Mitigation of the Influence of Optical Background Noise
by Using Turbo-Coded DOOK

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Abstract In this paper, turbo-coded on-off keying (OOK) with differential detection is proposed. The proposed system constitutes the standard turbo code with OOK modulation, differential encoding and a delay detection technique. The purpose of using the differential encoding system is to suppress the influence of background noise in an optical wireless channel (OWC). OOK systems use the threshold detection method to determine the data. In optical intensity modulation/direct detection (IM/DD) systems, disturbances in the channel such as background noise and scintillation make it more difficult to decide the threshold value. Hence, in order to deal with the degradation in the quality of communication due to background noise, a turbo-coded OOK system with differential encoding and delay detection is proposed. The bit error rate (BER) performance of the proposed system is analyzed through computer simulation of an OWC in the presence of background noise, scintillation and avalanche photodiode (APD) noise. In terms of the BER performance, the results of this study show that the proposed system outperforms the conventional turbo-coded OOK system by 2.0 [dBm] at BER=10⁻⁵.

Keywords: differential on-off keying, turbo code, optical wireless channel, background noise

1. Introduction

In recent years, optical wireless intensity modulation/direct detection (IM/DD) systems have attracted considerable interest arising from the fact that they can be easily implemented in transmitter and receiver sides [1]. They are widely used in various fields of application such as deep-space/inter-satellite communication, underwater search and rescue operations, home networks and ITS systems. Optical wireless communication is a possible alternative to RF wireless systems for short-distance wireless communication such as home networks because past research results have shown that much more data can be transmitted using light sources than in cellular networks, and communication can be carried out in a more straightforward, efficient, secure and widespread manner [2]. However, one of the major challenges that optical wireless communication faces is achieving high-reliability communication. The main causes are disturbances in the atmospheric channel such as optical background noise and scintillation [3]. Optical background noise produced by sunlight and fluorescent and tungsten filament lamps is a major source of interference in optical wireless communications [3],[4]. The presence of background noise and scintillation causes degradation of the bit error rate (BER) which results in unreliable communications [5],[6]. The implementation of error correction codes is one of the methods of reducing the effect of transmission impairments, which ultimately improves the BER performance. Various studies on turbo codes and low-density parity codes (LDPCs) have been carried out for an optical wireless channel [7]-[11]. For an optical wireless channel, it has been shown that it is most efficient to use incoherent optical modulation techniques such as on-off keying (OOK) and binary pulse position modulation (BPPM) [8],[9],[12]. In this paper, OOK is employed as a modulation scheme. Since received data are demodulated using threshold detection, it is difficult to determine the optimum threshold value in the presence of background noise [13]. Hence, to deal with this problem a complete system has been devised for the mitigation of optical background noise. Performance gain can be expected by embedding a differential encoder at the transmitter and a delay detector at the receiver of an
optical error-correction-coded OOK system.

Various studies have been conducted with the aim of reducing the effect of background noise in an OWC [14],[15]. In this paper, we propose a turbo-coded differential OOK (DOOK) system to deal with the effect of optical background noise in wireless IM/DD communication. We evaluate the BER performance of the proposed system by computer simulation. We also compare the proposed system with the conventional turbo-coded OOK system in terms of the BER performance. While executing the simulation, we take background noise, scintillation and avalanche photodiode (APD) noise into account and assume the communication scenario to be an indoor optical wireless home network.

This paper is organized as follows. In Sect. 2, we give an overview of the system components. In Sect. 3, we describe the channel model. Sect. 4 gives the simulation results and an analysis of the performance. Finally, we summarize the paper in Sect. 5.

2. Turbo-Coded Differential OOK

2.1 System overview

Figure 1 illustrates the system structure of turbo-coded differential OOK (DOOK). At the transmitter, source data are fed into the turbo encoder composed of two parallel concatenated RSC (recursive systematic convolutional) encoders. The outputs of the turbo encoder are further encoded by the differential encoder. The encoded data are then modulated by OOK and the optical source denoted by E/O in Fig. 1 transforms the electrical signal into an optical signal. The optical signal is transmitted wirelessly through the free space medium. The signal is affected by transmission impairments such as scintillation and background noise. At the receiver, the received signal is detected and converted back to an electrical signal by the APD. It is then decoded first by a delay detector. The outputs of the delay detector are further iteratively decoded by two MAP decoders using the BCJR-MAP algorithm for extra error correction. The final data are estimated by applying a hard decision to the outputs of the turbo decoder.

2.2 Differential encoder and delay detector

The differential encoding and the delay detection mechanisms are shown in Fig. 1. The k-bit output data block \(d_n = \{0, 1\}\) \((n = 1, 2, \cdots, k)\) from the turbo encoder is encoded differentially using

\[c_n = c_{n-1} \oplus d_n\]  

where \(\oplus\) indicates an exclusive OR operation. \(c_0\) is a default bit, which can be considered as a block synchronization bit stuffed before the differential encoding process. As an example, we have the data block \(d_n = \{'0111\}' with \(k=4\) bits as shown in Fig. 1. We assume the default bit \(c_0\) to be \('1'\), and the encoded data \(c_n\) are generated as

\[c_1 = c_0 \oplus d_1 = 0\quad (: c_0 = 1, d_1 = 1).\]

At the receiver side, the received encoded data block \(r_h\) is fed into the delay detector. The differential output \(s_n\) is obtained by subtracting the 1-slot-delayed signal \(r_{n-1}\) from the received signal \(r_n\). This process helps reduce the optical background noise from the noisy signal. The output of the delay detector is calculated based on the basis of the following equation:

\[s_n = r_n - r_{n-1}\]  

As shown in Fig. 1, the received noisy signal sequence \(r_n\) is \('10010'\) and the 1-slot-delayed signal sequence \(r_{n-1}\) is \('010010'\). \(s_n\) is generated by applying Eq. (2) to each slot, which regenerates a clean pulse free of background noise. \(s_n\) is then fed into the block synchronization system. The first and last bits are destuffed and the output \(u_n\) are fed into the turbo decoder. The final output data are retrieved through a hard decision based on the threshold value \(T_h = \log_2(\mu b_w - \mu b_e)\), which is the average power \(P_w\) of the transmitted signal. \(M_e\) is the modulation extinction ratio. The data bit ‘0’ is correctly determined in the range of \(-T_h < -T_h\) and ‘1’ is correctly determined in the range of \(-\infty < -T_h\) or \(T_h < \infty\).

3. Optical Wireless Channel

In the optical wireless channel, scintillation and background noise, which influence the received optical power of the signal, are taken into account. In IM/DD systems, the received optical power \(P_m\) can be expressed by

\[P_m = P_w X + P_b\]  

where \(P_w\) is the original received optical power without the effect of scintillation and background noise. The scintillation \(X\) is characterized by stationary random process. Its probability density function \(p(X)\) is given by

\[p(X) = \frac{1}{\sqrt{2\pi\sigma_X^2}} \exp \left(\frac{-\ln X + \sigma_X^2}{2\sigma_X^2}\right)\]  

where the average of scintillation \(X\) is normalized to unity, and \(\sigma_X^2\) is the logarithm variance. The variance \(\sigma_X^2\) depends on the atmospheric state. Let \(P_w\) be the received optical power, \(P_b\) be the background noise power, \(P_m\) be the received optical power, and \(\sigma_X^2\) be the variance of the scintillation.
and $X$ be the scintillation. Then, $P_{in}$ can be expressed as

$$P_{in} = \begin{cases} P_{w}X + P_{b} & \text{for a mark (presence of pulse)} \\ P_{w}M_{e}X + P_{b} & \text{for a space (absence of pulse)} \end{cases}$$

(5)

where $M_{e}$ is the modulation loss ratio at the photodiode output in the mark and space states.

### 4. Performance Evaluation

In this section, we present the BER performance of the proposed system in an IM/DD-based optical wireless channel. The parameters in the simulation are shown in Table 1 [10],[11].

Figure 2 shows the BER performance graphs of the proposed system and the conventional turbo-coded OOK system. From the result for the proposed system, we observe that a performance gain of about 2.0 [dBm] is obtained at BER=10^{-5} in comparison with the conventional system. This is because the proposed system minimizes the influence of background noise through the differential detection process illustrated in Fig. 1. The simulation results in Fig. 2 suggest that the proposed turbo-coded system with differential OOK outperforms the conventional turbo-coded OOK system.

Figure 3 shows the BER performance of the proposed and conventional systems with respect to various background noise $P_{b}$ values ranging from $-55$ [dBm] to $-35$ [dBm]. The average received optical power is set at $-42$ [dBm]. From the results, we noticed that in both cases the BER performance degrades as the background noise increases. However, the BER performance of the proposed DOOK system is better than that of the conventional OOK system. Comparing the results for the two systems, we can infer that the turbo-coded DOOK system can cope better with the effect of background noise in optical wireless communication.
5. Conclusion

In this paper, we proposed a turbo-coded differential OOK system and presented a BER performance evaluation for an optical wireless channel. The results derived through computer simulation suggest that the performance can be improved with the turbo-coded DOOK system, which exhibited better results than the conventional turbo-coded OOK system. In the case of a poor channel condition, the differential encoding and the delay detection technique can play an important role in suppressing the influence of optical background noise. Hence, we conclude that the combination of the turbo code and differential OOK can enhance the reliability of optical wireless IM/DD systems.

In future works, we will evaluate the BER performance of the combination of DOOK with other error-correcting codes in an optical wireless channel. We will thus clarify the effectiveness of the DOOK technique combined with other error-correcting codes.

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References


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