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# TRANSCEIVER DESIGN AND PERFORMANCE ANALYSIS OF FREE-SPACE OPTICAL COMMUNICATION

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## ABSTRACT

In free-space optical communication links, atmospheric turbulence causes fluctuations in both the intensity and the phase of received light signal, impairing link performance. In this paper, we describe several communication techniques to mitigate turbulence-induced intensity fluctuations, that is signal fading. These techniques are applicable in the regime in which the receiver aperture is smaller than the correlation length of the fading and the observation interval is shorter than the correlation time of fading. We assume that the receiver has no knowledge of the instantaneous fading state. When the receiver knows only the marginal statistics of the fading, a symbol-by-symbol Ml detector can be used to improve the detection performance. If the receiver has knowledge of the joint temporal statistics of fading, maximum- likelihood sequence detection (MLSD) can be employed, yielding a further performance improvement, but at the cost very high complexity

**Keywords-***Atmospheric Turbulence, Free-Space Optical Communication, MLSD, Spatial Diversity Reception.*

## 1. INTRODUCTION

Free space optical communication has attracted considerable attention recently for a variety of applications [1]-[4]. Because of the complexity associated with phase or frequency modulation, current free-space optical communication systems typically use intensity modulation with direct detection (IM/DD). Atmospheric turbulence can degrade performance of FSO links, particularly over ranges of the order of 1km or longer than that. In homogeneities in the temperature and pressure of the atmosphere lead to variations of the refractive index along the transmission path. These indexes in homogeneities can deteriorate the quality of received image and can cause fluctuations in both the intensity and phase of received signal. These fluctuations can lead to an increase in the link error probability, limiting the performance of communication systems. Atmospheric turbulence has been studied extensively and various theoretical models have been proposed to describe turbulence- induced image degradation and intensity fluctuations which are signal fading [7]-[13]. Two useful parameters describing turbulence-induced fading are the correlation length of intensity fluctuations and, the correlation time of intensity fluctuations. When the receiver aperture can be made larger than the related correlation length then turbulence-induced fading can be reduced substantially by aperture averaging [13]. FSO is an optical communication technology that uses light propagation in free space to transmit data for telecommunications or computer networking. Free space means air, outer space, vacuum, or something similar. This contrasts with using solids such as optical fiber cable or an optical transmission line. The technology is useful where the physical connections are impractical because of high costs or other considerations.

## 2. MODELING OF ATHMOSPHERE TURBULENCE:

Atmospheric turbulence can be physically described by Kolmogorov theory [6]-[9].the energy is large eddies is redistributed without loss to eddies of decreasing size until finally dissipated by viscosity. The size of turbulence eddies normally ranges from a few more millimetres to a few meters, denoted as the inner scale lo and the outer scale, respectively. We can express the refractive index as

$$n(\bar{r},t) = n_0 + n_1(\bar{r},t) \qquad (1)$$

Where no is the average index and n1 is the fluctuation component induced by spatial variations of temperature and pressure in the atmosphere. The correlation function of n1 is defined as

$$\lceil n_1(\overline{r_1}, t_t; \overline{r_2}, t_2) = E[n_1(\overline{r_1}, t_1).(\overline{r_2}, t_2)]$$

(2)

## B. Spatial and Temporal Coherence of the Optical Signals through Turbulence

To describe spatial coherence of optical waves, so called mutual coherence function is widely used [7]

$$\big[(P_1, t_1; P_2, t_2)] = \mathrm{E}[u(P_1, t_1).u^*(P_2, t_2)]\big] \quad (3)$$

Where u (P,t) is the complex optical field, setting in $t_1 = t_2$ in (4). We obtain the spatial MCF $\lceil(\overline{r_1}, \overline{r_2})$. The rytov method is frequently used to expand the field u($\bar{r}$):

$$u(\bar{r}) = A_0(\bar{r}).exp[i\varphi_0(\bar{r})] = u_0(\bar{r}).exp(\varphi_1)$$

(4)

Where $u_0(\bar{r})$ is the field amplitude without air turbulence:

$$u_0(\bar{r}) = A_0(\bar{r}).exp[i\varphi_0(\bar{r})]$$

(5)

Exponent of the perturbation factor is:

$$\varphi_1 = \log\left[\frac{A(\bar{r})}{A_0(\bar{r})}\right] + i[\varphi(\bar{r}) - \varphi_0(\bar{r})] = X + iS$$

(6)

Where X is the log amplitude function and S is phase function. We assume X and S be homogenous,

Isotropic and independent Gaussian random variables. This assumption is valid for long propagation distances through turbulence.

In order to characterise turbulence induced fluctuations of the log amplitude X, we use the log amplitude covariance function:

$$B_x(P_1; P_2) = E[X(P_1)X(P_2)] - E[X(P_1)], [X(P_2)]. \quad (7)$$

Since the random distribution is Gaussian distributed under the assumption of weak turbulence, we can use the rytov method to derive the normalized log amplitude covariance function for two positions in receiving plane perpendicular to the direction of propagation.

Since the random distribution is Gaussian-distributed under the assumption of weak turbulence, we can use the rytov method to derive the normalized log-amplitude covariance function for two positions in a receiving plane perpendicular to the direction of propagation.

$$b_X(d_{12}) = \frac{B_X(P_1, P_2)}{B_X(P_1, P_1)} \quad (8)$$

Where $d_{12}$ is the distance between $P_1$and $P_2$. We define the correlation length of intensity fluctuations, $d_0$, such that $b_X(d_0) = e^{-2}$. When the propagation path length L satisfies the condition $l_0 < \sqrt{\lambda \mathrm{L}} < L_0$ , where λ is the wavelength and $l_0$ and $L_0$ are inner and outer length scales, respectively, $d_0$ can be approximated by [13]

$$d_0 \approx \sqrt{\lambda \mathrm{L}}$$

## C. Probability Distributions of Turbulence-Induced Intensity Fading:

As discussed previously, when the propagation distance is long, log-amplitude fluctuations can become significant. In this section, we will derive the statistical properties of the log-amplitude fluctuations, which we refer to as “intensity fading” or simply “fading.” The marginal distribution of fading is derived while the joint spatial and temporal distribution of fading are derived.

**1) Marginal Distribution of Fading***:* In this section, we derive the marginal distribution of fading at a single point in space at a single instant in time. The marginal distribution is used in symbol-by-symbol ML detection. For propagation distances less than a few kilometres, variations of the log-amplitude are typically much smaller than variations of the phase. Over longer propagation distances, where turbulence becomes more severe, the variation of the log-amplitude can become comparable to that of the phase. Based on the atmosphere turbulence model adopted here and assuming weak turbulence, we can obtain the approximate analytic expression for the covariance of the log-amplitude fluctuation of plane and spherical waves [9]:

$$\sigma_X^2|plane = 0.56(\frac{2\pi f}{v})^{7/6} \int_0^L C_n^2\,(x)(L-x)^{5/6}dx$$

## 2) Joint Spatial and Temporal Distributions of Fading:

In this section, we derive the joint spatial and temporal distributions of fading. The joint spatial distribution describes the fading at multiple points in space at a single instant of time and is used in evaluating the performance of spatial diversity reception. The joint temporal distribution describes the fading at a single point in space at multiple instants of time. This distribution is the basis for the MLSD We assume that the log-amplitude at receivers is described by a joint Gaussian distribution. The auto-covariance matrix of the log-amplitude at receivers in a plane transverse to the direction of propagation is given by

$$C_X = \begin{bmatrix} \sigma_X^2 & \cdots & \sigma_X^2 b_X(d_{1n}) \\ \vdots & \ddots & \vdots \\ \sigma_X^2 b_X(d_{n1}) & \cdots & \sigma_X^2 \end{bmatrix}_{n\times n}$$

## 3. ML DETECTION OF ON-OFF KEYING IN TURBULENCE CHANNELS:

In this paper, we consider intensity modulation/direct detection (IM/DD) links using on-off keying (OOK). In most practical systems, the receiver signal-to-noise ratio (SNR) is limited by shot noise caused by ambient light much stronger than the desired signal and/or by thermal noise in the electronics following the photo detector. In this case, the noise can usually be modelled to high accuracy as additive, white Gaussian noise that is statistically independent of the desired signal. Let denote the bit interval of the OOK system and assume that the receiver integrates the received photocurrent for an interval during each bit interval. At the end of the integration interval, the resulting electrical signal can be expressed as:

$$r_e = n(I_s + I_b) + n$$

(10)

$$\sigma_X^2|spherical = 0.56(\frac{2\pi f}{v})^{7/6} \int_0^L C_n^2\,(x)\left(\frac{x}{L}\right)^{\frac{5}{6}}(L-x)^{5/6}dx$$

(9)

## 4. SPATIAL DIVERSITY RECEPTION:

Spatial diversity reception, which has been well-studied for application at radio and microwave frequencies, which has the potential to mitigate the degradation caused by atmospheric turbulence [10]-[12] and [14]-[15]. Spatial diversity reception in FSO communication has been proposed and studied in [14] and [15]. One of the scientists named Ibrahim [14] has been studied the performance of spatial-diversity optical reception on turbulence channels, assuming that turbulence-induced fading is uncorrelated at each of the optical receivers. In order for this assumption to hold true, then the spacing between receivers should exceed the fading correlation length in the plane of receivers, it may be difficult to satisfy this assumptions in practical, for various reasons. Available space may not be permit sufficient receiver spacing. In power-limited links, which often employ well-collimated beams, then the receiver spacing required for uncorrelated fading may exceed the beam diameter.

## 5. PROPOSED TRANSMITS DIVERSITY SCHEME:

The use of optical arrays, similar to the use of antenna-array technology for microwave system, is considered as the means of combatting fading. Specifically, we adopt a multiple- input-signal-output (MISO) array based on laser sources, assumed to be intensity-modulated only and all pointed towards distant photo detector assumed to be ideal receiver of noncoherent (direct-detection). The sources and the detector are physically situated so that all transmitters are simultaneously observed by the receiver. The fading experienced between source-detector pairs is assumed to be statistically independent. As we presented in [16], assuming transmission matrices based on real orthogonal; designs for full rate and full diversity space-time block codes, our MISO system model implies the diversity of order, so given that the conditional bit-error rate (BER) is given as

$$P_b(E|\{I_j\}_{1<j<L}) = Q\left(\sqrt{\frac{\left(\frac{d}{L}\right)^2}{2N_0}\sum_{j=1}^{L} I_j^2}\right)$$

(11)

Where Q(.) is the Gaussian- Q function. Here, the division by is considered so as to maintain the average optical power in the air at a constant level of being transmitted by each laser then an average optical power of a source alternative to this transmit diversity scheme is repetition coding where the same signal is simultaneously transmitted from different laser sources so then the conditional BER is given by

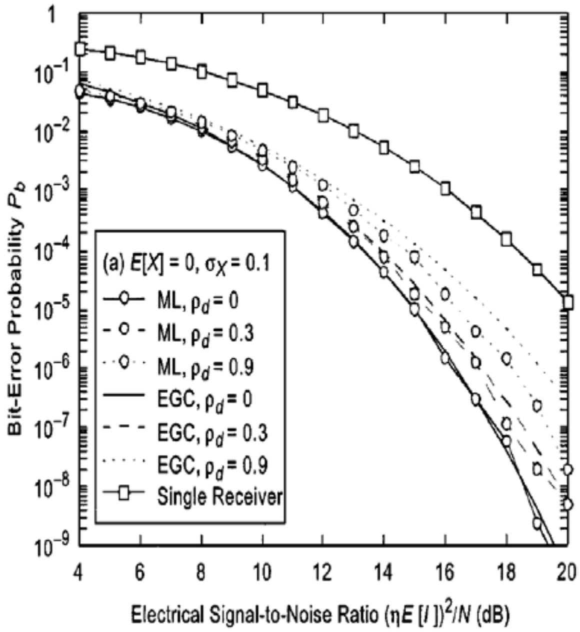

*Fig (A)*

$$P_b(E|\{I_j\}_{1<j<L}) = Q\left(\sqrt{\frac{\left(\frac{d}{L}\right)^2}{2N_0}}\sqrt{\left(\sum_{j=1}^{L} I_j\right)^2}\right)$$

(12)

## 6. RESULTS:

The ML detection schemes over turbulence channels are studied based on the statistical distributions of turbulence-induced fading. If the instantaneous fading state is unknown but the marginal fading statistics are known, we can apply

ML symbol-by-symbol detection to improve detection efficiency. If the temporal correlation of fading is known, i.e., the joint temporal distribution of turbulence-induced fading, we can apply MLSD, leading to a further improvement in detection performance.

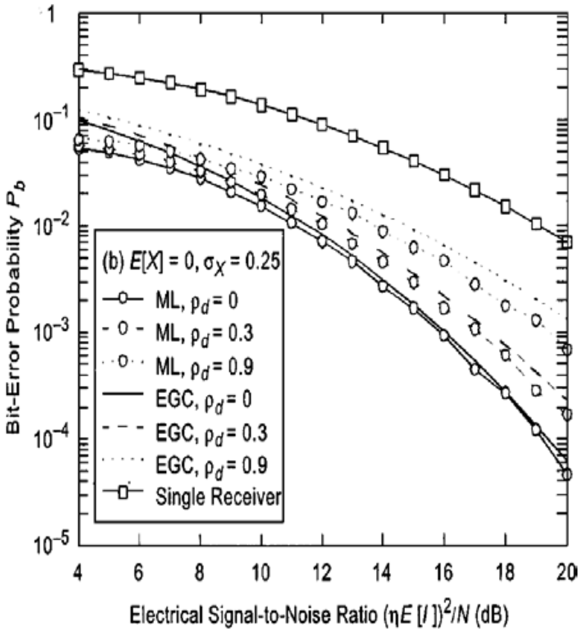

*Fig (b)*

Figure (a) and (b) shows that Bit-error probability of dual-branch receiver versus average electrical signal-to-noise ratio using maximum-likelihood detection (lines with circles) and equal-gain combining (lines without symbols) for different values of $\rho_d$ , the normalized correlation between the two receivers. The line with squares represents the bit-error probability using a single receiver. The turbulence induced $\sigma_X$=0.1 in fig (a) and $\sigma_X$=0.25 in (b) this fading has mean E[X] = 0.

## 7. CONCLUSION:

The ML detection schemes over turbulence channels are studied based on statistical distributions of turbulence-induced fading. If the instantaneous fading state is unknown but we know the marginal fading statistics, we can apply ML symbol-by-symbol detection to improve detection efficiency. If the temporal correlation of fading is known that is, the joint temporal distribution of turbulence-induced fading, we can also apply MLSD, leading to a further improvement in performance of detection. Spatial diversity reception can also help to mitigate turbulence-induced fading. When the spacing between receivers is not much greater than the fading correlation length, diversity gain of this is reduced by correlation, but ML detection can be used to overcome some of this loss. We have shown the same in then dual-receiver case, ML diversity reception performs the conventional EGC method.

## REFERENCES:

[1] Clint Turner (October 3, 2007). "A 173-mile 2-way all-electronic optical contact". Modulated light web site. Retrieved June 28, 2011.

[2] Wilson, K. "Recent Development in High-Data Rate Optical Communications at JPL". Jet Propulsion Laboratory. NASA Technical Reports Server. Retrieved 4 October 2011.

[3] W. Elmenreich, N. Marchenko, H. Adam, C. Hofbauer, G. Brandner, C. Bettstetter, and M. Huemer (2008). "Building blocks of cooperative relaying in wireless systems". e & i, Springer 125 (10): 353–359. doi:10.1007/s00502-008-0571-7.

[4] John G. Proakis (1995). Digital Communications (3rd ed.). Singapore: McGraw-Hill Book Co. pp. 767–768. ISBN 0-07-113814-5.

[5] Bernard Sklar (July 1997). "Rayleigh Fading Channels in Mobile Digital Communication Systems Part I: Characterization". IEEE Communications Magazine 35 (7): 90–100. doi:10.1109/35.601747+ISSN+0163-6804.

[6] M. Born and E. Wolf, Principles of Optics, 6th ed. city??, Canada:
Pergamon, 1980.

[7] J. W. Goodman, Statistical Optics. New York: Wiley, 1985.

[8] A. Ishimaru, Wave Propagation and Scattering in Random
Media. New York: Academic, 1978, vol. 1–2.

[9] S. Karp, R. Gagliardi, S. E. Moran, and L. B. Stotts, Optical Channels.
New York: Plenum, 1988.

[10] G. L. Stuber, Principles of Mobile Communication. New York: Kluwer Academic, 1996.

[11] J. G. Proakis, Digital Communication, 3rd ed. New York: McGraw- Hill, 1995.

[12] M. Srinivasan and V. Vilnrotter, “Avalanche photodiode arrays for optical
Communication receivers,” NASA TMO Progress Rep. 42-144,
2001.

[13] L. C. Andrews and R. L. Phillips, Laser Beam Propagation through Random Media: SPIE Optical Engineering Press, 1998.

[14] M. M. Ibrahim and A. M. Ibrahim, “Performance analysis of optical receivers
with space diversity reception,” Proc. IEE—Commun., vol. 143,
no. 6, pp. 369–372, December 1996.

[15] X. Zhu and J. M. Kahn, “Maximum-likelihood spatial-diversity reception on correlated turbulent free-space optical channels,” presented at the IEEE Conf. on Global Commun. San Francisco, CA, Nov.–Dec. 27–1, 2000.

[16] I. S. Gradshteyn and I. M. Ryzhik, Table of Integrals, Series and Products,7th ed. New York: Academic, 2007