Subtraction dual-wavelength for enhanced transmission performance of free-space optical communication over turbulence effect

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Performance of a free-space optical communication system is influenced by atmospheric turbulence which degrades signal transmission quality. A gamma–gamma channel model is employed to characterise this turbulence under weak-to-strong conditions. The proposed dual diffuser modulation using subtraction dual-wavelength concept is combined with a phase screen diffuser to improve signal transmission. Its performances are compared with conventional intensity modulation-direct detection on off keying and partial coherent beam on off keying techniques. In comparison, results show that the dual diffuser modulation demonstrates superior performances in both received power and bit rate transmission under different turbulence conditions.

Introduction: Free-space optical (FSO) communication is strongly influenced by atmospheric attenuation and atmospheric scintillation [1]. Signal scattering and absorption due to the atmospheric attenuation would require either sufficiently high power for transmission within the safety limit or reduction in the propagation link [2]. Meanwhile, atmospheric scintillation attributed to temperature inhomogeneity results in constructive and destructive interference of the optical beam traversing the atmosphere [3, 4]. A typical scintillation fade margins of around 2–5 dB for short propagation link is lesser than that of the atmospheric attenuation [5]. Hence, the effect of scintillation for short range FSO systems can be considered insignificant. Nevertheless, the scintillation is expected to impair the FSO link availability and degrade the FSO performance significantly once the range goes beyond 1 km [4, 6].

On-Off Keying (OOK) modulation is a simple technique that is currently being employed in terrestrial FSO systems [7]. Its major problem is the threshold signal level. The threshold level/point is used in the decision circuitry, and it is fixed midway between the expected levels of data bits one and zero in order to reduce error performance in non-fading channels [5]. However, in the presence of turbulence, the received signal level would fluctuate and the fluctuation must be tracked by the threshold detector to determine the optimum decision point [5]. Ignoring the signal fluctuation and leaving the FSO to operate at a fixed threshold level would unfortunately results in the increment of error detected [7]. Since the channel noise and fading will have to be continually tracked for the OOK in FSO to perform optimally, this ultimately poses a design challenge.

By using a phase screen diffuser which is mounted at the laser exit of the transmitter, the scintillation index can be reduced and the FSO performance can be enhanced at the expense of attenuation in the power transmitted due to beam divergence. Consequently, lesser power is received at the detector. The effect of diffuser is found to be less effective with the increase of turbulence. In this study, subtraction dual-wavelength technique is proposed to overcome the limitations of conventional intensity modulation-direct detection -on off keying (CIM/DD-OOK), and the performance is also compared with partial coherent beam OOK (PCB-OOK) technique [8].

Proposed system models: By modifying the CIM/DD-OOK, the proposed subtraction dual wavelength system consists of transmission and detection parts [9]. As illustrated in Figure 1, the former constitutes of laser source, data inverter and phase screen diffuser while the latter consists of photodetector and subtractor. The inverter is used to invert the original signal. At receiver, both signal, respectively, transmitted by the diffuser and the detector will be subtracted to generate the output signal.

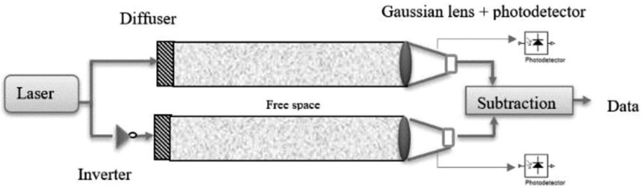

Fig. 1 *Proposed subtraction dual-wavelength transmission system*

Effective power for subtraction dual-wavelength technique:

In subtraction dual wavelength system, the total signal power at the receiver can be written as

$$i_s = i_{s1} - i_{s2}, \tag{1}$$

where i_s is the signal power and i_{s2} is the complimentary of i_{s1}. Thus, the total signal power can be written as

$$i_s = 2\Re P_r, \tag{2}$$

where $\Re$ is the responsivity and P_r is the power received.

Signal to Noise ratio: The output signal to Noise ratio (SNR) in the absence of optical turbulence can be defined as the ratio of signal power (i_s^2) over signal noises (σ_N^2). The SNR in the absence of turbulence, SNR$_\text{o}$ without the diffuser effect can be written as

$$SN\,\text{R}_\text{o} = \frac{\Re^2\left(\left(\frac{\pi D^2}{8}\right)\left(\frac{2P_o}{\pi W^2(L)}\right)\right)^2}{2e\Re\left(\left(\frac{\pi D^2}{8}\right)\left(\frac{2P_o}{\pi W^2(L)}\right)\right)B + \frac{4k_bT_nB}{R_L}} \tag{3}$$

where D, P_o, W, L and B are the aperture diameter responsivity, power at transmitter, beam spot size, distance and bandwidth, respectively. The thermal noise is denoted by $\frac{4k_bT_nB}{R_L}$.

SNR of subtraction dual-wavelength: In subtraction dual-wavelength system, the SNR in the absence of turbulence without the effect of diffuser, SNR_{wo}, can be written as

$$\text{SN R}_{wo} = \frac{2^2\Re^2\left(\left(\frac{\pi D^2}{8}\right)\left(\frac{2P_o}{\pi W^2(L)}\right)\right)^2}{4e\Re\left(\left(\frac{\pi D^2}{8}\right)\left(\frac{2P_o}{\pi W^2(L)}\right)\right)B + \frac{4k_bT_nB}{R_L}} \tag{4}$$

Meanwhile, the shot noise, i_shot produced can be denoted as

$$i_\text{shot} = 4e\Re\left(\left(\frac{\pi D^2}{8}\right)\left(\frac{2P_o}{\pi W^2(L)}\right)\right)B. \tag{5}$$

Taking into account the effect of diffuser and shot noise, the SNR in the absence of turbulence, SNR$_{DDM}$, can be denoted such that

$$\text{SNR}_{DDM} = \frac{\left(\frac{2^2\Re^2\left(\left(\frac{\pi D^2}{8}\right)\left(\frac{2P_o}{\pi W^2(L)}\right)\right)^2}{4e\Re\left(\left(\frac{\pi D^2}{8}\right)\left(\frac{2P_o}{\pi W^2(L)}\right)\right)B + \frac{4k_bT_nB}{R_L}}\right)}{\sqrt{1 + q_c\Lambda_1}}, \tag{6}$$

where q_c is the strength of the diffuser and Λ_1 is the Fresnel ratio.

In the presence of atmospheric turbulence, the received signal exhibits additional power losses (refraction and diffraction) and random turbulence fluctuations. The mean SNR, $\langle\text{SNR}_{DDM}\rangle$ due to flux variance can be written as

$$\langle\text{SNR}_{DDM}\rangle = \frac{\text{SNR}_\text{o}}{\sqrt{\left(\frac{P_{SO}}{\langle P_S\rangle}\right) + \sigma_{flux}^2\left(L + L_f, \Omega_G\right)\text{SNR}_\text{o}^2}}, \tag{7}$$

where P_{SO} is the signal power in the absence of atmospheric effects and $\sigma_\text{flux}^2(L + L_f, \Omega_G)$ is the intensity flux variance on the photo