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Channel Estimation and Signal Detection of Pulse Code Modulated Optical Scattering Communication

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Abstract: ***For developing the receiver side digital signal processing techniques, necessary for the non-line of sight (NLOS) optical wireless scattering communication channel model. A linear time-invariant (LTI) Poisson channel modeling method, to model the NLOS optical wireless scattering communication, which was originally proposed for molecular communication is considered. In such a model the stochastic inter-symbol interference (ISI) is analyzed. The transmitter side is characterized by the pulse code modulation (PCM) and transmitted through the above. The channel estimation schemes, based on the least squares and correlation criteria is done, and analyzed the performance of the proposed channel estimation schemes. Also two signal detection schemes, namely the simple linear minimum mean square error (LMMSE) receiver treating ISI as noise and the maximum-likelihood sequence detection (MLSD) scheme that takes ISI into account and compared the same. PCM gives the fastest transmission and better SNR value than that of PPM. This paper presents a novel and effective study of the performance of the channel using PCM and the comparison of the same with PPM.***

Keywords: Optical wireless scattering communication, LTI-Poisson channel, Estimation techniques, Detection techniques.

1. Introduction

Because of its appealing features in security and flexibility, outdoor non-line-of-sight (NLOS) optical scattering communication has attracted great attention from worldwide researchers. Extensive studies have focused on the ultraviolet spectrum utilizing the strong scattering property in the ultraviolet band. In the atmosphere, light over broad spectra is scattered and/or absorbed by air molecules and aerosol particles, especially in foggy or hazy days when the multiple scattering and absorption effects become significant. For NLOS scattering communication, a channel's path loss has been one of the most important factors that adversely affects the communication system performance, especially when communication distance is in the order of kilometer range. The scattering and absorption by suspended particles are major contributors, and their effects depend on wavelength. Therefore, NLOS operation may need to identify a proper wavelength across broad spectra to achieve the best performance.

A stochastic non-line-of-sight (NLOS) ultraviolet (UV) communication channel model is developed using a Monte Carlo simulation method based on photon tracing [2]. By computing photon arrival probabilities and associated propagation delay at the receiver, the expected channel impulse response is obtained. This method captures the multiple scattering effects of UV signal propagation in the atmosphere, and relaxes the assumptions of single scattering theory. Here focuses on modeling of NLOS channel impulse response and analysis of link performance. In a NLOS UV communication system, photons interact with abundant atmospheric molecules and aerosols. In addition to absorption, multiple scattering may occur when the particle density is large and/or the propagation distance is long. The single scattering assumption does not always lead to accurate communication performance prediction.

The discrete-time Poisson channel with large-inputs asymptotic capacity of a peak-power and average-power limiting is derived using non-asymptotic lower bound and an asymptotic upper bound [5]. The upper bound is upon the channel capacity (dual expression) and the notion of capacity- achieving input distributions that escape to infinity. The lower bound is on a lower bound on the entropy of a conditionally Poisson random variable in terms of the differential entropy of its conditional mean.

Due to its potential use in various applications, Free space optical (FSO) communication is a wireless technology which has recently attracted much interest within the research community, [6]. Despite of their significant advantages, with adverse atmospheric conditions, the widespread deployment of FSO systems is limited by their high vulnerability. Even in a clear sky, due to in-homogeneities in temperature and pressure changes, the refractive index of the atmosphere varies and results in atmospheric turbulence. This affects severely the overall reliability of the FSO link and degrades the expected performance. Because atmospheric turbulence produces turbulence-induced fading where there is rapid fluctuations at the intensity of the received optical signal. A simple symbol-by-symbol maximum-likelihood (ML) detector has been proposed in [6], used the channel's statistics for determining the threshold in the detection process of the OOK bits, this detector suffers from significant performance loss. The maximum likelihood sequence detector (MLSD) which performs with the joint detection of multiple symbols based on the channel's temporal and statistical characteristics. Despite its efficiency, MLSD suffers from high complexity, since it involves the computation of complicated integrals in its metric. The aim of this scheme is to use pulse code modulation for obtaining the fastest and error free transmission. Data transmission through the channel is faster as compared to PPM. PPM is

often called FM but that is false, both PPM and PCM can sent on exactly the same FM radio. PCM's big advantage used to be that it alone could do error detection (though not error correction) and then go into failsafe. If interference is switching rapidly on and off PCM can get a bit
more of its signal through uncorrupted compared to PPM due to the way it tends to split the whole data set into smaller packets whereas PPM has to send the whole data set in one packet.

2. System Architecture

A linear time-invariant (LTI) Poisson channel is used to model the optical wireless scattering communication from the communication. In the model, the entire transmission is divided into various transmission slots, and the transmitter transmits the modulated pulses to the receiver. The channel response to a unitary transmission power in one slot is a finite-length pulse of Poisson distributed received photon numbers with certain mean values. The stochastic channel model is parameterized by the mean value of Poisson distributed photon numbers corresponding to a unitary transmission power, which needs to be estimated from the received signal. These block diagram of the system is illustrated in Figure 1.

A training sequence is transmitted for the parameter estimation, at the cost of several pilots. The information bits are coded by the channel encoder which is a linear encoder with length 8. Then it is modulated with the optical modulation scheme pulse position modulation with the constraint that some pulses will overlap to each other and is then sent to the NLOS channel. Due to the weak signal nature, the received signal exhibits the characteristics of discrete photons, where a photon-counting receiver is employed to detect the number of photons received.

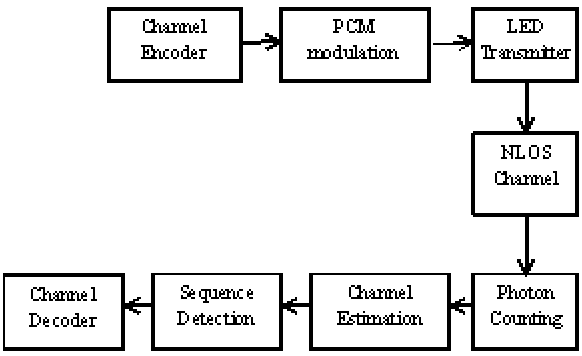

Figure 1: System Block Diagram

The physical-layer signals are characterized by Poisson distributed non-negative integer numbers. Based on the non-negative integer signal, the receiver performs channel estimation and the sequence detection based on the estimated channel state information. The error bits are corrected by the channel decoding block, which outputs the decoded information bits. A pilot-based channel estimation is used, where the transmitter sends known pilots to the receiver, and the receiver performs channel estimation based on the number of received photons in each slot. Least-squares (LS) and correlation bank (CB) estimation, for estimating the parameters of Poisson Distribution. The detection schemes used are Least Minimum Mean Square Error (LMMSE) detection and Maximum-Likelihood Sequence Detection (MLSD).

The ISI inevitably increases the mean square error (MSE) of the channel estimate. Besides, the channel estimation accuracy is critical to the performance of receiver-side signal processing schemes. In this work, channel parameter estimation methods such as, least-squares (LS) estimation and correlation banks (CB) is calculated, and analyze the performance of the proposed channel estimation methods. Furthermore, maximum-likelihood sequence detection (MLSD) scheme for the transmitted pulse coded sequence (PCM) sequence through the considered ISI channel. Numerical results show the significant SNR and error probability of the MLSD. It reveals the impact of ISI and the significance for corresponding processing for weak-link optical wireless scattering communication.

2.1 Pilot-Based Channel Estimation

According to the system block diagram shown in Figure 1, the channel estimation provides the estimated channel state information to the subsequent processing blocks. The channel parameters needed to be estimated are the ratio between the transmission power and mean value of Poisson distribution for the LTI-Poisson channel. The transmitter sends known pilots to the receiver, and the receiver performs channel estimation based on the number of received photons in each slot.

3. Channel Estimation and Signal Detection

In all communication the signal goes through a medium (called channel) and the signal gets distorted or various noise is added to the signal while the signal goes through the channel. To decode the exact received signal with comparatively less errors are to remove the distortion and noise exerted by the channel from the received signal. for this, figure out the characteristics of the channel that the signal has gone through. The procedure to describe the distinctive nature or features of the channel is called channel estimation. There are various ways for channel estimation, but underlying fundamental concepts for all are same. The process is explained as follows.

1) Correlate transmitted signal and received signal using channel matrix for that set a mathematical model for the system.
2) Transmit a pilot signal (reference signal) and detect the received signal for the same.
3) Compare the transmitted signal and the received signal from the matrix, then figure out each elements of channel parameters.

The LS channel estimation aims to find the channel parameters that minimize the following sum expected distortion. It is well known that, for RF communication with additive Gaussian noise, the LS channel estimator is unbiased. For Poisson type channel, it is proved that the LS channel estimator is biased, and is asymptotically unbiased as the transmission power approaches infinity.

$$D(\{\alpha_d\}_{d=0}^{D}) \triangleq \sum_{t=D}^{T} \mathbb{E}\Big[(\sum_{d=0}^{D} v_{t-d,d} + n_t - u_t)^2\Big]$$

For Poisson channel, the channel estimation MSE involves other two terms, which implies longer transmission duration to obtain a satisfactory channel estimation. Moreover, for Poisson type channel, the MSE minimization problem is different from that for the RF channel. But the optimal pilot design to minimize the MSE or based on other optimization criteria can be performed by elegant approaches in [10]. It is seen that the channel estimation MSE attenuates asymptotically in proportional to $P-1$ as the transmission power P approaches infinity.

$$MSE_{RF} = Tr\big((ZZ^T)^{-1}\big)$$

It is seen that the variance decreases linearly with the estimation length $T-\tau'+1$, which is of the same order as that for the RF communication. The first three terms are due to the nature of the correlation bank-based channel estimation, which does not vanish for RF communication with additive Gaussian noise; and the last term is due to the Poisson signal nature. It is seen that Poisson signal increases the variance for the correlation bank-based estimator $R(\tau)$, and thus longer pilot length is needed to obtain a satisfactory estimation. The Poisson signal nature does not change the order of the estimation variance with respect to the pilot length.

$$D_R(\tau) = \frac{D_\tau}{(T-\tau'+1)^2}$$

4. Simulation Results

MATLAB R2015b is used as a simulation platform. The least square estimation and correlation bank estimation is done for PCM modulation and PPM modulation [1]. The detection techniques, linear minimum mean square error detection and maximum likelihood detection is done and is characterized by the SNR value for the channel. From the computed results it is obvious that the PCM modulation scheme gives the fastest transmission and better SNR value than that of the PPM signal. Then the comparison plot for both is obtained.

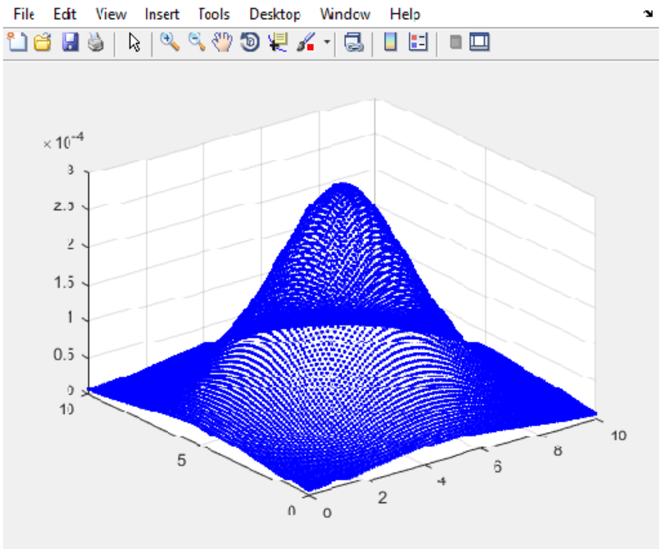

Figure 3: Intensity plot of LED

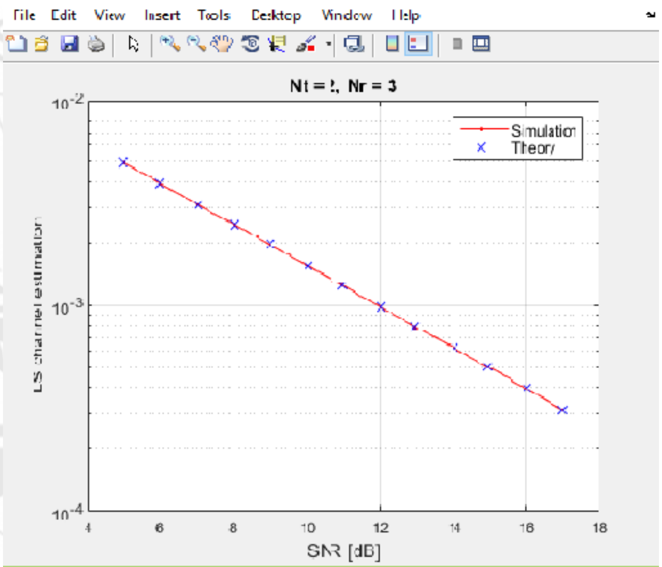

Figure 4: Least square estimation

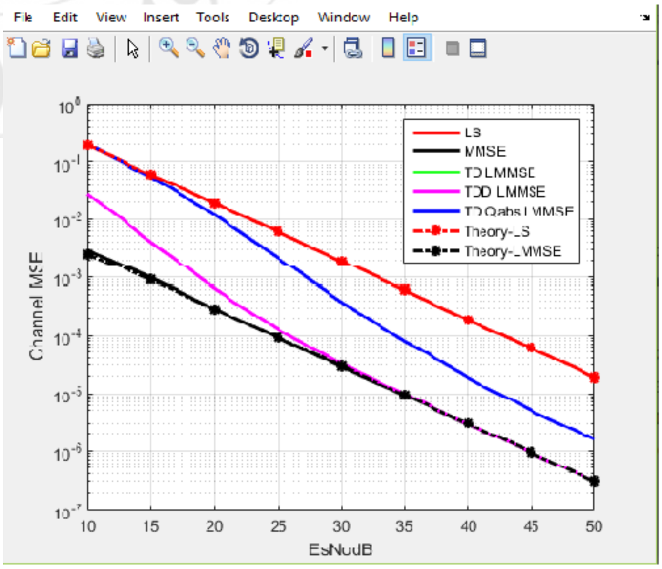

Figure 5: Comparison for Estimation

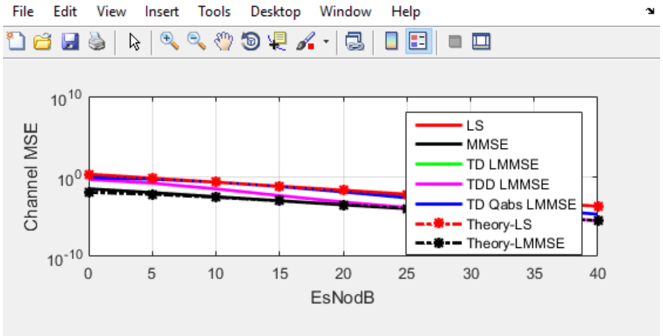

Figure 6: Comparison

5. Conclusion

An optical wireless scattering communication channel and system model by following an existing LTI-Poisson channel is modeled. The severe and stochastic ISI is caused by channel dispersion much longer than the symbol duration. Analyzed the LS- and CB based channel estimation schemes, and plotted the associated channel estimation performance. Furthermore, the performance degradation caused by ISI, and proposed the structure-based MLSD scheme is analyzed. For the input signal, encoding and pulse position modulation is done. The LED transmitter is obtained which has a power in milli-watt range and calculated the intensity plot of the LED. The Poisson distributed channel is taken with some interferences. The channel is estimated and the bit error rate is plotted. The input signal is encoded and pulse code modulation is done. Signal detection and bit error rate is obtained for the same.

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