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Performance Analysis of a Free-Space Optical Code Division Multiple Access through Atmospheric Turbulence Channel

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***Abstract*—**In this paper, the effect of atmospheric turbulence on bit error probability in free-space optical CDMA scheme with Sequence Inverse Keyed (SIK) optical correlator receiver is analyzed. Here Intensity Modulation scheme is considered for transmission. The turbulence induced fading is described by the newly introduced gamma-gamma pdf[1] as a tractable mathematical model for atmospheric turbulence. Results are evaluated with Gold and Kasami code & it is shown that Gold sequence can be used for more efficient transmission than Kasami sequence in an atmospheric turbulence channel.

***Keywords*—**CDMA, gamma-gamma pdf, atmospheric turbulence, Kasami, Gold, SIK, BER, Power Penalty, FSO.

I. Introduction

IN terms of asynchronous access, privacy, large bandwidth potential and security consideration, optical code division multiple-access technique has received much popularity in fiber optic communication. In order to replete the gap between the end user and fiber optic infrastructure,[2] free space optical (FSO) communication technology is introduced. FSO is a powerful and potential branch of optical communication of modern age. In FSO, communication, optical transceivers communicate directly through the air to form point-to-point line-of-sight (LOS) links. One major impediment of FSO communication is the atmospheric turbulence. It occurs due to the variations in the refractive index due to inhomogeneities in temperature and pressure fluctuations. Atmospheric turbulence has been studied extensively and various theoretical models have been proposed to describe turbulence-induced image degradation and intensity fluctuations (i.e. channel fading). In this paper, an analytical formulation is presented to study the effect of atmospheric turbulence on bit error rate (BER) performance in optical CDMA scheme along with 512 chip length and different code (i.e, Kasami & Gold sequence).

II. System Model

It is considered that at the transmitter a sequence of unit amplitude rectangular data bits each of duration T, denoted as B(t), is used to sequence inverse key A(t),where A(t) is a periodic sequence of N unit amplitude, rectangular chips of duration T_c and $N=T/T_c$, such that either the a sequence A(t) or its complement A'(t) is transmitted for 1 or 0 data bits

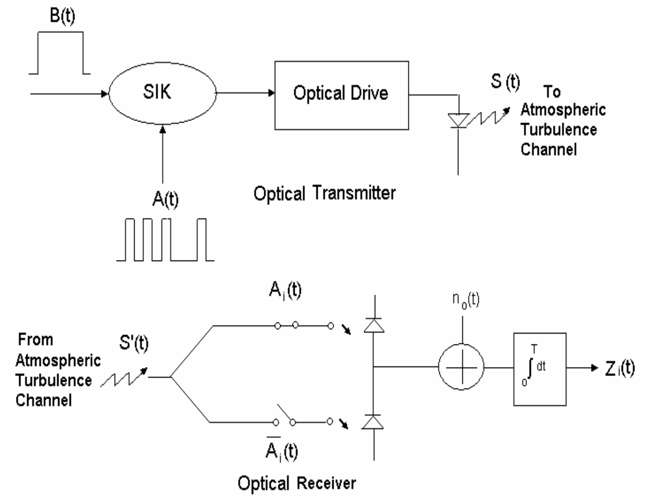

Fig. 1 Schematic block diagram for an optical CDMA transmission system with Sequence Inversed Keyed (SIK) optical correlator receiver

respectively. Then power transmitted [3],

$$S(t)=\sum_{k=1}^{K}\sum_{l=0}^{N-1} 2P_t B_k(t)\otimes A_k(t-lT_c) \quad (1)$$

Where P_t is the peak incident chip optical power for K'th user at the transmitter output, I is the chip delay. K is the number of simultaneous user and $\otimes$ operator denotes the SIK modulation such that either the sequence A(t) or its complement A'(t) is transmitted for 1 or 0.

At the receiving end, the signal is received by optical correalator receiver. The output of the correlator matched to I'th user is given by[2],

$$Zi(t) = \frac{RP_r}{2}\int_0^T \sum_{k=1}^{K}\sum_{l=0}^{N-1} B_k(t)Sout_k(t)\otimes A_k(t-lT_c)\{A_i(t-lT_c) - \overline{A_i(t-lT_c)}\}dt + \int_0^T n_0(t)dt \quad (2)$$

Since $a_i(.)=\{A_i(.)-\overline{A_i}(.)\}$ and $B_k(.)*A_k(.)=\{1+b_k(.)a\}/2_k(.)$ and $S_{out}(.)=s_{out}(.)$, where ai(.),$b_k(.)$ and $s_{out}(.)$ are bipolar forms of $A_i(.)$, $B_k(.)$, $S_{out}(.)$ respectively.

Then the equation is reduced to,

$$Zi(t) = \frac{RP_R}{2}\int_0^{Tb}\sum_{k=1}^{k=K}\sum_{l=0}^{N-1}\frac{1+b_k(t-lTc)a_k(t-lTc)}{2}$$

$$* Sout_k(t-lT_C)a_i(t-lT_C)\}dt + \int_0^{T_B} n_0(t)dt$$

$$= \frac{RP_r}{4}\int_0^{Tb}\sum_{l=0}^{N-1}\{Sout_i(t-lT_c)a_i(t-lT_C)\}dt$$

$$+ \frac{RP_R}{4}\int_0^{Tb}\sum_{l=0}^{N-1}\{Sout_i(t-lT_c)dt$$

$$+ \frac{RP_R}{4}\int_0^{T_b}\sum_{\substack{k\neq i\\k=1}}^{K}\sum_{l=0}^{N-1}\{b_k(t-lTc)Sout_k(t-lT_C)$$

$$\times a_i(t-lT_C)a_k(t-lT_C)\}dt$$

$$+ \int_0^{T_b} n_0(t)dt \qquad (3)$$

The first term in this equation is the offset effect which is removed by using balanced signature sequence. The second and third term in the equation are the phase autocorrelation and multiple access interference(MAI), respectively,

The mean of Z'(t) is given as,

$$U = \frac{RP_r}{4Tb}\int_0^{Tb}\sum_{l=0}^{N-1}Sout_i(t-lT_c)dt \qquad (4)$$

The variance of noise, n_0 is given by

$$N_0 = N_{th} + N_{sh} \qquad (5)$$

N_{th} is the receiver thermal noise which is given by,

$$N_{th} = 4kTB_rR_L \qquad (6)$$

and N_{sh} is the Photodetector shot noise which is given by,

$$N_{sh} = \frac{2qRKP_R}{4T} \qquad (7)$$

where,

k= Boltzmann constant.
T= Receiver temperature(K)
B_r= Receiver bandwidth=1/T.
R_L= Load Resistance of the receiver

K= number of simultaneous user
q= electron charge (1.6e-19)

The signal to noise ratio of the correlator output can be obtained as

$$SNR = \frac{U^2}{MAI + N_0} \qquad (8)$$

Hence Bit Error Rate of OCDMA transmission system is then given by[3]

$$BER = \frac{1}{2}erfc(\frac{\sqrt{SNR}}{\sqrt{2}}) \qquad (9)$$

Here Bit error rate is calculated with 512 chip Gold and Kasami code.

III. Atmospheric Turbulence Channel Model

To represent the FSO channel, it is very important to represent the scintillation. Several probability density functions have been proposed for the intensity variation of the receiver of the optical link. Most prominent among the model is Raleigh model, log-normal model, gamma-gamma model etc. In gamma-gamma model the irradiance of the received optical wave is modeled as a product $I=I_xI_y$. Where I_x arises from large scale turbulent eddies and I_y from small scale eddies. Specifically, gamma-gamma pdf is used to model both small and large scale fluctuations. The influence of atmospheric turbulence channel described by gamma-gamma pdf [1],

$$f(I) = \frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)}I^{(\frac{\alpha+\beta}{2})-1}K_{(\alpha-\beta)}(2\sqrt{(\alpha\beta)I} \qquad (10)$$

Where, I is the signal intensity $\Gamma(.)$ is tha gamma function, and $K_{\alpha-\beta}$ is the modified Bessel function of the second kind of order $\alpha-\beta$. Here α and β are the effective number of small and large scale eddies of the scattering environment. These parameters can be directly related to atmospheric conditions according to [1],

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

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

and the power affected by turbulence pdf is given by,

$$P_s = \int P_{s|I}\, f_I(\bar{I})dI \qquad (11)$$

The gamma-gamma model approaches for heavy turbulence the exponential distribution, whereas in less turbulence it is suitably approximated by a log-normal distribution[1].

IV. RESULTS AND DISCUSSIONS

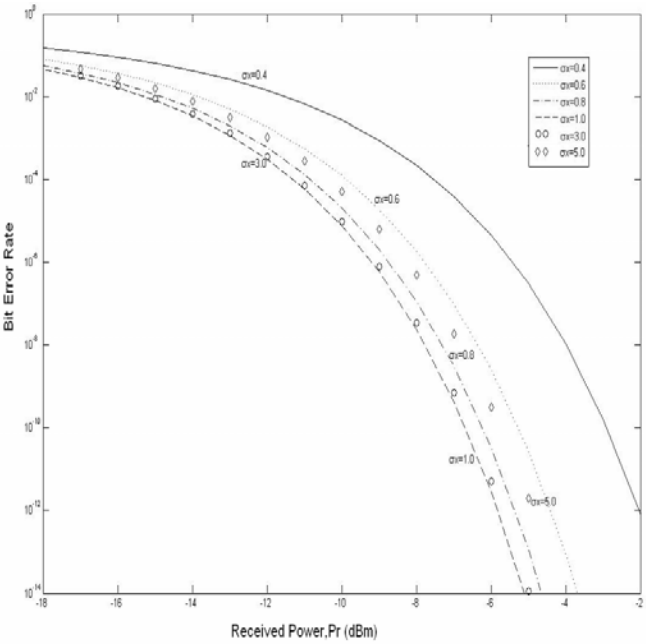

Fig. 2 Bit Error Rate vs Received Power for different σ_x with no Multiple Access Interference (MAI)

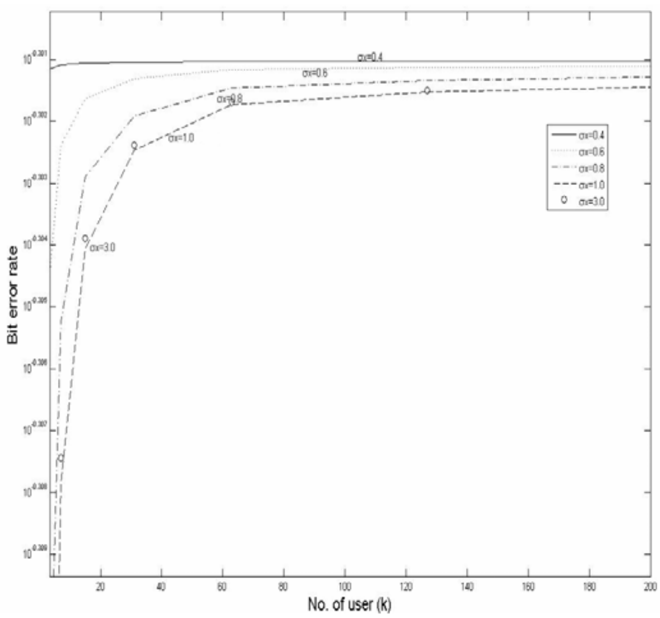

Fig. 3 Bit error rate vs No. of Users using Kasami Sequence with sequence length 512

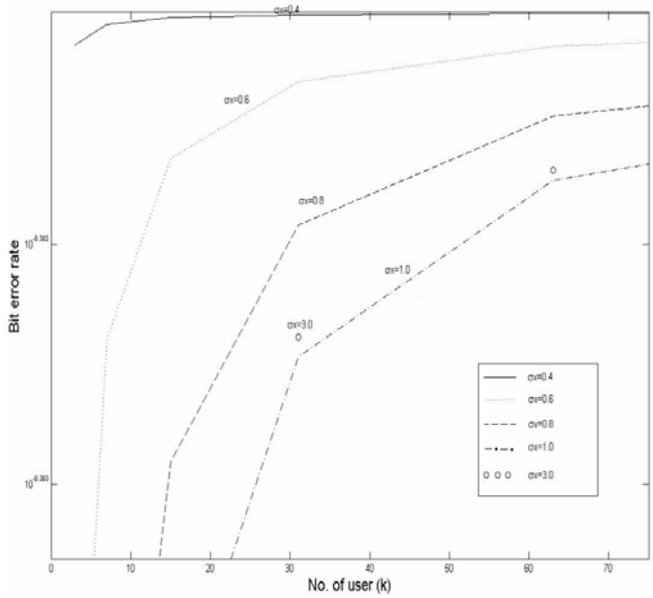

Fig. 4 Bit error rate vs No. of Users using Gold Sequence with sequence length 512

In this analysis the Bit error rate vs Received power is represented for different σ_x .Bit Error Rate vs No. of users using Kasami and Gold sequences are shown in Fig. 3 and Fig. 4 respectively. It is observed that Kasami sequence exhibits more Bit Error Rate than Gold Sequence for a given number of user.

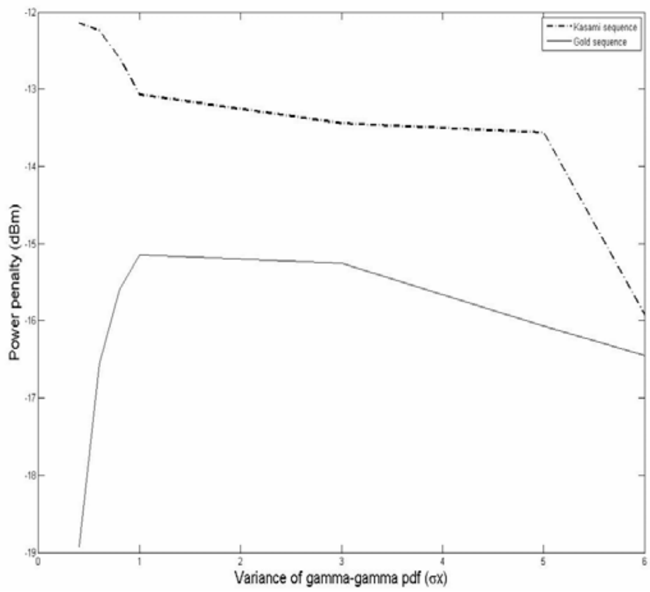

Fig. 5 Power penalty vs σ_x for Gold and Kasami sequence

Fig. 5 shows the power penalty vs σ_x for both Kasami and Gold sequences for a particular Bit Error Rate (10^{-3}).It can be inferred from the analysis that for a desired Bit Error Rate signal can be transmitted at a lower power using Gold sequence than Kasami sequence in an Atmospheric Turbulence channel.

V. CONCLUSION

Here, the performance of a free space optical CDMA system influenced by atmospheric turbulence is evaluated. Gold sequence provides relatively efficient transmission than Kasami sequence in such kind of channel.

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