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A New Modulation Technique to Improve Received Power Under Turbulence Effects For Free Space Optical Communication

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Abstract. This paper focus on new modulation technique to improve the performance of the conventional modulation that uses intensity modulation/direct detection (IM/DD) for On-Off Keying (OOK) modulation. This new modulation technique that is Dual Diffuser Modulation (DDM) can create superior modulation with able to reduce scintillation index, enhance power received and threshold signal level. The analysis result shows that the free space optical (FSO) can have good performance of power received under strong turbulence. The DDM are better performance as compare with conventional IM/DD-OOK and IM/DD-OOK with diffuser. This can help FSO system to combat with severe turbulence effect for optimum operation.

1. Introduction

The FSO communication is strongly influenced by the atmospheric channel effect which can cause the beam signal fading and wander. There are two main effects that can deteriorate the quality signal of FSO, namely the atmospheric attenuation and atmospheric turbulence as reported in [1]–[4]. Atmospheric attenuation will cause the signal scattering and absorption, therefore modification is needed on an FSO system design in order to transmit higher power without exceeding the safety limits or has to reduce the propagation link [5], [6]. Meanwhile, atmospheric scintillation is caused by the atmospheric temperature inhomogeneity as presented in [7], [8]. The scintillation effect will cause the signal fading due to the constructive and destructive interference of the optical beam traversing the atmosphere. Typical scintillation fading margins for short propagation link is around 2 to 5 dB which is less than the margins for atmospheric attenuation [8], making scintillation insignificant for short range FSO systems. Nevertheless, if the range is exceeding more than 1 km the scintillation will impairs the FSO link availability and degrade the FSO performance significantly [2], [4], [7], [9].

The OOK modulation technique is a simple modulation technique to be implemented and it has become the most popular for commercially modulation technique available for terrestrial FSO systems currently [4], [10]. The major problem with OOK is it suffers from the threshold signal level. The threshold level or point in the decision circuitry is used to distinguish between bits zero and one is always fixed midway between the expected levels of data bits one and zero. This will produce an optimum less error performance in non-fading channels. However when there is presence of turbulence, the received signal level will fluctuate and at the same time the threshold detector has to track this fluctuation in order to determine the optimum decision point [11], [12]. As a result, this will need a great design challenge, as the channel noise and fading will have to be continuously tracked for the OOK in FSO to perform optimally. Ignoring the signal fluctuation and letting the OOK FSO system to operate with a fixed threshold level will cause the increment of detection error [13].

By using a phase screen diffuser which is mounted at the laser exit of transmitter, it can reduce the scintillation index and enhanced the FSO performance. Nevertheless, the use of the phase screen diffuser will attenuate the power transmit due to the expended of beam divergence caused by the diffuser effect. Consequently, less power will be received at the receiver detector. The effect of the diffuser will also become less effective when increased to strong turbulence. This condition will not give the advantage over FSO to improve the overall performance. Therefore, the new DDM overcomes this limitation of conventional IM/DD-OOK where it optimizes the diffuser effects, increases the power received and fix the zero threshold level signal to create robust modulation against atmospheric turbulence effect.

2. Effect Scintillation in Laser Beam

The most practical implementation for FSO communication involves the use of an intensity modulation/direct detection (IM/DD) system. The transmitted data is on-off keying (OOK) intensity modulated and goes through an atmospheric channel to the receiver. The receiver aperture collects the received optical signal and focuses it onto a photodetector, which converts the instantaneous optical power into electrical current for the detection process. In the presence of atmospheric turbulence between transmitter and receiver, the received signal exhibits random intensity fluctuations.

The instantaneous received signal power P_R as expressed in Equation (1) is a random quantity. The observed quantity is now the averaged or mean received signal power $\langle P_R \rangle$ given by

$$\langle P_R \rangle \cong \frac{\pi}{8} D^2 \langle I(0,L) \rangle = \frac{P_R}{1+1.33\sigma^2 \Lambda^{5/6}} \tag{1}$$

Furthermore, it follows that the mean signal current is $\langle i_s \rangle = R\langle P_R \rangle$, where R is the photodetector responsivity. The output current from the detector $i = i_S + i_N$ in the case is a random variable, which has the mean value $\langle i_s \rangle$ and the variance $\sigma_i^2 = \sigma_S^2 + \sigma_N^2$, , where σ_s^2 represents fluctuations in the signal that become a contributor to the detector noise and related to the normalized intensity variance σ_I^2 by

$$\sigma_S^2 = \langle i_S^2 \rangle - \langle i_s \rangle^2 = \langle i_s \rangle^2 \sigma_I^2 \tag{2}$$

Using the relations given in Equation 1 and Equation 2 and the averaged SNR $\langle \Gamma_0 \rangle$ at the output of the detector assumes the form

$$\langle \Gamma_0 \rangle = \frac{\langle i_S \rangle^2}{\sigma_i^2} = \frac{\Gamma_0}{\left(1+1.33\sigma_I^2 \Lambda^{5/6}\right)^2 + \Gamma_0 \sigma_I^2} \tag{3}$$

The BER can be expressed as

$$P_r(e)_{OOK} = \frac{1}{2} erfc\left(\frac{i_s}{2\sqrt{2}\sigma_N}\right) = \frac{1}{2} erfc\left(\frac{1}{2\sqrt{2}}\sqrt{\Gamma_0}\right) \tag{4}$$

In the presence of optical turbulence, the expression in Equation (1) must be modified to incorporate the effects of signal fluctuations. In this case, the threshold level is now set to half the average signal corresponding to a received pulse $(i_T = \langle i_S \rangle/2)$.

The false alarm probability P_f does not depend on the random received signal and can be written as

$$P_f = P_R|(1|0) = \frac{1}{2} erfc\left(\frac{1}{2\sqrt{2}}\sqrt{\Gamma_0}\right) \quad (5)$$

However, the miss probability p_m is now,

$$P_m = P_R|(0|1) = \frac{1}{2} erfc\left[\left(\frac{2i_s}{\langle i_s\rangle} - 1\right)\frac{1}{2\sqrt{2}}\sqrt{\Gamma_0}\right] \quad (6)$$

where i_s is the random detector signal corresponding to the instantaneous received intensity. To compute the average BER $\langle P_R(e)\rangle$, these questions must average over the intensity fluctuation spectrum. This gives:

$$\langle P_r(e)\rangle = \frac{1}{4}\left\{erfc\left(\frac{1}{2\sqrt{2}}\sqrt{\Gamma_0}\right) + \int_0^\infty P_I(i_s)\left[\left(\frac{2i_s}{\langle i_s\rangle} - 1\right)\frac{1}{2\sqrt{2}}\sqrt{\Gamma_0}\right] di_s\right\} \quad (7)$$

where $P_I(i)$ is the PDF of the intensity fluctuations.

The limiting performance of average BER can be achieved by assuming the threshold level is dynamically set at half instantaneous received signal level i_t, which lead to expression,

$$\langle P_r(e)\rangle_L = \frac{1}{2}\int_0^\infty P_I(i_s) erfc\left(\frac{i_s}{2\sqrt{2\langle i_s\rangle}}\sqrt{\langle\Gamma_0\rangle}\right) di_s \quad (8)$$

This shows that the turbulence will deteriorate the signal performance FSO and the most problem OOK signalling is relating threshold ability.

3. Results and Discussion

The parameters used for modulation comparison performance are wavelength λ= 1550 nm, distance $L =$ 2000 m, electron charge $e = 1.6 \times 10^{-19}$ C, plank constant $h = 6.6 \times 10^{-34}$ Js, speed of light $c = 3 \times 10^8 ms^{-1}$, photodetector efficiency $\eta = 0.7$, power transmit $P_o = 0\ dBm$, receiver aperture diameter $l_c = 0.1$, radius of curvature $F_O = \infty$, spot beam at transmitter $(z = 0)$ $W_o = 0.025$m.

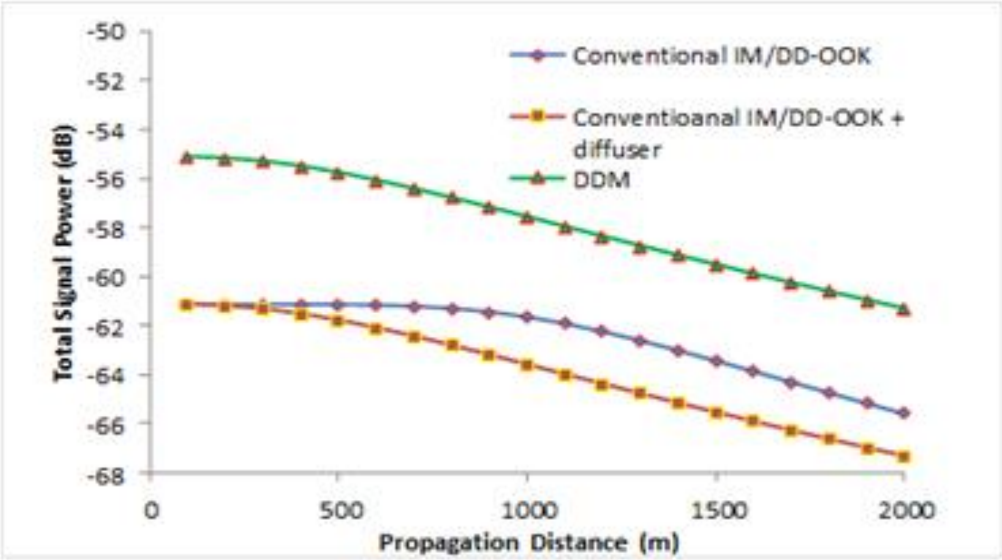

Figure 1. Performance of total signal power versus propagation distance in without presence of turbulence

The Figure 1 shows the corresponding of the total signal power over propagation distance in the absence of turbulence. From the graphs, the signal power under diffuser effect experiencing decline condition due to diffraction beam as shown by the curve conventional IM/DD-OOK with diffuser. Nonetheless, DDM technique has a better signal power due to double magnitude power yield after subtracting process. When there is presence of turbulence, the intensity of signal begins to become unstable and the diffuser helps to reduce the scintillation index which can produce a better signal power. Figure 2 and Figure 3 present the intensity signal power when experiencing the turbulence effect.

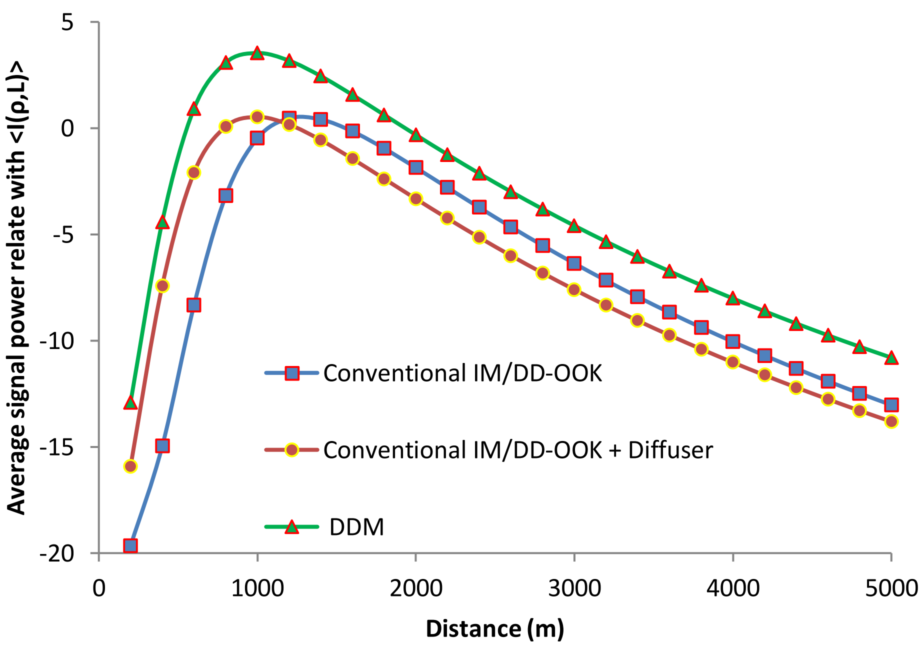

Figure 2. Performance of mean intensity signal versus distance under strong turbulence

The Figure 2 shows the mean intensity signal power correspond to propagation distance for strong turbulence. From the graphs, the DDM increases the mean intensity signal if compares with the conventional IM/DD-OOK and conventional IM/DD-OOK with diffuser. However, all the performances of mean intensity decreases as the propagation distance increases.

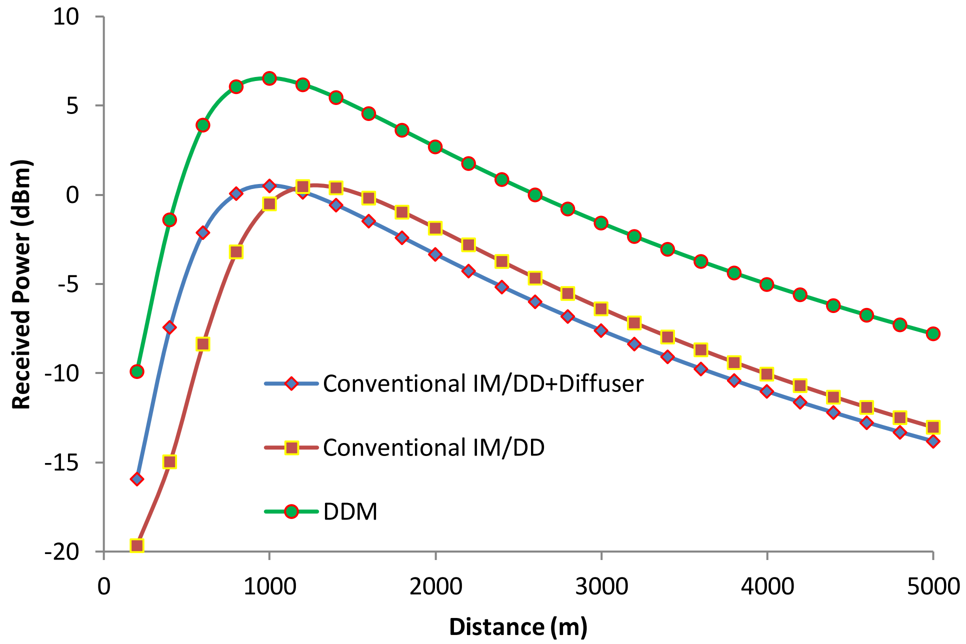

Figure 3. Performance of receiving power versus distance under strong turbulence

Meanwhile Figure 3 shows the power received versus the distance corresponds to mean intensity signal. Under strong turbulence, DDM technique is able to support high power received compared to the conventional IM/DD-OOK and conventional IM/DD-OOK with diffuser. It shows that the capability of this new technique of modulation is able to detect weak signal and maintain the better level of power received.

4. Conclusion

This DDM technique improves the ability of received power in free space optic transmission. The results show that under strong turbulence the DDM technique can have a better power received as compared with conventional IM/DD-OOK and IM/DD-OOK with diffuser. The phase screen diffuser effect enhances the impact of DDM. Therefore, it is possible to be operated on long distance transmission laser beam.

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