Novel Parallel Optical Turbo-code Communication System using RGB LEDs for Partial Erasure Channel

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Abstract: In optical parallel communications using RGB LEDs, the different attenuation rates of each colors cause the partial erasure channel, which makes the performance of communications down seriously. In this paper, a novel parallel optical Turbo-code communication system using RGB LEDs is proposed and investigated. It is assumed to be effective to solve the partial erasure channel transfer problem by re-arranging the Turbo-code parity-bit streams. Binary Pulse Position Modulation (BPPM) is used as the modulation technique. Moreover, for showing the effectiveness of the proposed system, the bit error rate (BER) performance of the proposed system is analyzed by computer simulation in Addict White Gaussian Noise (AWGN) channel and Optical Wireless Channel (OWC) taking background noise and scintillation in account, respectively.

Keywords—**optical wireless communication, turbo-code, partial erasure channel, RGB parallel transfer**

1. Introduction

In 1993, Turbo-code, which can approach Shannon limit, was introduced by Berrou et. al[1]. Since then, Turbo-code has been considered to be used in the optical wireless communication. Kiasaleh introduced Turbo-coded optical PPM communication systems in 1998[2]. Recently, numerous researches of multi-color parallel transfer have been carried out, such as "color shift keying", a visible light communication intensity modulation scheme outlined by IEEE 802.15.7. They have a good transmission efficiency, but significantly deteriorate the bit error rate (BER) performance. For improving the performance of multi-color optical parallel transfer, we consider to apply the error-correcting code: Turbo-code into the transmission. In the optical channel, there is a serious problem that the signal may be lost by attenuation, shadowing, etc.. Particularly, in parallel transfer, due to the different attenuation rates of color R, G, B, in quite a lot of situations, we can receive only a part of colors successfully. This situation is called "Partial Erasure Channel".

In this paper, for enhancing the performance in the partial erasure channel, we propose a new Turbo-code system with the re-arrangement scheme of parity-bit streams. For investigating the effectiveness, we evaluate the BER performance through computer simulation in Addict White Gaussian Noise (AWGN) channel. Moreover, for verifying the practicality of our proposed system, we also analyze the BER performance in Optical Wireless Channel (OWC) taking background noise and scintillation into account.

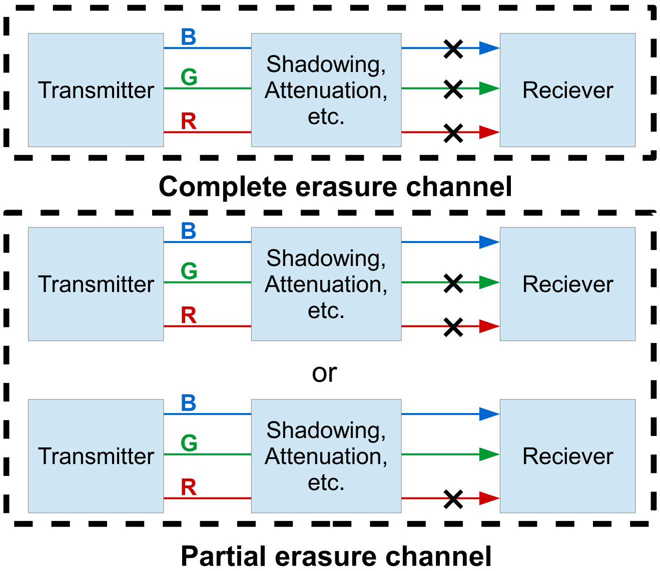

Figure 1. Erasure Channel

2. Partial Erasure Channel

In this section, we discuss the channel model of the system. First, let's understand what the partial erasure channel is. As we mentioned in Introduction, it is a serious problem in optical wireless channel that the signal may be lost by attenuation, shadowing, etc.. Thus, in parallel transfer, due to the different attenuations of color R, G, B, in quite a lot of situations, we may receive only a part of colors successfully.

As shown in Fig. 1, the situation, which we fail to receive the signal of all colors, is called "Complete Erasure Channel". In this channel, we are not able to receive any transmission data. Opposite to the complete erasure channel, the situation, which we receive a part of the colors, is called "Partial Erasure Channel". In this channel, we can receive only a part of the transmission data, in conventional communication system the bit error rate (BER) performance degrade seriously. We expects that the proposed system can improve the BER performance.

Then, we describe the optical wireless channel. In the optical wireless communication, background noise (ambient light, sunlight, etc.) causes loss of the signal strength, and the variation of refraction gives rise to a phenomena called scintillation. These two factors cause the fluctuation of received optical power principally. The received optical power $P_s(t)$ taking background noise and scintillation into account is given by,

$$P_s(t) = X(t)P_\omega(t) + P_b(t) \qquad (1)$$

where, $P_\omega(t)$ means the original received optical power without interference, and $P_b(t)$ is the power of background noise. $X(t)$ is based on the probability density function $p(X)$:

$$p(X) = \frac{1}{\sqrt{2\pi\sigma_s^2 X}} \exp - \frac{\ln X + \frac{\sigma_s^2}{2}}{2\sigma_s^2} \qquad (2)$$

where, the mean value of scintillation X is normalized to unity and logarithmic variance σ_s^2 depends on the atmospheric state and transmission distance.

An internal photoelectric converter called APD is used as photo-detector. Let's assume the average APD gain as G, and the signal power increases to G^2 times the value obtained from photo-diode. However, the noise in APD, represented in terms of shot-noise, gets increased concurrently.

We assume the accumulated output during each chip interval is a Gaussian random variable. Thus, the average number of electrons emitted by APD, $\mu(P_{in})$, is given by,

$$\mu(P_{in}) = GT_c(\frac{\eta P_{in}}{hf} + \frac{I_b}{e}) + \frac{IsTc}{e} \qquad (3)$$

where, T_c is the chip interval, f is the frequency of light, h is the Planck's constant, hf denotes the energy of a single photon, η is the quantum yield, e is the electronic charge, I_b is the average bulk leakage current and I_s is the average surface leakage current. The variance $\sigma^2(P_{in})$ of the electrons emitted by APD is given by,

$$\sigma^2(P_{in}) = G^2 F_e T_c(\frac{\eta P_{in}}{hf} + \frac{I_b}{e}) + \frac{IsTc}{e} + \sigma_{th}^2 \qquad (4)$$

$$\sigma_{th}^2 = \frac{2k_B T_r T_c}{e^2 R_L} \qquad (5)$$

where,σ_{th}^2 represents the variance of thermal noise, k_B is the Boltzmann constant, T_r is the receivers noise temperature and R_L is the load resistance. F_e is the excess noise index, which can be expressed as,

$$F_e = k_{eff}G + (2 - 1/G)(1 - k_{eff}) \qquad (6)$$

where, k_{eff} is the APD effective ionization ratio. Let P_w be the received optical power and P_b be the background noise. Then, P_in can be expressed as,

$$P_{in} = \begin{cases} P_\omega X + P_b & for\ a\ mark \\ P_\omega X M_e + P_b & for\ a\ space \end{cases} \qquad (7)$$

where, M_e is the modulation extinction ratio at the diode output between the space and mark states.

3. System Model

Figure 2 shows the proposed Turbo-code system model. The proposed system consists of two parts: transmitter and receiver.

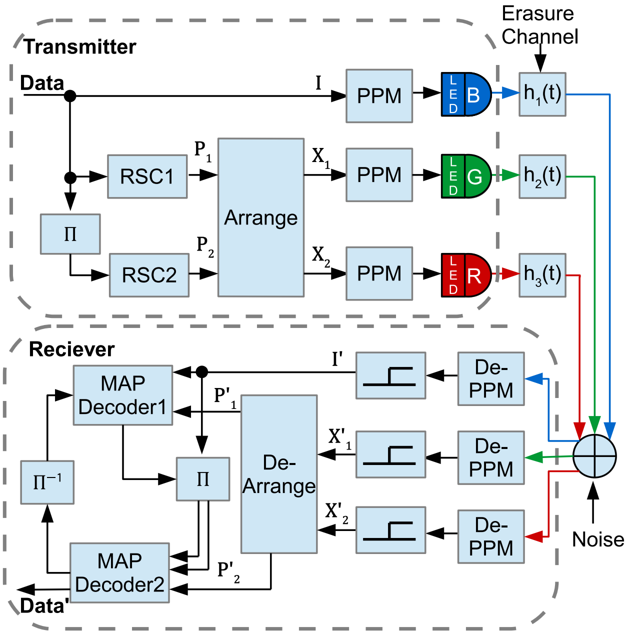

Figure 2. System Model

In the transmitter, first, we use an rate-1/3 Turbo-code encoder to output an information-bit stream: $\mathbf{I}=\{i_1, i_2, i_3, i_4, ...\}$ and two parity-bit streams: $\mathbf{P_1}=\{p_{11}, p_{12}, p_{13}, p_{14}, ...\}$ and $\mathbf{P_2}= \{p_{21}, p_{22}, p_{23}, p_{24}, ...\}$. Next, we arrange the parity-bit streams to output two new parity-bit streams: $\mathbf{X_1}=\{p_{11}, p_{22}, p_{13}, p_{24}, ...\}$ and $\mathbf{X_2}=\{p_{21}, p_{12}, p_{23}, p_{14}, ...\}$. We can also decide the permutation of the new parity-bit streams with a puncturing matrix. In this paper, we just exchange the even numbered bits of the parity-bit streams: $\mathbf{P_1}$ and $\mathbf{P_2}$, for example. Finally, we transfer the bit streams: $\mathbf{I}, \mathbf{X_1}, \mathbf{X_2}$ in parallel by LEDs with B,G,R colors. Binary Pulse Position Modulation (BPPM) is used as the modulation technique.

Because of the arrangement scheme of the parity-bit streams, in the receiver, we determine whether the bit streams have been received successfully with the threshold decision of each photo-diode's energy. When all of the bit streams have been received successfully, the parity-bit streams will be re-arranged to the original permutation, and decoded as standard Turbo-codes. When we fail to receive the parity-bit streams, the bit streams outputted from the photo-diodes will be replaced by the bit streams consists entirely of bit "0" : $\{0, 0, 0, 0, ...\}$. Therefore, when we lose one of the parity-bit streams, the codes can be decoded as punctured Turbo-codes. When we lose both of the parity-bit streams, the codes also can be decoded just by the information-bit stream.

4. Performance Analysis

We analyze BER performance of the proposed system in AWGN channel and OWC respectively by computer simulation. Moreover, we compare the proposed system with the conventional Turbo-code system without the arrangement of parity-bit streams.

Table 1 shows the parameters of Turbo-code in the computer simulation, and Table 2 shows the parameters of OWC.

Table 1. Turbo-code Parameters

Channel	AWGN,OWC
Turbo-code generator	$(7,5)_{oct}$
Block length & Interleaver size	1024(AWGN),256(OWC)
Number of iterations	8
Decoding algorithm	modified BCJR[3]

Table 2. OWC Parameters

Laser wavelength of R,G,B	625,530,470[nm]
Background noise	-45[dBm]
Variance of scintillation	0.01
Quantum efficiency	0.6
APD Gain	0.6
Effective ionization ratio	0.22
Bulk leakage current	0.1[nA]
Surface leakage current	10[nA]
Modulation extinction ratio	0.01
Receiver noise temperature	1100[K]
Receiver load resistor	$1030[\omega]$

4.1 BER performance in AWGN Channel

Figure 3 shows the BER performance in AWGN channel. The line marked with triangle means the BER when both of the two parity bit streams have been received successfully. The line marked with circle means the BER when neither of the two parity-bit streams have been received successfully. In these situations, the BER performance of the proposed system is much the same as that of the conventional system. The line marked with square means the BER when either of the two parity-bit streams has been lost. The dashed line shows the BER performance of conventional system, and the solid line shows the BER performance of the proposed system. It seems that the proposed system can prevent the deterioration of BER performance in the partial erasure channel. When BER=10^{-5}, using conventional system, the BER performance degradation from the standard Turbo-code is up to 5.1[dB]. While, using the proposed system the degradation decrease to 2.1[dB], just as a result caused by losing 1/3 of transfer energy which is occupied by the unavailable parity-bit stream. Thus, when BER is 10^{-5}, the proposed system performs 3.0 dB better than the conventional system.

It is considered as a result of losing 1/3 of energy which is occupied by the unavailable parity-bit stream.

Figure 4 shows us the BER performance versus the number of iteration in the situation that either of the two parity-bit streams is unavailable. The solid line shows the BER performance of proposed system, and the dashed line shows that of conventional system. It is shown that in the conventional system the BER can not be converged with the number of iteration, but in our proposed system the BER can be converged.

4.2 BER performance in Optical Wireless Channel

Figure 5 presents the BER performance in optical wireless channel. We can also see the performance of our proposed system is better than the conventional system. While, because

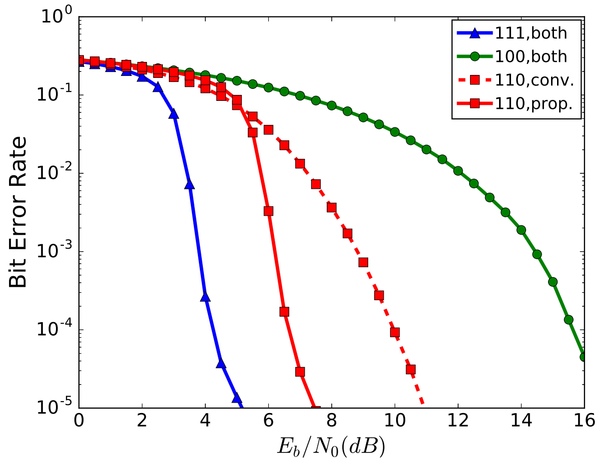

Figure 3. BER performance of systems in the situations that the received signal energy rates of B,G,R are 1:1:1 (111), 1:1:0 (110) and 1:0:0 (100) in AWGN channel

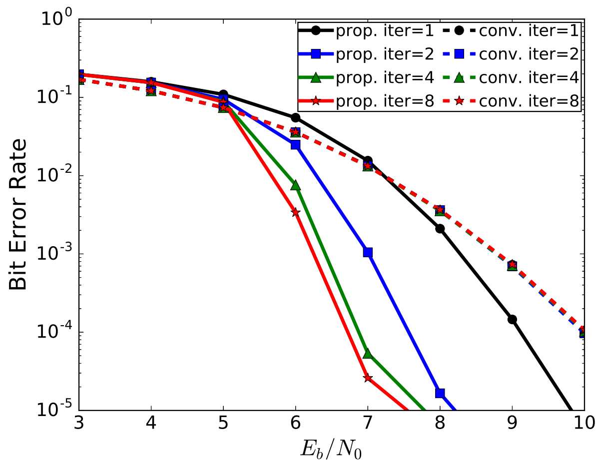

Figure 4. BER performance of systems vs the number of iteration in the situation that the received signal energy rates of B,G,R is 1:1:0 in AWGN channel

of the different wavelength between light R and G, the APDs of R and G output different values. Thus, the performances losing light R and G are different as well.

Figures 6, 7 show the BER versus the number of iteration when we lose R bit stream and G bit stream, respectively. Similar to the results in AWGN channel, the BER of conventional system is not converged. Besides, it seems that the increase of the iteration number is not quite effective for decreasing the BER. Therefore, it implies that in optical wireless channel maybe a small iteration number is enough for a good performance.

5. Conclusion

In this paper, the parallel optical Turbo-code communication system using RGB LEDs, which is effective to solve the par-

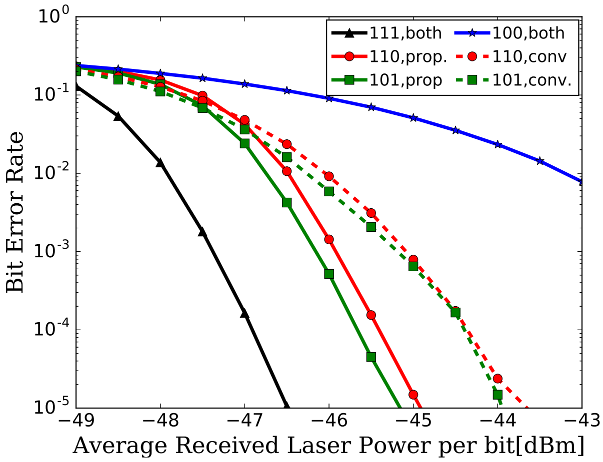

Figure 5. BER performance of systems in the situations that the received signal energy rates of B,G,R are 1:1:1 (111), 1:1:0 (110),1:0:1 (101) and 1:0:0 (100) in OWC, when background noise is -45[dBm] and the variance of scintillation is 0.01

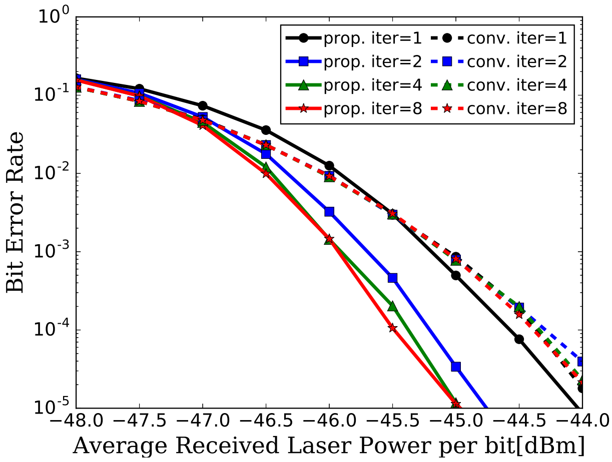

Figure 6. BER performance of systems with the number of iteration in the situation that the received signal energy rates of B,G,R is 1:1:0 in OWC, when background noise is -45[dBm] and the variance of scintillation is 0.01

tial erasure channel transfer problem, was proposed. We analyzed the BER performances of proposed system in both AWGN channel and OWC through computer simulation, and compared them with that of the conventional Turbo-code system without the arrangement of parity-bit streams . As results, the BER performance of the proposed Turbo-code system was the same as that of the conventional system, when both or neither of the two parity-bit streams was received successfully. But the proposed system presented a better BER performance than the conventional system, when either of the two parity-bit streams was unavailable. Besides, because of the different wavelength between light R and G, in OWC the

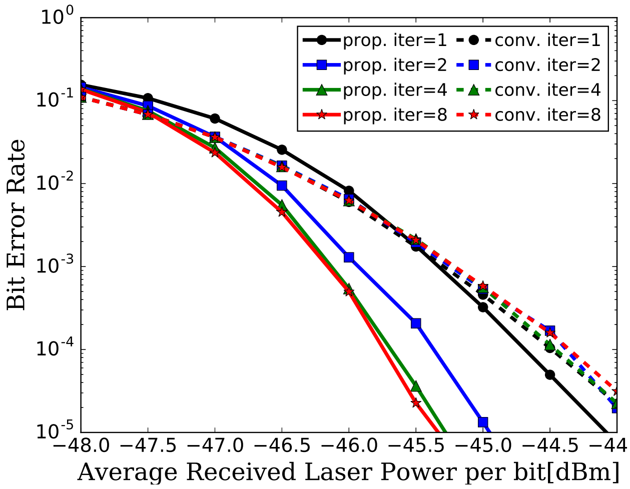

Figure 7. BER performance of systems with the number of iteration in the situation that the received signal energy rates of B,G,R is 1:0:1 in OWC, when background noise is -45[dBm] and the variance of scintillation is 0.01

performances losing light R and G were different as well. We will try to solve this problem in our next study.

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