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A blind detection scheme based on modified wavelet denoising algorithm for wireless optical communications

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ABSTRACT

This paper investigates a detection scheme without channel state information for wireless optical communication (WOC) systems in turbulence induced fading channel. The proposed scheme can effectively diminish the additive noise caused by background radiation and photodetector, as well as the intensity scintillation caused by turbulence. The additive noise can be mitigated significantly using the modified wavelet threshold denoising algorithm, and then, the intensity scintillation can be attenuated by exploiting the temporal correlation of the WOC channel. Moreover, to improve the performance beyond that of the maximum likelihood decision, the maximum a posteriori probability (MAP) criterion is considered. Compared with conventional blind detection algorithm, simulation results show that the proposed detection scheme can improve the signal-to-noise ratio (SNR) performance about 4.38 dB while the bit error rate and scintillation index (SI) are 1×10^{-6} and 0.02, respectively.

1. Introduction

Wireless optical communication (WOC) is an attractive alternative method to solve the access network bottleneck and has attracted much interest within the research community [1–6]. Compared with conventional wireless communication, it can provide high data rate transmission with higher security, higher flexibility, smaller volume, and absence of government regulations restricting the usage of bandwidth [1,7]. However, there are more challenges in WOC, such as absorption and scattering caused by small atmospheric particles, intensity scintillation caused by turbulence and additive noise caused by background radiation and photodetector [7–13]. Among all the impairments to WOC links, intensity scintillation and the additive noise are the major impairments, which result into the difficulty of signal detection.

Several detection algorithms have been proposed to recover data deteriorated by the random channel. Zhu and Kahn [13] proposed a maximum likelihood (ML) symbol by symbol detection with the knowledge of the statistical distribution of the channel gain and the parameters of the distribution. Reference [13] also shows that the maximum-likelihood sequence detection (MLSD) can be employed if the receiver has the knowledge of the joint temporal statistics of fading. For these two methods, even though the instantaneous channel state information (CSI) is not necessary, the receiver must have perfect channel model information, which is difficult to obtain in practice. To solve this problem, a pilot-symbol assisted modulation (PSAM) scheme is proposed in [14,15]. PSAM requires frequent insertion for accurate channel estimation, leading to loss of data rate. A conventional blind detection (CBD) is developed in [16], which means both CSI and the channel model information can be unknown. However, the performance of the CBD is limited by the additive noise. Hence, this paper proposes a detection scheme, named a blind detection based on modified wavelet threshold denoising (BD-MWTD) algorithm. The algorithm can diminish the intensity scintillation effectively as well as the additive noise. Simulation results show that performance of the algorithm is much better than ML symbol by symbol detection and the CBD proposed in [13,16].

This paper is organized as follows. In Section 2, we review the mathematical model of the WOC channel and the signal, which is impaired by the intensity scintillation and additive noise. We then illustrate why it is necessary to use the denoising algorithm. In Section 3, the BD-MWTD scheme is introduced. We present the simulation results for the proposed detection scheme and compare it with other schemes in Section 4. In the last section, our conclusions are drawn.

2. Mathematical model

2.1. Channel model

In the WOC channel, the gamma-gamma probability density

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function (PDF) is usually used to describe the intensity distribution, which is given by [17,18]

$$f_I(I) = \frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} I^{(\alpha+\beta)/2-1} K_{\alpha-\beta}\left(2\sqrt{\alpha\beta I}\right), \quad I > 0 \tag{1}$$

where $\Gamma(\cdot)$ is the gamma function, $K_\nu(\cdot)$ is the νth-order modified Bessel function, α and β are related with the atmospheric conditions. I denotes the normalized intensity. The scintillation index (SI) can be calculated from α and β according to $\mathrm{SI} = \alpha^{-1} + \beta^{-1} + (\alpha\beta)^{-1}$.

2.2. Signal model

Consider a long-distance WOC system where the receiver's signal-to-noise ratio (SNR) is effectively restricted by the shot-noise caused by background radiation and thermal noise arising at the photodetector. In this case, the noise can usually be modeled as additive white Gaussian noise (AWGN) which is statistically independent with the transmitted data [13]. The received discrete-time signal of the kth symbol interval is modeled as [13,16]

$$r_e[k] = s[k] I_s[k] + I_b + i_n[k] \tag{2}$$

where $s[k]$ is the transmitted data, and is either 0 or 1 for on-off-keying (OOK) system. Without loss of generality, we assume that the probability of 0 and 1 is equal. $I_s[k]$ is the channel fading intensity which is caused by atmospheric turbulence and the PDF of $I_s[k]$ is shown in (1). I_b is the mean of AWGN and $i_n[k]$ is AWGN with variance σ_w^2 and mean zero. Note $r[k] = r_e[k] - I_b$. Then the signal model can be expressed as

$$r[k] = s[k] I_s[k] + i_n[k] \tag{3}$$

Similar to the [6,16], we define the SNR as

$$\gamma = \frac{E\left\{(s[k]I_s)^2\right\}}{E\left\{(i_n[k])^2\right\}} = \frac{E\left\{(s[k]I_s)^2\right\}}{\sigma_w^2} \tag{4}$$

where $E\{\cdot\}$ means the statistical expectation. The condition probability can be expressed as

$$P(r|0) = \frac{1}{\sqrt{2\pi}\sigma_w} \exp\left(-\frac{r^2}{2\sigma_w^2}\right) \tag{5}$$

$$\begin{aligned} P(r|1) &= \int_0^{+\infty} P(r|1, I) f_I(I) dI \\ &= \int_0^{+\infty} \frac{1}{\sqrt{2\pi}\sigma_w} \exp\left(-\frac{(r-I)^2}{2\sigma_w^2}\right) f_I(I) dI \end{aligned} \tag{6}$$

The bit error rate (BER) is

$$P_b = P(0)\cdot P(1|0) + P(1)\cdot P(0|1) = P_{b0} + P_{b}' \tag{7}$$

$$P_{b0} = \frac{1}{2} P(0)\, erfc\left(\frac{\tau}{\sqrt{2\sigma_w^2}}\right) + \frac{1}{2} P(1) \int_\tau^{+\infty} erfc\left(\frac{I-\tau}{\sqrt{2\sigma_w^2}}\right) f_I(I) dI \tag{8}$$

$$P_{b}' = \frac{1}{2} P(1) \int_0^{\tau} erfc\left(\frac{I-\tau}{\sqrt{2\sigma_w^2}}\right) f_I(I) dI \tag{9}$$

where τ is the threshold. In general, $f_I(I)$ is quite small when $I < \tau$. Therefore, we can analyze P_{b0} to obtain the characters of P_b. Because P_{b0} increases with the increase of σ_w^2 when τ is constant, it can improve the performance of the system if σ_w^2 can be diminished. Based on this idea, the denosing algorithm is proposed.

3. BD-MWTD algorithm

Clearly, from (7), (8) and (9), we can elicit that the performance of the system can be improved if σ_w^2 is diminished. Therefore, the modified wavelet threshold denoising (MWTD) algorithm is proposed. Then, block detection is illustrated and simplified signal model is introduced. The algorithm to find the optimal threshold under MAP criterion is shown at last. The procedure of the proposed detection can be summarized in three steps. Firstly, using the MWTD algorithm processes the signal. Then, consider an observation sequence of N bit interval. At last, using the optimal threshold under MAP criterion for the signal decision, the received data can be obtained.

3.1. Denoising algorithm

The denoising algorithm proposed in this paper is the MWTD algorithm. Firstly, using the discrete wavelet transform (DWT) algorithm transforms the signal to wavelet domain. DWT is a multi-resolution analysis (MRA) tool where signals are divided into different frequency bands at different level of the decomposition [19,20]. The fast algorithm of the DWT can be done by using the filter bank [21]. The signal is filtered by a series of high pass filters (HPF) $g[n]$ and low pass filters (LPF) $h[n]$ to analyze the high and low frequency components, as illustrated in Fig. 1. The decomposition process uses $h[n]$ and $g[n]$ to split the signal into its approximation and detail coefficients and then down samples by two. The coefficients of the wavelet domain $y_{jh}[k]$ (detail coefficients) and $y_{jl}[k]$ (approximation coefficients) at the decomposition level j can be obtained from [19,22]

$$y_{jh}[k] = \sum_n y_{(j-1)l}[n]\cdot g[2k-n] \tag{10}$$

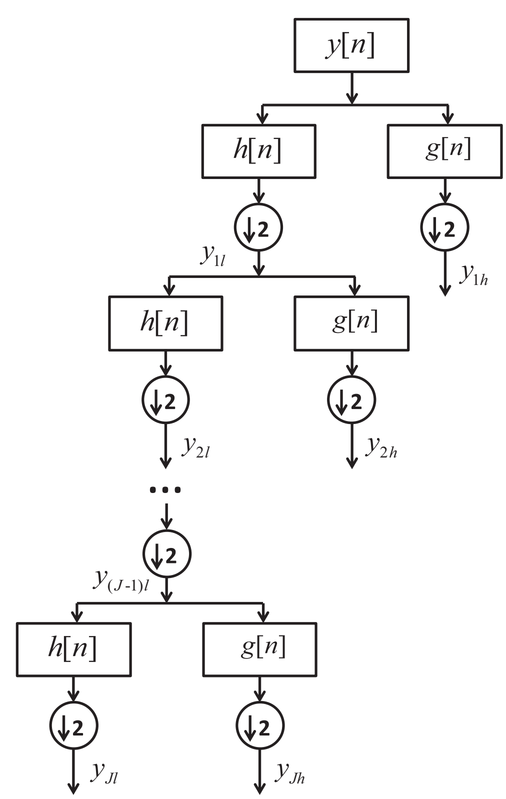

Fig. 1. The decomposition process using high and low pass filters, J is the maximum number of decomposition levels.