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BER Analysis of Multipath PPM and MSK Carrier Intensity Modulation

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Abstract: **In order to improve the bit-error-rate (BER) performance of free-space optical (FSO) communication systems employing binary phase-shift keying subcarrier intensity modulation (BPSK-SIM), an innovative hybrid modulation scheme called PPM-MSK-SIM is proposed, which is based on pulse position modulation (PPM) and minimum shift keying (MSK) subcarrier intensity modulation. Subsequently, the BER performance of PPM-MSK-SIM is studied in detail for an FSO system over log-normal turbulence channels with avalanche photodiode detection. The results of the numerical simulation show that PPM-MSK-SIM has the advantages of improving the BER performance compared with BPSK-SIM and PPM. This makes PPM-MSK-SIM a favorable candidate for the modulation technique in FSO communication systems. In this paper, we investigate the bit error rate (BER) performance of FSO links with spatial diversity over lognormal atmospheric turbulence fading channels, assuming both independent and correlated channels among transmitter/receiver apertures. Our analytical derivations build upon an approximation to the sum of correlated log-normal random variables. The derived BER expressions quantify the effect of spatial diversity and possible spatial correlations in a log-normal channel.**

Index Terms: **Free-Space Optical Communication; Subcarrier Intensity Modulation; Atmospheric Turbulence; Atmospheric Attenuation; Bit-Error Rate (BER);**

I. INTRODUCTION

FREE-SPACE optical (FSO) communications is a costeffective, license-free, and high bandwidth access technique, which has attracted significant attention recently for a variety of applications [1]-[3]. Despite the major advantages of FSO communications, its widespread use is hampered by several challenges in practical deployment. For example, aerosol scattering caused by rain, snow, and fog results in performance degradations, leaving the FSO link vulnerable to adverse weather conditions. Another possible impairment over FSO links is building-sway as a result of wind loads, thermal expansion, and weak earthquakes. A major impairment is the effect of atmospheric turbulence [4], which will be the focus of this paper. Atmospheric turbulence occurs as a result of the variations in the refractive index due to in homogeneties in temperature and pressure changes. This results in rapid fluctuations at the received signal, i.e., signal fading, impairing the link performance severely.

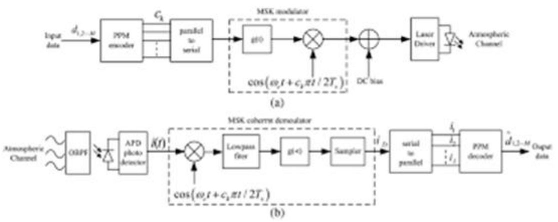

Fig1. FSO Block Diagram

Thus, the atmospheric turbulence lead to severe degradation of signal optical intensity at the receiver, increase the BER, and even break the communication link [4]. For different atmospheric turbulence intensity, in recent years, a number of statistical models have been introduced. For example, lognormal, gamma-gamma, and negative exponential models are the most commonly used for the cases of weak-to-moderate Analyzing a Scheme Based on PPM and MSK SIM moderate-to-strong, and saturated turbulence channels, respectively [5]–[9]. To overcome the challenges of atmospheric turbulence, one of the main factors in the implementation of high performance FSO systems is the modulation technique. Under the premise of high transmission rate and low BER, by choosing one appropriate modulation scheme and the corresponding demodulation technology will reduce the affects of atmospheric turbulence on the FSO communication. Conventionally, on-off keying (OOK) based on intensity modulation/direct detection (IM/DD) is the most widely adopted modulation scheme thanks to its simple implementation and low cost [3]. But FSO systems employing OOK has been found to be sub-optimal over atmospheric turbulence channels. Then, the pulse position modulation (PPM) has been used widely in FSO communication systems. However, the bandwidth efficiency of PPM is poor, and it needs symbol synchronization [9]. As a potential alternative to the OOK is subcarrier intensity modulation (SIM), which was first proposed for

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FSO systems by Huang etc. Thereafter, the performance of subcarrier binary phase shift keying (BPSK) intensity modulation FSO systems has been extensively studied. As we all know, compared with the traditional SIM in FSO communication systems, the BER performance of BPSK-SIM is superior over the other modulation schemes such as MPSK, QPSK, DPSK, QAM and so on [11]–[12]. For further improving the BER performance of FSO systems employing BPSK-SIM, in this paper, an innovative hybrid modulation scheme called PPM-MSK-SIM is proposed, which is based on PPM and MSK subcarrier intensity modulation. Then the BER performance of PPM-MSK-SIM is theoretically analyzed, verified using simulated data and compared with BPSK-SIM and PPM over lognormal turbulence channels for an avalanche photodiode (APD) detection scheme. The rest of the paper is organized as follows. We introduce the configuration of FSO communication system with PPM-MSK-SIM and its corresponding theory. We describe the channel models with atmospheric turbulence and attenuation, we analyze the BER performance of the proposed modulation scheme over the lognormal turbulence channels. Numerical results and discussions are presented and finally, conclusions are given.

II. FSO COMMUNICATION SYSTEM WITH PPM-MSK

Free Space Optics (FSO) is a promising solution for very high data rate point-to-point communication. In practice, several factors such as pointing errors and propagation loss associated with visibility can degrade the performance of an FSO system. We assumes clear atmosphere conditions and that the transmitter and the receiver are perfectly aligned. Even under these conditions, the system performance can be limited due to atmospheric turbulence. The resulting channel fading, i.e., random fluctuations in both the amplitude and the phase of the received signal, can deteriorate considerably the quality of data transmission. To reduce the destructive effect of turbulence, channel coding could be used under weak turbulence conditions. However, in the cases of moderate to strong turbulence, channel coding alone is not sufficient to mitigate fading efficiently and diversity techniques should be employed. The performance of the FSO link can also be improved by employing an appropriate modulation scheme that makes a good compromise between complexity and performance. In this view, we consider in this paper the pulse position modulation (PPM) which has the interesting advantage of being average-energy efficient. We first study the upper bound on the information transmission rate for PPM modulation in the absence of turbulence. Then, we consider the channel coding adapted to PPM. As a matter of fact, for non-binary PPM, we should use a non-binary code to correct efficiently the demodulation errors. The disadvantage of such a method is that it necessitates computationally complex decoding at the receiver. An important point is hence to use a channel coding technique adapted to PPM and of reasonable complexity. We propose to use a classical binary convolutional code and to perform iterative soft signal demodulation and channel decoding at the receiver. We study the performance of this scheme that we call BCID (standing for Binary Convolutional encoding with Iterative Detection), by presenting some simulation results. We assume that we do not have any source of diversity available: we use a monochromatic laser with a single beam at the transmitter and a single lens of very small size at the receiver, usually referred to as a point receiver. we present our system model and general assumptions. Next, a brief state of the art on PPM and the proposed coding schemes for this modulation are presented. Also, the information transmission bounds are studied for a non-random PPM channel, i.e., in the absence of turbulence. Iterative detection, including PPM and soft demodulation,

III. SYSTEM MODEL AND ASSUMPTIONS

At the transmitter, the encoded information bits are transformed into symbols according to the PPM modulation that is explained in the next section. The encoder is a classical binary convolutional code.

We denote the transmitted light intensity and by the corresponding received intensity in an PPM slot. Denoting the channel fading coefficient by h. The received signals are optical/electrical conversion

$$r = \eta_h I_0 + n,$$

where η is the optical/electrical conversion efficiency assumed here to be unity for simplicity. Also, n is the receiver noise, assumed to be dominated by thermal noise, and modelled by a zero-mean Gaussian additive random process. Note that for an OFF PPM slot, we have r = n. We perform soft demodulation on the received signal r based on the maximum a posteriori (MAP) criterion, followed by soft channel decoding. Soft information at the demodulator or decoder outputs is considered in the form of logarithmic likelihood ratio (LLR). We assume that we do not have inter-slot interference (ISI). That is, we assume perfect time synchronization and that the signal corresponding to each time slot is independent of those of the other slots.

Channel coding for PPM

An important issue is to use an appropriate channel coding scheme in the case of using PPM. A number

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of coding techniques including convolutional codes, turbo codes (TC), and Reed-Solomon (RS) codes, have been proposed so far. The classical binary convolutional codes have been applied to QPPM. More powerful codes such as turbo-codes have also been considered for QPPM. However, the main drawback of these schemes is that binary codes are not suitable for using with Q-ary symbols in the sense that they are not efficient for correcting demodulator output errors. Non-binary codes are more appropriate. However, the problem with non-binary convolutional or turbo-codes is their decoding complexity that can be prohibitively large for a practical implementation in a Gbps-rate FSO system. RS codes are appropriate from this point of view: an (n, k) RS code is naturally matched to QPPM by choosing n = Q−1. However, the performance improvement by RS coding is not considerable due to the fact that, usually hard RS decoding is performed at the receiver which has the advantage of low complexity. Soft RS decoding, on the other hand, is computationally too complex and is rarely implemented. A concatenation of convolutional and RS coding has also been proposed. This scheme has a rather limited performance as hard decision Viterbi decoding is done for the former. In this work, we explain how to adapt a simple binary convolutional code to the case of PPM. As we will see, in order to efficiently correct demodulation errors.

Channel capacity

It is interesting to compare the upper bounds on the information transmission rate for OOK and PPM modulations. Although these bounds cannot really be called capacity in the sense of Shannon (because of restricting the distribution of the transmitted signal according to the underlying modulation), for simplicity we will call them capacity of OOK or PPM. For the case of deep-space communication using a photon counting receiver, where the Poisson channel model is considered. We consider in this paper the case of terrestrial FSO systems used over ranges up to several kilometers. In such systems, photon counting is not feasible in practice. In fact, the received photon flux is important and we can detect the received signal based on the beam intensity directly. Here, we consider the channel capacity for different modulation schemes for intensitybased signal detection. The channel capacity is the maximum of the mutual information I(X; Y) between the channel input X and output Y , with respect to the input distribution $P_X(x)$:

$$C = \max_{P_{X(x)}} I(X; Y)$$

$P_X(x)$ is in fact the probability mass function (PMF) of X. Let us denote by $f_Y(y)$ the distribution of Y and by $f_{Y|X}(y|x)$ the conditional distribution of Y to X. Variable X takes the values 0 or 1, corresponding to an OFF or ON slot, respectively.

To evaluate the BER performance, it is desirable to compare the PPM-MSK-SIM with PPM and BPSK-SIM schemes via computer simulations. In this section, the analytical and simulation error probabilities are carried out over the lognormal turbulence channels. Unless otherwise noted, the parameters associated with the system model and constants are listed in Table 1. The BER for 2-PPM-MSK-SIM compared with 2-PPM and BPSK-SIM schemes over the different lognormal turbulence channels the consistency of the results of numerical simulation and theoretical analysis are quite good, which shows that our numerical simulation is correct. In addition, we found that the error performance of 16-PPM-MSK-SIM & 32 PPM-MSK-SIM is obviously better than that of 16-PPM and BPSK-SIM.At the same time, this advantage of 16-PPM-MSK-SIM increase gradually compared with 2-PPM and BPSK-SIM as the strength of turbulence increases.

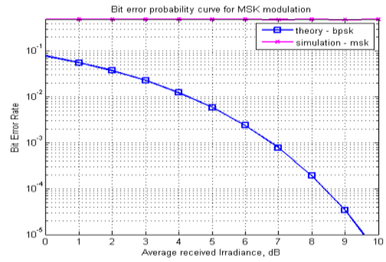

Fig 2: Bit Error Rate Analysis for MSK -16 bit

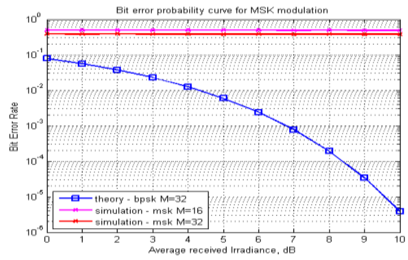

Fig 3: Bit Error Rate Analysis for MSK -32 bit

Hence, the PPM-MSK-SIM can significantly improve the system performance over the lognormal turbulence channels. The reasons for these results are that the PPM-MSK-SIM has not only the strong anti-interference of MSK but the high power utilization ratio of PPM as well. When the average length of symbol L of PPM-MSK-SIM is changed, its BER performance.The resulted figure shows the variation of BER analysis by increasing the number of bits from 16 to 32 MSK. PPM-MSK-SIM increasing the number of bits will increase the performance.

IV. CONCLUSION

In this paper, we propose a new hybrid modulation scheme called PPM-MSK-SIM, which is based on PPM and MSK-SIM and combines the advantages of MSK's strong anti-interference and PPM's high power utilization ratio concurrently. Then, its BER

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performance is investigated in detail over lognormal atmospheric turbulence channels with an APD detector. The results show that the BER performance of PPM-MSK-SIM is obviously better than PPM and BPSK-SIM not only for different average length of symbol L but also for increased link distance; Particularly, this kind of superiority can be moderately improved as the turbulence increase in the lognormal channel. Moreover, the BER performance of PPM-MSK-SIM schemes over the lognormal turbulence channels are compared, the research achievement shows that the error performance decreases with the increase of L. These above considerations make the PPM-MSK-SIM a favorable candidate to select as the modulation technique in FSO communication systems.

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