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Comparison of BER and Bandwidth of OOK, PPM, PAM and BPSK for FSO Communication

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Abstract - In this paper most efficient modulation technique having minimum bandwidth and best Bit Error Rate (BER) for Free Space Optics (FSO) communication system has been investigated. One of the reasons for BER in FSO is atmospheric turbulence. A model of weak atmospheric turbulence is discussed. The mathematical model of BER and bandwidth efficiency are analyzed and compared.

Keywords - Free Space Optic, Bit Error Rate, Bandwidth Efficiency, Turbulence, log-normal channel model.

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I. INRODUCTION

The FSO technology is based on the line of sight (LOS) link that uses a small divergence angle laser or LED and a narrow field of view (FOV) receiver to communicate data between two points. FSO is an economically viable option to the fibre optics and RF systems as it offers a bandwidth similar to the optical fibre, but at a low cost, and the ease of deployment. The features of FSO systems like unregulated spectrum, light weight, fast deployment and a secure communication, make it more attractive for commercial uses for the last mile access [1]. But reliability of an FSO communication system is greatly influenced by the atmospheric conditions. Aerosol, fog, gases, rain and other suspended particles in the atmospheric channel causes the optical beam absorption and scattering which results in a large path loss, thus limiting the link length to <100m[2,3,4]. Even in clear sky conditions atmospheric turbulence, which is caused by temperature and pressure inhomogeneities in the atmosphere, leads to refractive index fluctuations. When signal passes through such a turbulent atmosphere, it will experience random fluctuations. These fluctuations in the amplitude and phase of the received signal due to atmospheric turbulence are known as scintillation. Scintillation causes deep signal fades leading to increased bit error rate and thus degrades the link performance especially for link ranges >1km[4]. The effect of scintillation is more severe for small aperture receivers [2, 5].

II. ATMOSPHERIC TURBULANCE

When an optical beam propagates in atmosphere, it experiences different refractive indices in its path which causes random variation in its intensity and phase that results in the signal fading [6]. In order to give an account of the atmospheric turbulence a number of models have been proposed by L.C Andrew and others such as lognormal, negative exponential and gamma-gamma models [7].

The turbulence which induced fading should be weak for validity of the log-normal model [8]. Beyond the weak turbulence regime, other models such as the gamma-gamma [9] and the negative exponential [4] will have to be considered. Under Rytov approximation the intensity of the received signal can be explained as $I = I_0 \exp(l)$, where l is the log intensity of the optical signal and is normally distributed and I_0 is the received intensity without turbulence. Therefore the probability density function (PDF) of the light intensity follows the lognormal distribution is shown in eqn. (1) [7]:

$$p_I = \frac{1}{\sqrt{2\pi}}\frac{1}{I\sigma_l}\exp\left\{-\frac{\left(\ln\left(\frac{I}{I_0}\right)+\frac{\sigma_l^2}{2}\right)^2}{2\sigma_l^2}\right\} \qquad I \geq 0 \tag{1}$$

where σ_l is log-amplitude variance. The log-normal distribution is generally used to model the fading associated with the weak atmospheric turbulence regime related to the terrestrial propagation distance of <100 m [8, 10, 11].

III. FSO MODULATION TECHNIQUES

The main aim of modulation is to squeeze as much data into the least amount of spectrum possible. Spectral efficiency, measures how quickly data can be transmitted in an assigned bandwidth [12]. And it is also desirable for the modulation scheme to be power efficient, but this is not the only deciding factor in the choice of a modulation technique [13, 14].

A. On-Off Keying (OOK)

It is the dominant modulation scheme employed in commercial terrestrial FSO communication systems due to its simplicity and resilience to the nonlinearities of the laser and the external modulator. OOK can use either Non Return-to-Zero (NRZ) or Return-to-Zero (RZ) pulse formats. The probability of error for NRZ-OOK-coded optical data, detected with a photodiode, can be expressed as a function of the Signal-to-Noise Ratio (SNR) as in equation (2)

$$BER_{NRZ\text{-}OOK} = \frac{1}{2}\text{erfc}\left(\frac{1}{2\sqrt{2}}\sqrt{SNR}\right) \quad (2)$$

And the required bandwidth for NRZ-OOK is equal to the bit rate. i.e., "Breq=Rb" [12]. The BER for RZ-OOK can be expressed as a function of Signal-to-Noise Ratio (SNR) as shown in eqn. (3):

$$BER_{RZ\text{-}OOK} = \frac{1}{2}\text{erfc}\left(\frac{1}{2}\sqrt{SNR}\right) \quad (3)$$

B. Pulse Position Modulation (PPM)

The elimination of decision threshold dependence on the input power is a great advantage of PPM scheme. In this modulation scheme, each pulse of a laser can be used to represent one or more bits of information by its position in time, relative to the start of a symbol whose duration is identical to that of information bits it contains [15]. Bits in block encoding are transmitted in blocks instead of one at a time. Optical block encoding is achieved by converting each word of "K_1" bits into one of "$L=2^{K_1}$" optical fields for transmission. Since "L" is the possible pulse positions code for "K_1" bits of information in PPM. The bit rate is shown in eqn. (4) [12]

$$R_b = B_{req}\frac{\log_2 L}{L} \quad (4)$$

For Gaussian noise, the BER for L-PPM is shown in eqn. (5) [12]:

$$BER_{PPM} = \frac{1}{2}\text{erfc}\left(\frac{1}{2\sqrt{2}}\sqrt{\frac{\log_2 L}{L} SNR \frac{L}{2}}\right) \quad (5)$$

C. Pulse Amplitude Modulation (PAM)

This type of modulations is a form of signal modulation where the message information is encoded in the amplitude of a series of signal pulses; and the BER for PAM is shown in eqn. (6) [16]:

$$BER_{PAM} = \frac{1}{2}\text{erfc}\left(\frac{\sqrt{SNR \log_2 M}}{2\sqrt{3}(M-1)}\right) \quad (6)$$

Since "M" is the possible pulse amplitudes code for "K2" bits of information in PAM, i.e., "$M=2^{K2}$", and generally the notation M-PAM is used to indicate the order. And the bit rate can be shown as in eqn. (7) [16]:

$$R_b = B_{req}\log_2 M = B_{req}K \quad (7)$$

D. Binary Phase Shift Keying (BPSK)

This type of a digital modulation scheme conveys data by changing or modulating the phase of a reference signal. It is appropriate for low cost passive transmitters, and it uses two phases which are separated by180^0. The BPSK modulation is the simplest form of Phase Shift Keying (PSK); it is the most robust of all the PSKs since it takes the highest level of noise or distortion to make the demodulator reach an incorrect decision. The BER equation of BPSK modulation is shown in eqn. (8) [17]:

$$BER_{BSK} = \frac{1}{2}\text{erfc}\left(\sqrt{SNR}\right) \quad (8)$$

And the required bandwidth for BPSK is equal to the bit rate. i.e., "$B_{req}=R_b$".

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IV. COMPARISION BETWEEN FSO MODULATION TECHNIUES

The bandwidth efficiency is defined as the ratio between the bit rate "R_b" and the required bandwidth "B_{req}", and measured in bits per second per hertz "b/s/Hz". So that for NRZ-OOK and BPSK bandwidth efficiency is shown in eqn. (9):

$$\eta_{NRZ-OOK} = \eta_{BPSK} = \frac{R_b}{B_{req}} \tag{9}$$

Table I of comparison has been shown for different modulation techniques according to BER and required bandwidth.

Table I: Comparison of BER and required Bandwidth

Modulation Techniques	BER	Required Bandwidth
NRZ-OOK	$\frac{1}{2}\text{erfc}\left(\frac{1}{2\sqrt{2}}\sqrt{SNR}\right)$	R_b
RZ-OOK	$\frac{1}{2}\text{erfc}\left(\frac{1}{2}\sqrt{SNR}\right)$	$2R_b$
PPM	$\frac{1}{2}\text{erfc}\left(\frac{1}{2\sqrt{2}}\sqrt{\frac{\log_2 L}{L} SNR \frac{L}{2}}\right)$	$\frac{R_b L}{\log_2 L}$
BPSK	$\frac{1}{2}\text{erfc}\left(\sqrt{SNR}\right)$	R_b

And the bandwidth efficiency "η_{PPM} " for L-PPM can be expressed as a function of the number of bits "K_1" as shown in eqn. (10):

$$\eta_{PPM} = \frac{R_b}{B_{req}} = \frac{\log_2 L}{L} = \frac{K_1}{L} = \frac{K_1}{2^{k1}} \tag{10}$$

Equation (10) shows that the bandwidth efficiency "η_{PPM}" for L-PPM is decreases with the increase of the number of bits "K_1", and it is less than the bandwidth efficiency of the other modulation techniques except RZ-OOK when L = 2 or 4 and it is more than the bandwidth efficiency of all modulation technique used in FSO communication systems mentioned above.

V. CONCLUSION

From above discussion it is concluded that the required bandwidth for NRZ-OOK and BPSK is equal to the bit rate, i.e. "B_{req}=R_b" whereas required bandwidth for RZ-OOK is double the bit rate. When number of bits "K" is increased, then bandwidth requirement is decreased for PAM modulation but increased for PPM modulation technique used in FSO communication system. So for "K > 2" the most bandwidth efficient technique is M-PAM. For a given signal to noise ratio, BER in increasing order will be PAM, NRZ-OOK, RZ-OOK, BPSK and PPM. But it also depend on the number of bits as the 16-PPM will have better BER when compared to 8-PPM followed by BPSK, 4-PPM and 2-PPM.

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