Analysis of BER Performance Differentially Coherent Detected Signal Considering Cloud Effect in FSO Link.

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Abstract— The optical signal propagating through the Free Space Optical (FSO) channel suffers from fluctuations in phase which results in Bit Error Rate (BER) performance degradation. In this study the performance of the differentially coherent detected signal based FSO communication system is investigated considering the effect of cloud caused Inter Symbol Interference (ISI).To mitigate the effect of fading, the differential coherent detection technique is employed. BER performance of the system has been analyzed under the presence and absence of ISI caused by cloud. A key motivation for employing differentially coherent detection is that BER performance has been improved significantly in binary DPSK than non-coherent OOK which has been observed in simulation. Different graphical analysis by varying carrier wavelength of the system has been investigated in this study.

Index Terms— Free Space Optical (FSO), Bit Error Rate (BER), Inter Symbol Interference (ISI), Differential Coherent Detection, Signal Interference Noise Ratio (SNR), Differential Phase Shift Keying (DPSK).

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1 INTRODUCTION

FSO communications is a complementary technology to the radio frequency (RF) technology and optical fiber networks. It has been proposed as a “last mile” solution for broadband wireless links in certain applications and scenarios [1,2].Other advantages of FSO consist of THz license-free band width, secure transmission, smaller transceiver architecture, low development and installation cost and immunity to electromagnetic interference. However, the performance of FSO system is limited by varying atmospheric conditions. One such a scenario is the turbulence induced fading experienced by the received optical signal, error control coding introduces vast processing delays and efficiency degradation. Increments in the aperture size to an optimum value results in improved signal -to -noise ratio (SNR) performance. Beyond this very little improvement in the SNR performance can be achieved. An important factor on the selection of modulation technique for FSO systems is the receiver sensitivity as there is always a trade -off between the receiver sensitivity and complexity. Though amplitude shift keying (ASK) is the simplest and widely reported, it does not offer immunity to the turbulence induced fading[3]. Differential phase shift keying (DPSK) with coherent phase -diversity system offers the best sensitivity in optical fiber systems. However, there is an additional power penalty caused by the frequency offset because of delayed and not-delayed bits not being in phase. Furthermore, there is a further power penalty due to the phase noise of the semiconductor lasers sources. The inter symbol interference (ISI) due to multipath propagation is considered because of cloud. Doppler distortion causes inter -carrier interference which prevents the use of differentially coherent detection in OFDM systems. Doppler Effect is not considered for current situation. On-Off keying is the simplest form of amplitude shift keying (ASK) modulation that represents digital data as the presence or absence of a carrier wave. In its simplest form, the presence of a carrier for a specific duration represents a binary one, while its absence for the same duration represents a binary zero. Differentially coherent detection relies on the assumption that the channel response changes slowly either between carrier frequencies or between blocks (differential encoding/detection in time). However, channel estimation errors degrade the performance of coherent detection, rendering it equal or even inferior when the channel variation is non -negligible [4].

2 TRANSFER FUNCTION OF CLOUD

Clouds cause temporal widening and attenuation of optical pulse power as a part of optical communication channel. In all practical cases , part of the optical channel passes through the earth's atmosphere that contains cloud s .One important distortion effect imposed by the atmosphere is the signal temporal broadening. This produces inter symbol interference which limit s maximum transmission band width [5]. Using transmission with a wider temporal frequency band width will cause significant degradation in received signal quality because of the narrow information band width per mitted by clouds. Usually, in open optical communication severe bandwidth limitation occur s particularly when cloud s are present. In order to improve performance, adaptive methods may be used according to atmospheric conditions. A theoretical model is presented. It is followed by calculations of the electro-optical properties of the clouds. This includes solving the Mie equations of scattering and absorption coefficients and the scattering phase function for the poly dispersion case. All calculations were carried out at three different wavelengths in the visible and near infrared (IR) spectral range, i.e. 0.532 µm, 0.8 µm and 1.3 µm wavelengths. These wavelengths are those under consideration for optical satellite communication [6,7].Longer wavelengths in the IR atmospheric windows exhibit very high absorption. Mid -IR wavelengths exhibit much more scattering than shorter ones because of the size distribution of cloud particulates. Mathematical models were developed for temporal impulse response at the three wavelengths listed above for the visible and near IR. Optical radiation propagating through clouds experiences temporal distortions. A function that describes well the temporal impulse response is the double gamma function which is shown below:

$$h(t) = \{k_1(c_1)te^{-k_2(c_1)t} + k_3(c_1)te^{-k_4(c_1)t}\} \quad \ldots\ldots (1)$$

Frequency transfer function of cloud [8] is obtained by Fourier transformation of equation (1)

$$H(f) = \{\frac{k_1(c_1)}{[k_2(c_1)+j2\pi f]^2} + \frac{k_3(c_1)}{[k_4(c_1)+j2\pi f]^2}\} \quad \ldots\ldots. (2)$$

The general transfer function of cloud in terms of poles and zeros can be expressed as

$$H(f) = \frac{G\left[1+j(\frac{f-b}{f_3})\right][1+j(\frac{f+b}{f_3})]}{\{[1+j(\frac{f}{f_1})][1+j(\frac{f}{f_2})]\}^2} \quad \ldots\ldots\ldots. (3)$$

Where,

$$f_1 = \frac{k_2}{2\pi} \quad ; \quad f_2 = \frac{k_4}{2\pi} \quad \& \quad f_3 = \frac{(k_2k_4+k_2k_3)}{2\pi(k_1+k_3)}$$

$$b = \frac{4\pi^2(k_1+k_3)f_3{}^2}{(k_2k_4)^2}$$

$$G = \frac{4\pi^2(k_1+k_3)k_3{}^2}{(k_2k_4)^2}$$

Where, h(t) and H(f) are in m-2, c1 is a parameter which depends on the physical characteristics of the cloud particle, wavelength, scattering coefficient etc. kl-k4 are the gamma function constants depending on c1.

The value of the gamma constants are shown in following table for different wavelengths [8]:

Table 1: Double Gamma function Constants: cloud thickness=250 m

Gamma function constant	**Wavelengths**		
	0.532µm	**0.8µm**	**1.3µm**
k_1	12.4	5.2	2
k_2	1.1×107	0.83×107	0.71×107
k_3	0.66	0.41	0.3
k_4	2.4×106	1.9×106	1.8×106

3 DIFFERENTIAL COHERENT DETECTION

Differential coherent detection offers the simplest way of achieving carrier synchronization with phase - shift keying (PSK), and, thus, represents an attractive solution for systems where error in signal is caused by the channel itself. However, differentially coherent detection is based the premise that there is no inter symbol interference (ISI) in the received signal. When a frequency selective multipath channel introduces ISI, differentially coherent detection must be combined with equalization [9]. In fact, when carrier phase noise effects are not severe Coherent detection performs better than non - coherent detection. In non coherent detection, a receiver computes decision variables based on a measurement of signal energy. In differentially coherent detection, a receiver computes decision variables based on a measurement of differential phase between the symbol of interest and one or more reference symbol(s). In differential phase -shift keying (DPSK), the phase reference is provided by the previous symbol [10].

In this article, a maximum likelihood approach to partially coherent detection is taken. There has been a considerable improvement in performance by introducing a maximum likelihood sequence estimation (MLSE) type algorithm. Let us consider the transmission of PSK signal over an FSO channel containing cloud. The base band representation of transmitted signal has the following form:

$$s(t) = Re\{\sqrt{2P}\sum_{k=0}^{k-1} d_k e^{2\pi f_k t} \qquad (4)$$

Where d_k is the transmitted bit, P is the constant power and the transmitted signal phase has uniformly distributed value in the interval of 0 to π. The received sequence r can be expressed as

$$r = se^{j\theta} + n \qquad (5)$$

Where r=(r0 , r1 , ……., rN - 1), s=(so , s1 , ……., s N - 1) and n=(no , n1 , ……., n N-1) are the received sequence, transmitted sequence and noise sequence respectively .For present case the signal is assumed to be added with a white

Gaussian noise and the length of data sequence is 2N sent at a time. For partially coherent detection, the receiver contains a tracking loop which provides an estimation of unknown channel phase. After demodulation the tracked signal becomes

$R=re^{j\varphi}$ (6)

Where carrier phase angle is given by

$\emptyset_e = \theta - \emptyset$

The probability of received sequence [11] given the transmitted sequence s and the carrier phase error is given below:

$$p(R\backslash s,\emptyset_c) = \frac{1}{(2\pi\sigma^2)^N}\exp\left\{-\frac{\left|R - se^{j\emptyset_e}\right|^2}{2\sigma^2}\right\}$$

=

$$\frac{1}{(2\pi\sigma^2)^N}\exp\{-\frac{1}{2\sigma^2}[\textstyle\sum_{i=0}^{N-1}[|R_{k-i}|^2 + |s_{k-i}|^2] - 2\textstyle\sum_{i=0}^{N-1}|R_{k-i}s^*{}_{k-i}|\cos(\emptyset_e - \alpha)]\}$$

…… (7)

Where,

$$\alpha = \tan^{-1}\frac{Im\sum_{i=0}^{N-1}|R_{k-i}s^*{}_{k-i}|}{Re\sum_{i=0}^{N-1}|R_{k-i}s^*{}_{k-i}|}$$

Averaging equation (7) we find,

$$p(R\backslash s) = \int_{-\pi}^{\pi} p(R\backslash s,\emptyset_e)p(\emptyset_e)d\emptyset_e$$

$$= \frac{1}{I_0(\rho)}\frac{1}{(2\pi\sigma^2)^N}\exp\{-\frac{1}{2\sigma^2}[\sum_{i=0}^{N-1}[|R_{k-i}|^2 + |s_{k-i}|^2]\}$$

$$\times I_0(\frac{1}{\sigma^2}\sqrt{(Re\{\sum_{i=0}^{N-1}R_{k-i}s^*{}_{k-i}\}+\rho\sigma^2)^2 + (Im\{\sum_{i=0}^{N-1}R_{k-i}s^*{}_{k-i}\})^2} \qquad (8)$$

Since $|s_k|^2$ is constant and Io(x) monotonic function of its argument, p(R\s) will gain its maximum value by finding the following terms:

$$s_{\max}\left\{(Re\{\sum_{i=0}^{N-1}R_{k-i}s^*{}_{k-i}\}+\rho\sigma^2)^2 + (Im\{\sum_{i=0}^{N-1}R_{k-i}s^*{}_{k-i}\})^2\right\}$$

$$= s_{\max}\left\{\left|\sum_{i=0}^{N-1}R_{k-i}s^*{}_{k-i} + \rho\sigma^2\right|\right\}^2$$

$$= s_{\max}\{\left|\sum_{i=0}^{N-1}R_{k-i}s^*{}_{k-i}\right|^2 + 2\rho\sigma^2 Re\{\sum_{i=0}^{N-1}R_{k-i}s^*{}_{k-i}\}\} \qquad (9)$$

Now such values of $\psi_k, \psi_{k-1}, \cdots \cdots \psi_{k-N+1}$ has to be chosen so that the value of

$$\left|\sum_{i=0}^{N-1}R_{k-i}e^{-\psi_{k-i}}\right|^2 + \frac{2\rho\sigma^2}{\sqrt{2P}}\{\sum_{i=0}^{N-1}R_{k-i}e^{-\psi_{k-i}}\}\} \qquad (10)$$

becomes maximum.

Where, $\psi_k, \psi_{k-1}, \cdots \cdots \psi_{k-N+1}$ is a particular sequence of transmitted signal phase. The first term of equation (10) is representing the component associated with differential detection and the second term is associated with ideal coherent detection. For ρ=0, the combination corresponds to unique term of differential coherent detection [11].

4 BIT ERROR PROBABILITY PERFORMANCE

Bit error rate of the received signal is determined after propagation through cloud. It is observed from the transfer function of cloud that high attenuation of transmitted signal occurs while it passes through cloudy environment. Therefore there is higher probability of error due to inter symbol interference which is occurred by pulse broadening in cloud. The inherent non -linear frequency response of cumulus cloud causing successive symbols to blur together. The presence of ISI in the system introduces error s in the decision device at the receiver output. Figure (1) shows the effect of different signal wavelengths on BER performance with ISI effect of cloud in FSO link. It is found that for three different wavelengths 0.532µm,0.8 µm and 1.3µm in Mid IR range , the lowest wavelength shows better BER performance. In figure (2) the ISI effect of cloud on bit error rate performance is depicted. There is significant reduction of signal power and quality while it goes through cloud. Figure (2) plots the received signal with and without the presence of ISI effect in channel. The received signal which passes through cloud is plotted with a gain increment of 20 dB than the signal that doesn't contain any ISI effect for cloud. Though having this high amplification the cloud caused ISI contained signal shows worse performance than the signal which is not affected by cloud caused ISI .

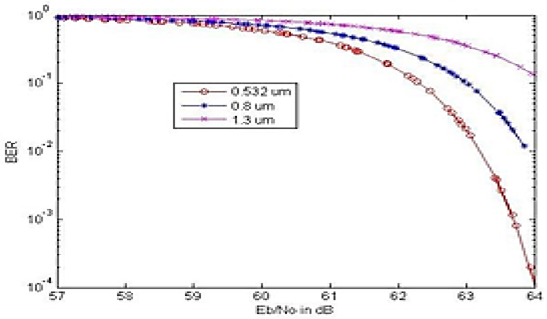
The bit error rate for BPSK signal in AWGN can be calculated as

$$P_b = Q\left(\sqrt{\frac{2E_b}{N_0}}\right) \qquad (11)$$

However the decision statistic γ can be defined from equation (9) and (10) by

$$\gamma = \left|\sum_{i=0}^{N-1}R_{k-i}e^{-\psi_{k-i}} + \frac{\rho\sigma^2}{\sqrt{2P}}\right|^2 \qquad (12)$$

When differential coherent detection is considered the loop SNR ρ is set as zero. Analysis shows that differential encoding approximately doubles the error rate compared to ordinary MPSK but this may be overcome by only a small increase in $\frac{E_b}{N_o}$, where analysis are based on a system in which the only corruption is AWGN. However, In this paper cloud exists as physical channel between the transmitter and receiver. Hence in this case the differential schemes can yield a better error -rate than the ordinary schemes which rely on precise phase information.



Figure(1): BER performance with ISI effect of cloud for three different wavelength λ=0.532µm,0.8 µm,1.3 µm. Cloud thickness=250m.

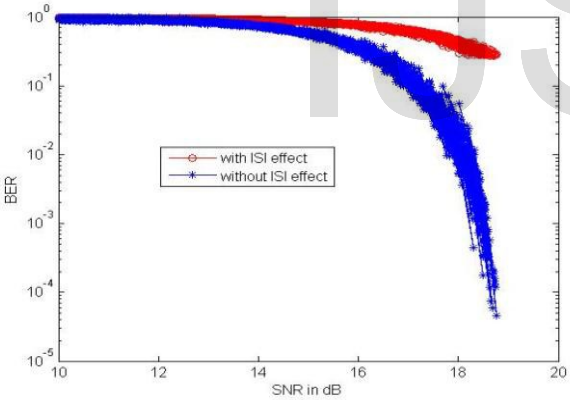


Figure (2): BER performance of received signal with and without the effect of ISI caused by cloud. Cloud thickness=250m.

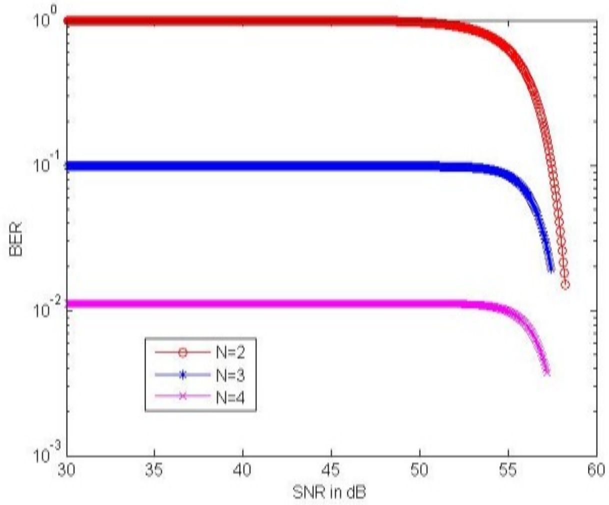


Fig3: BER performance of differently coherent detected signal in presence of cloud for different length of data sequence (Data sequence length is 2N, where N=2, 3, 4).

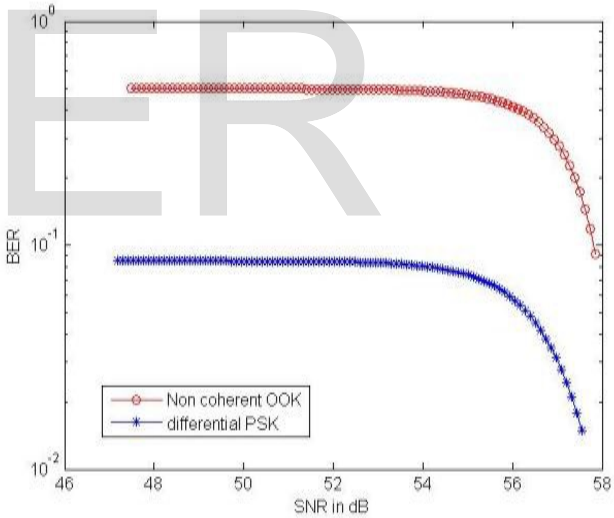


Fig4: Comparative BER performance of Non Coherent ON OFF Keying (OOK) detected signal and differentially coherent detected signal in presence of cloud transfer function.

5 CONCLUSION

In our work, using a maximum likelihood approach a decision metric is determined to find out the optimum condition for differential detection of BPSK signal. It is evident from analysis that there is signal power and signal quality both degrades a lot for cloud effect. As a result of pulse broadening in cloudy media ISI effect is severe in received signal so that high SNR (nearly 78 dB)is needed to achieve a BER at the scale of 10 -8 .

However with the increase of received data sequence length and combination of adaptive algorithm with differentially coherent detected signal better BE R performance can be achieved than conventional OOK detection.

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