A NOVEL PROPAGATION TECHNIQUE IN FREE SPACE OPTICAL COMMUNICATION

A.K. RAHMAN, C.B.M. RASHIDI, S.A. ALJUNID, M.S. ANUAR, R.ENDUT, K.R. UMMUL
School of Computer and Communication Engineering,
Universiti Malaysia Perlis (UniMAP),
Perlis, Malaysia
E-mail: rahmankram@unimap.edu.my

ABSTRACT

This paper focus on mitigating the atmospheric turbulence effect in free space optical communication using a dual diffuser modulation (DDM) technique. The most deteriorate the FSOC is scintillation where it affected the wave front cause to fluctuating signal and ultimately receiver can turn into saturate or loss signal. DD approach enhances the detecting bit '1' and bit '0' and improves the power received to combat with turbulence effect. The performance focus on Signal-to-Noise (SNR) and Bit Error Rate (BER) by using the Kolmogorov's scintillation theory. The numerical result shows that the DD approach improves the range where estimated approximately 40% improvement under weak turbulence and 80% under strong turbulence.

Keywords: *Dual Diffuser Modulation, Free Space Optical Communications, Atmospheric Turbulence*

1. INTRODUCTION

Free space optical communication is an attractive alternative over fiber optical communication where provides high bandwidth, fast-installation and high security [1]. However FSOC is suffering with the atmospheric turbulence which can lead the laser beam (a) beam wanders, (b) beam spreading and (c) scintillation. The beam wanders is refer to the condition beam deflected randomly through the changing refractive index oddities. Meanwhile beam spreading refers to conditions where the beam spread more than diffraction estimated predict. Lastly, for scintillation it affected the phase front of the beam can vary and resulting fluctuation irradiance or well know as intensity signal. The combination of all these effect will cause both the spatial and temporal experience random fluctuations in refractive index of the variability of element factor such as temperature, pressure and wind variations along the optical propagation path through the channel [2-9].

2. DUAL-DETECTION APPROACH

The system employs two transmitters and On-Off Shift Keying (OOK) modulation as reference for conventional system. When the first transmitter sends binary '1', the second transmitter which is set in compliment condition will send the binary '0' in simultaneously and vice versa. Meanwhile at the receiver part, the signal will go through the subtractor for the differential detection process. Here we assume the ideal subtractor condition where no losses signal occurs during subtraction. Therefore, the signal output will become bit '1' for sending binary '1' and bit '-1' for sending binary '0'. This condition leads to modification on conventional OOK modulation particularly in improving signal threshold detection and reduce power loss.

3. THEORY OF ANALYSIS

Based on the Rytov theory, the field of the plane wave in random media is given [10].

$$E_o(\vec{r}) = A_o(\vec{r}) \exp\left(i\varphi_o(\vec{r})\right)$$

(1)

where $A_o(\vec{r})$ is amplitude of the laser beam in the atmosphere without the presence of turbulence. φ_o and $E_o(\vec{r})$ are the phase and laser beam profile, respectively. However in the presence of turbulence, the scintillation effect is more dominant which change the refractive index and as a consequence lead to intensity fluctuations. Therefore this condition directly change the laser beam profile [10,11].

$$E_o(\vec{r}) = A_o(\vec{r}) \exp\left(i\varphi_o(\vec{r})\right) = E_o(\vec{r}) \exp(\Phi)$$

(2)

where $A(r)$ is amplitude of the laser in the turbulence atmospheric, Φ is the exponential factor due to turbulence given as:

$$\Phi = \mathrm{Ln}\left(\frac{A(\vec{r})}{A_o(\vec{r})}\right) + i[\phi(\vec{r}) - \phi_o(\vec{r})]$$
$$= \chi + iS$$

(3)

where χ represent the fluctuation of the log-amplitude of the field and S is the phase fluctuations. This equation predicts a fluctuation in intensity and phase of receiving signal due to turbulence is weak and assuming that the refractive index structure coefficient C_n^2 is symmetrical along the beam path, Rytov suggested a variance for the log-irradiance given as [6]:

$$\sigma_{\ln IR}^2 = \langle(\ln I - \langle\ln I\rangle)^2\rangle = 1.23 C_n^2 k^{7/6} L^{11/6}$$

(4)

where k is wave number, $k = 2\pi/\lambda$, L is propagation distance and I is intensity signal. However in practical FSOC for plane wave in weak condition and for the symmetrical turbulence of the log-amplitude fluctuation is given by [9,10]:

$$\langle\chi^2\rangle = 0.31 C_n^2 k^{7/6} L^{11/6}$$

(5)

By neglecting other source noises, we assume the only dominant noise source is atmospheric turbulence which give the log-amplitude as:

$$\chi = \mathrm{Ln}\left(\frac{A(\vec{r})}{A_o(\vec{r})}\right) = \ln\left[\frac{A_o(\vec{r}) + A_n(\vec{r})}{A_o(\vec{r})}\right] = \ln(1 + \varepsilon)$$

(6)

where $A_n(\vec{r})$ is the amplitude of noise and $\varepsilon = A_n(\vec{r})/A_o(\vec{r})$ is the ratio of the amplitude of noise to signal. Both SNR and BER are used to evaluate the quality of the communication systems. The BER performance depends on the average received power, the scintillation strength, receiver noise and threshold bits (1 or 0) detection. Here the dual-detection approach is a modification from the conventional OOK detection that using direct detection where improves power received and eliminated the need of complex adaptive threshold. The SNR for case only dominant turbulence noise in term of mean signal and noise intensity I_o and $\langle I_n\rangle$ given as:

$$SNR = \frac{I_o}{\langle I_n\rangle} = \frac{\langle A_o^2(\vec{r})\rangle}{\langle A_n^2(\vec{r})\rangle} = \frac{1}{\langle\varepsilon^2\rangle}$$

(7)

So, the BER for OOK modulation can be written as [10]:

$$BER = \frac{1}{2}erfc\left(\frac{Q}{2}\right) = \frac{e^{(-\frac{Q^2}{2})}}{Q\sqrt{2\pi}}$$

(8)

where $erfc()$ the complementary error function and Q is defined as:

$$Q = \frac{A_1 - A_0}{\sigma_1 + \sigma_0}$$

(9)

Where A_1, σ_1 are the mean signal and noise at the receiver for a bit '1' respectively, and for a bit '0' the mean signal and noise are denoted as A_0, σ_0.

For conventional OOK bit detection,

$$A_1 = \langle A_o(\vec{r})\rangle, \quad A_0 = 0, \quad \text{and} \quad \sigma_1 + \sigma_0 = \langle A_n(\vec{r})\rangle$$
$$SNR = \frac{\langle A_o^2(\vec{r})\rangle}{\langle A_n^2(\vec{r})\rangle} = Q^2$$

(10)

However for case dual-detection approach,

$$A_1 = \langle A_o(\vec{r})\rangle, \quad A_0 = \langle -A_o(\vec{r})\rangle, \quad \text{and} \quad \sigma_1 + \sigma_0 = \langle A_n(\vec{r})\rangle$$
$$SNR = \frac{\langle 2A_o^2(\vec{r})\rangle}{\langle A_n^2(\vec{r})\rangle}$$

(11)

For weak turbulence model, ε is very small thus (6) is given as [10]:

$$\chi = \ln(1 + \varepsilon) \approx \varepsilon$$

(12)

When turbulence is strong, the SNR and χ can be relating using Tailor series for function $f(x) = (e^x - 1)^2$ and can be approximately to:

$$SNR = \frac{1}{\langle\chi^2 + \chi^3 + \cdots\rangle} \cong \frac{1}{\alpha\langle\chi^2\rangle}$$

(13)

4. RESULT AND DISCUSSION

www.jatit.org

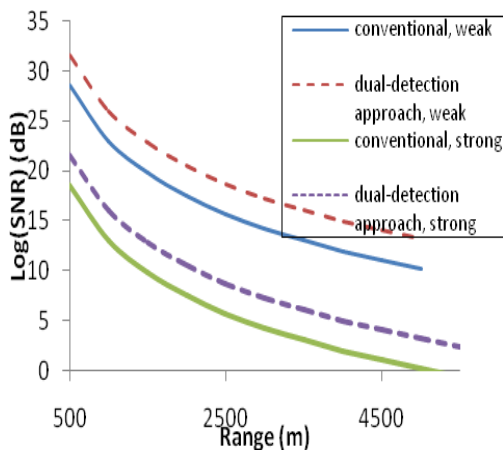*Fig. 1: SNR (Db) Versus Range Propagation*

In this numerical result section, we use parameters wavelength 1550nm, $Cn^2 = 1 \ x10^{-15}$ for weak turbulence and $Cn^2 = 1 \ x10^{-14}$ for strong turbulence and range propagation 5km for all calculations. In Fig. 1 shows the SNR in dB response to turbulence strength. From the graph pattern, we can know that as the distance increase, the SNR also decrease. The SNR is influenced by turbulence strength. Therefore by using the dual-detection approach the SNR can improve approximately 3 dB or 17% compare to the conventional approach.
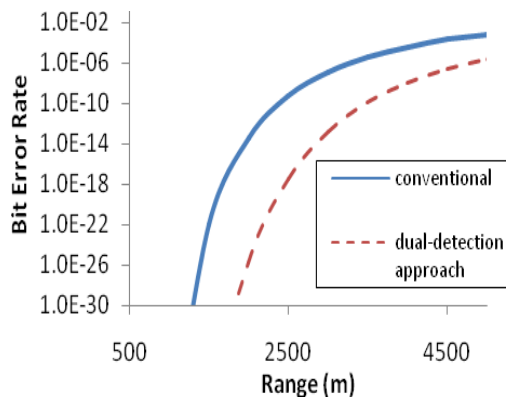

Fig. 2: BER Versus Range Propagation For Weak Turbulence Condition

In Fig. 2 shows the BER versus range propagation in response to weak turbulence. By using the standard communication for acceptable BER at 10^{-9}, the conventional approach only reaches the range propagation 2.5km but the dual-detection approach can reach further to 3.5km which approximately 40% improvement.
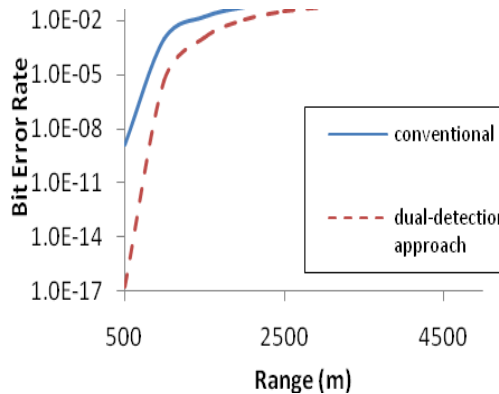

Fig. 3: BER Versus Range Propagation For Strong Turbulence Condition

In Fig. 3 shows the BER versus range propagation for strong turbulence condition. Here we assume the value of α is 2. In range of good quality communication (BER=10^{-9}), the conventional approach only reaches the range propagation about 0.5km but the dual-detection approach still manage to reach 0.9km where about 80% improvement.

5. CONCLUSION

In this paper, we focus on the scintillation effect deteriorate the performance of FSOC. We make a comparison performance in term of SNR and BER between two approach that are conventional (OOK-direct detection) and dual-detection. Analyses that carried out shows that the proposed dual-detection approach improve the margin SNR and BER. The range of propagation can be predicted improved 40% in weak turbulence and 80% in strong turbulence.

REFERENCES

[1] Kim, Isaac "Wireless optical transmission of fast Ethernet, FDD!, ATM and ESCON protocol data using the Terralink laser communication", SPIE. 1998

[2] A.K. Rahman, S.A. Aljunid, M.S. Anuar and H.A. Fadhil "Enhance the performance of free space optical (FSO) communication due to atmospheric turbulence via the dual diffuser modulation (DDM)",Journal Key

Engineering Materials 594-595,pp. 1027-1031, 2014.

[3] S. Trisno, I. Smolyaninov, S. D. Milnerb, and C. C. Davis, "Characterization of Time Delayed Diversity to Mitigate Fading in Atmospheric Turbulence Channels", Proc. of SPIE, Vol. 5892, pp. (589215) 1-10, 2005.

[4] M. C. R. Cordeiro, C. P. Colvero, and J. P. von der Weid, International Conference on Microwave and Optoelectronics, pp. 393-395, 2005.

[5] M. Uysal, J. Li, and M. Yu, "Error Rate Performance Analysis of Coded Free-Space Optical Links over Gamma-Gamma Atmospheric Turbulence Channels", IEEE Transaction on Wireless Communications, Vol. 5, No. 6, pp. 1229-1233, 2006.

[6] I. B. Djordjevic, B. Vasic, and M. A. Neifeld, "Multilevel Coding in Free-Space Optical MIMO TransmissionWithQ-Ary PPM Over the Atmospheric Turbulence Channel", IEEE Photonis Technology Letters, Vol. 18, No. 14, pp. 1491-1493, 2006.

[7] M. Tariq," Free Space Optical Communications (FSO)", Avionics, Fiber-Optics and Photonics Technology Conference, IEEE, pp. 21-21, 2007.

[8] X.Zhu, and J.M Kahn, "Free-Space Optical Communication through Atmospheric Turbulence Channels" IEEE Transactions on Communication, Vol.50, No.8,pp.1293-1300,2002

[9] J. Li, and M. Uysal, "Achievable Information Rate for Outdoor Free Space Optical", Global Telecommunications Conference, Vol. 5, pp. 2654- 2658, 2003.

[10] X. Guoliang, Z. Xuping, W. Junwei, and F. Xiaoyong,"Influence of atmospheric turbulence on FSO link performance,"Proc. SPIE, Optical Transmission, Switching, and Subsystems,Vol. 5281, pp. 816-823, 2004.

[11] L. C. Andrews, R. L. Phillips, and C. Y. Hopen, Laser Beam Scintillation with Applications, SPIE Optical Engineering Press,Bellingham, Washington, 2001.