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Performance Analysis of Free Space Communication System for Gamma–Gamma Turbulence

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***Abstract*---In this paper, we presented the ergodic capacity of free space optical communication systems over Gamma-Gamma atmospheric turbulence fading channels with perfect channel state information for the developed system. The intensity fluctuations of the received optical signal are accounted for Gamma-Gamma atmospheric turbulence. A closed-form expression for the average capacity of the heterodyne differential phase shift keying for free-space optical (FSO) communication systems over gamma-gamma turbulence channel is derived.**

***Keywords*---**Free Space Optical, Pulse Amplitude Modulation, Signal to Noise Ratio, Probability Density Function.

I. INTRODUCTION

Optical wireless communications using intensity modulation and direct detection could provide high-speed links for a various applications, providing an unregulated spectral segment with high security. Here, the transmit power ought to be constrained by power consumption concerns and eye-safety considerations [1]. In addition, these systems are intrinsically bandwidth limited due to the use of large inexpensive optoelectronic components. In last few years, the use of atmospheric free-space optical (FSO) transmission is being specially interesting to solve the bandwidth problem, above all in densely populated urban areas, as well as a supplement to radio-frequency links and the recent development of radio on free-space optical links. Though, atmospheric turbulence produces fluctuations in the irradiance of the transmitted optical beam, which is recognized as atmospheric scintillation, severely degrading the link performance.

An upper bound on the capacity of the indoor optical wireless channel was determined in for the specific case of multicarrier systems where the average optical amplitude in each disjoint symbol interval is fixed. By contrast, to determine an upper bound by not assuming a particular signalling set and allowing for the average optical amplitude of each symbol to vary. The upper bound is improved at low signal-to-noise ratio for IM/DD channels with pulse amplitude modulation [2]. A new closed-form upper bound on the capacity is found through a sphere-packing argument for channels using equiprobable binary pulse amplitude modulation (PAM) and subject to an average optical power constraint, presenting a tighter performance at lower optical signal-to-noise ratio (SNR) if compared with. Recently, using a dual expression for channel capacity introduced [3]. have derived new upper bounds on the capacity of the indoor optical wireless channel when the input is constrained in both its average and its peak power. In the analysis of the capacity of the atmospheric FSO channel, Numerical results for the capacity of gamma-gamma atmospheric turbulence channels using on-off keying (OOK) formats are presented by maximizing the mutual information for this channel over a binomial input distribution. The capacity of log-normal optical wireless channel with OOK formats is computed for known channel state information (CSI).

II. THE GAMMA–GAMMA TURBULENCE MODEL

This model is based on the modulation process where the fluctuation of light radiation traversing a turbulent atmosphere is assumed to consist of small-scale (scattering) and large-scale (refraction) effects [5]. The former includes contributions due to eddies/cells smaller than the Fresnel zone $R_F = (L_p / k)^{1/2}$ or the coherence radius ρ_0, whichever is smaller Large-scale fluctuations on the other hand are generated by the turbulent eddies larger than that of

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the first Fresnel zone or the scattering disk $L/k\rho_0$, whichever is larger. The small-scale eddies are assumed to be modulated by the large-scale eddies. Consequently, the normalized received irradiance *I* is defined as the product of two statistically independent random processes I_x and I_y.

$$I = I_x I_y \qquad [1]$$

Ix and *Iy* arise from the large-scale and small-scale turbulent eddies, respectively, and are both proposed to obey the gamma distribution[4]. Their pdfs are thus given by

$$p(I_x) = \frac{\alpha(\alpha I_s)^{\alpha-1}}{\Gamma(\alpha)} exp(-\alpha I_x)$$

$$I_x > 0; \qquad \alpha > 0 \qquad [2]$$

$$p(I_y) = \frac{\beta(\beta I_y)^{\beta-1}}{\Gamma(\beta)} exp(-\beta I_y)$$

$$I_y > 0; \quad \beta > 0 \qquad [3]$$

By fixing I_x and using the change of variable, $I_y = I/I_x$, the conditional pdf given by Equation 4 is obtained in which *Ix* is the (conditional) mean value of *I*.

$$p(I/I_x) = \frac{\beta(\beta I/I_x)^{\beta-1}}{I_x\Gamma(\beta)} exp\left(\frac{-\beta I}{I_x}\right) I > 0 \qquad [4]$$

To obtain the unconditional irradiance distribution, the conditional probability $p(I/I_x)$ is averaged over the statistical distribution of I_x given by Equation 2 to obtain the following gamma–gamma irradiance distribution function [6]

$$p(I) = \int_0^\infty p(I/I_x)p(I_x)dI_x \qquad [5]$$

$$= \frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} I^{(\alpha+\beta/2)-1} K_{\alpha-\beta}\left(2\sqrt{\alpha\beta I}\right) \qquad I > 0$$

where α and β, respectively, represent the effective number of large- and small-scale eddies of the scattering process *Kn*(·) is the modified Bessel function of the 2nd kind of order *n*, and Γ(·) represents the gamma function [5]. If the optical radiation at the receiver is assumed to be a plane wave, then the two parameters α and β that characterize the irradiance fluctuation pdf are related to the atmospheric conditions by [7].

$$\alpha = \left[exp\left(\frac{0.49\sigma_l^2}{\left(1+1.11\sigma_l^{12/5}\right)^{7/6}} \right) - 1 \right]^{-1} \qquad [6]$$

$$\beta = \left[exp\left(\frac{0.51\sigma_l^2}{\left(1+0.69\sigma_l^{12/5}\right)^{5/6}} \right) - 1 \right]^{-1} \qquad [7]$$

While the *S.I.* is given by

$$\sigma_N^2 = exp\left[\frac{0.49\sigma_l^2}{\left(1+1.11\sigma_l^{12/5}\right)^{7/6}} + \frac{0.51\sigma_l^2}{\left(1+0.69\sigma_l^{12/5}\right)^{5/6}} \right] - 1 \qquad [8]$$

III. RESULTS AND DISCUSSIONS

A plot of this distribution, shown in figure.1 is for three different turbulence regimes, namely weak, moderate and strong. The plot shows that as the turbulence increases from the weak to strong regime, the distribution spreads out more, with an increase in the range of possible values of the irradiance.

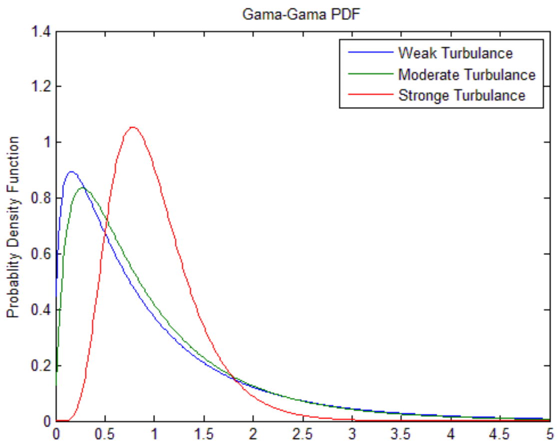

Fig. 1 Gamma–gamma pdf for three different turbulence regimes, namely weak, moderate and strong

The gamma–gamma turbulence in the given model is valid for all turbulence scenarios from weak to strong and the values of α and β at any given regime can be obtained from Equations 6 and 7. Figure 2 shows the variation of *S.I.* as a function of the Rytov parameter based on Equation 8 this graph shows that as the Rytov parameter increases, the *S.I* approaches a maximum value greater than 1, and then approaches unity as the turbulence-induced fading approaches the saturation regime The values of α and β under different turbulence regimes are depicted in Figure 3.

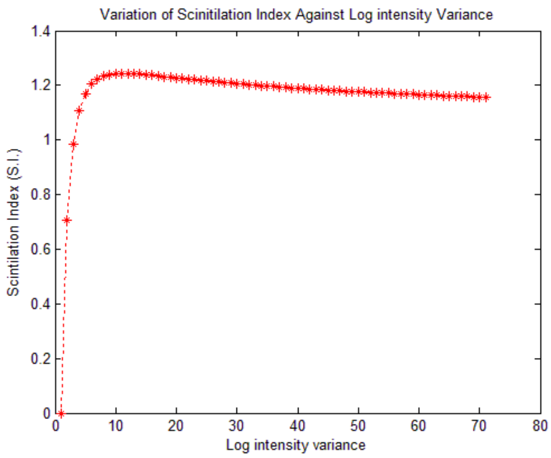

Fig. 2 *S.I.* against log intensity variance for $C_n^2 = 10^{-15}$ m$^{-2/3}$ and λ = 850 nm

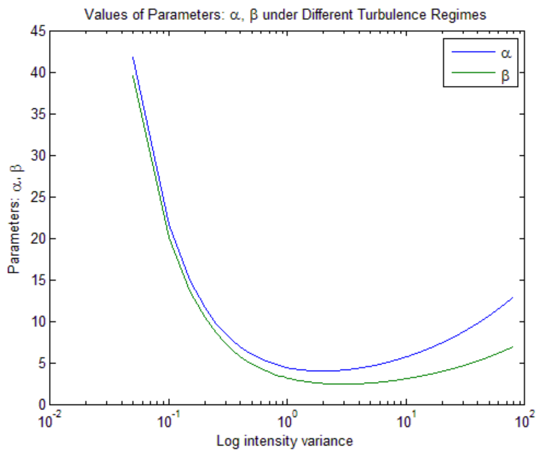

Fig. 3 Values of α and β under different turbulence regimes: weak, moderate to strong and saturation.

In the very weak turbulence regime, $\alpha >> 1$ and $\beta >> 1$ as shown in Figure 3, this means that the effective numbers of small and large-scale eddies are very large But, as the irradiance fluctuations increase and the focusing regime is approached, where α and β then decrease substantially as illustrated in Figure 3. Beyond the focusing (moderate-to-strong) regime and approaching the saturation regime, β → 1 The implication of this according to, is that the effective number of small scale cells/eddies ultimately reduces to a value determined by the transverse spatial coherence radius of the optical wave. On the other hand, the effective number of discrete refractive scatterers α increases again with increasing turbulence and eventually becomes unbounded in the saturation regime as shown in Figure 3. Under these conditions, the gamma–gamma distribution approaches the negative exponential distribution below.

IV. CONCLUSION

The gamma–gamma turbulence in the given model is valid for all turbulence scenarios from weak to strong and the values of α and β at any given is presented. Results shows that the effective numbers of small and large-scale eddies are very large. But, as the irradiance fluctuations increase and the focusing regime is approached, where α and β then decrease substantially and the intensity fluctuations of the received optical signal are accounted for Gamma-Gamma atmospheric turbulence.

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