fig.3. Influence of transmit / receive aperture on average BER

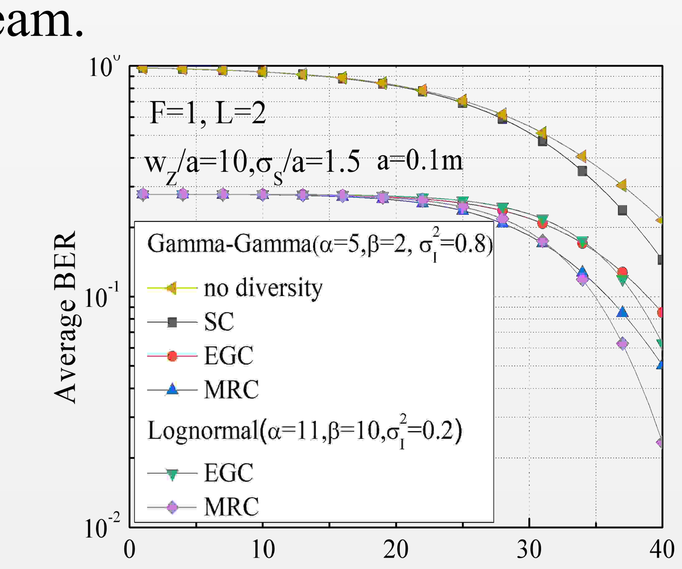

Fig.4 Average BER of three merging modes

In Fig.3, It shows that the average BER performance is greatly affected by atmospheric turbulence and pointing errors when SNR is small. When the number of aperture is fixed, the SNR needed to improve the BER of MRC system is smaller than that of EGC system. Fig.4 shows the MRC has the best BER performance under the same turbulence intensity scenario. And when SNR is less than 25dB, the average BER performance of SC is similar to no diversity, and worse than other combining methods.

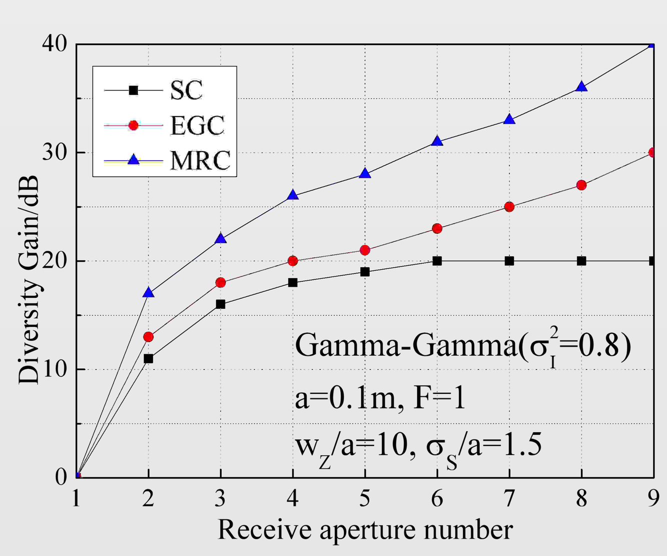

Fig.5 diversity gain of three merging methods

In Fig.5,when the average BER is 10^{-4},the improvement of SNR is the diversity gain compared with the case of diversity combining and no diversity. When the number of receiving apertures increase, the diversity gain of MRC increases rapidly. MRC can obtain about 6dB gain compared with EGC and 7dB gain compared with SC at L=4.

VI. CONCLUSIONS

In this paper, the average BER asymptotic expressions for MIMO system with three combing methods are derived under the joint influence of Malaga turbulence and pointing error. The performance of MIMO system with different diversity combining modes is disscussed for different turbulence intensity, beam waist radius, jitter deviation and aperture number. When $\sigma_s/a = 1.5$ and $w_z/a = 10$, the average BER performance is the best. For the three merging methods, MRC system has the best performance of average BER and diversity gain, while SC system has the worst performance. The increase of the number of apertures can effectively restrain the influence of turbulence and pointing errors on the system performance.