Modified LDPC decoding rule for pulse position modulation

Yongsheng Wu (吴永胜), Aiying Yang (杨爱英)*, Yunan Sun (孙雨南), and Qiuling Zhao (赵秋领)

Department of Opto-electronic Engineering, Beijing Institute of Technology, Beijing 100081, China

**Corresponding author: yangaiying@bit.edu.cn*

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In this letter, a modified grouped bit-flipping decoding algorithm for low-density parity-check (LDPC) coded pulse position modulation (PPM) signals is proposed. The improvement in performance is observed by Monte Carlo simulations. The coding gain is more than 1 and 2 dB for the order numbers of PPM of 4 and 16 respectively.

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Free space optical communication, or optical wireless communication, is a promising solution for very high data rate point-to-point communication[1]. Pulse position modulation (PPM) is widely used in optical wireless communication system due to its high energy efficiency[2,3]. But the performance of the system could be affected severely by the channel noise. As the PPM modulation order M is increasing, the bit error rate (BER) of the system becomes worse. Consequently, combining PPM with error control coding was applied to optical wireless communication system[4,5]. In state of the art, low density parity check (LDPC) code is almost the best error control coding, which is originally invented by Gallager[6]. Richardson *et al.* constructed irregular LDPC codes that easily beat the best known turbo codes when the block length of the code was large[7]. Chung *et al.* developed improved algorithms to construct good LDPC codes that nearly approach the Shannon limit. For rate 1/2, the best code had a threshold within 0.0045 dB of the Shannon limit of the binary-input additive white Gaussian noise (AWGN) channel[8].

The information was coded with LDPC code first, and then modulated in PPM format before being transmitted. In this procedure, we could have both high energy efficiency and a good error control. LDPC codes are used in BPSK modulation widely, and need the soft value for decoding, which is based on detailed knowledge of probability distribution of the channel[9]. Although the algorithm based on the soft value could get the better performance, the bit-flipping (BF) decoding algorithm would be adopted in various situations, due to the simplicity and low cost of the system. In this letter, we present a kind of LDPC decoding rule for PPM modulated signals and calculate the BER performance in AWGN channel with intensity detection. The proposed algorithm could have better error correcting ability when the PPM order number is increasing.

Simplified block scheme of the LDPC coded using PPM modulation transmission in AWGN channel is given in Fig. 1. The data from information source coded by LDPC code and modulated in PPM format is converted into optical pulse through the optical transmitter. For the M order PPM, only one of M slots has optical signal. The AWGN channel adds the noise in the transmission system, such as $y_i = x_i + n_i$, where y_i is the received signal, x_i is the signal from the transmitter, and n_i is the AWGN with zero mean. The optical receiver converts the optical signals to electrical power. We could pick up the slot with the maximum power received as the output of PPM demodulation.

According to the Mackay's construction 1A, the LDPC matrices **H** (192, 96, 0.5) are created[10]. A 96 by 192 matrix (96 rows, 192 columns) is created at random with weight per column 3, and weight per row as uniform as possible, and overlap between any two columns no greater than 1. The Monte Carlo simulations applied to analyze the performance of the algorithm for LDPC coded PPM transmission. We consider the AWGN as the channel noise in the simulation, and take the same condition in the rest simulations. Figure 2 shows the results of BER curves at different SNR values with various order numbers of PPM. The iteration value is 30 in simulation. As we can see that, when the order number of PPM is 2, the BF decoding algorithm could get about 3 dB coding gain at the BER level with 10^{-5} against to the uncoded PPM transmission. As the order number of PPM is increasing, the gain is decreasing. From Fig. 2 with the order number M=64, the BER couldn't be controlled less than 10^{-5} even when the value of SNR is 16. By analyzing the characteristics of PPM symbol, we could find the reason obviously. The slots of PPM symbol increase with the increasing of the value of M, and just one of those slots has the optical signal. Under the same channel condition, the probability of error occurred is proportional to the number of slots. This could explain why the performance of uncoded transmission becomes worse with the increasing of the value of M. As the order of PPM is increasing, the PPM symbol represents that

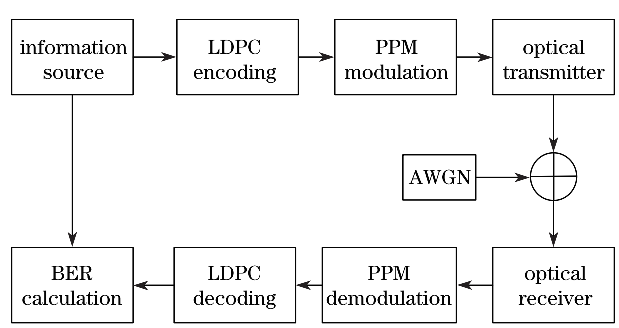

Fig. 1. Block scheme of LDPC coded FSO transmission.

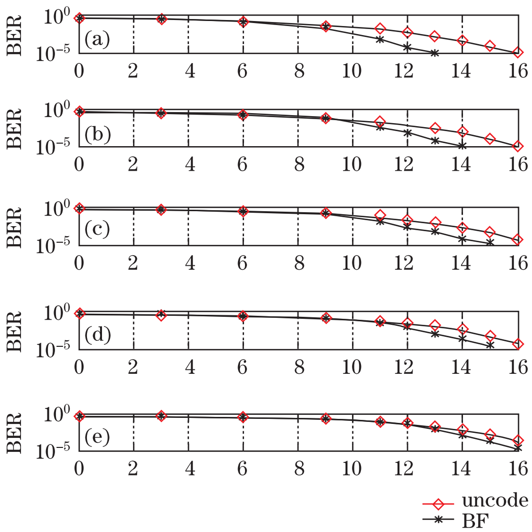

Fig. 2. BER curves versus SNR with PPM modulation numbers of (a) 2, (b) 4, (c) 8, (d) 16, and (e) 64.

the bits of data is increasing. For M-order PPM symbol, it represents $\log_2 M$ bits as $(a_1 a_2 a_3 \cdots)$, and when the error is occurred for PPM symbol, $\log_2 M$ bits would be affected rather than one bit. This could be the reason for the worse performance with the larger value of M.

According to the characteristics of PPM symbol as mentioned above, the proposed grouped BF (GBF) decoding algorithm is given here.

Step 1. Compute the parity-check sum as the standard BF algorithm. If all the parity-check check sums are zeros, stop the decoding.

Step 2. Find the number of failed parity-check equations for each bit, denoted by $\mathrm{err\_}b_i$, $i = 1, 2, \cdots n$;

Step 3. Find the $\mathrm{err\_}b_i$ which is larger than zeros, then subtracted by one correspondingly. According to the sequence with PPM symbol, $\log_2 M$ bits of $\mathrm{err\_}b_i$ could be grouped and the sum of bits denoted as $\mathrm{err\_}g_j$, $j = 1, 2, \cdots, n/\log_2 M$. In this way to ensure the efficient of decoding algorithm, illustrated the order number 8 of the PPM for example, a PPM symbol represents 3 bits with $\mathrm{err\_}b_i$ [0, 3, 0] or [1, 1, 1], the proposed algorithm could make sure that the error occurred probability of the group with [0, 3, 0] should higher than the others.

Step 4. Identify the set S of groups for which $\mathrm{err\_}g_j$ is the largest.

Step 5. Flip the bits in S with the $\mathrm{err\_}b_i$ is larger than one.

Step 6. Repeat steps 1 to 5 until all the parity-check sums are zero (in this case, we stop the iteration in step 1) or go to step 7 when a preset maximum number of iterations is reached (in this letter, we set the value to 10).

Step 7. Recalculate the $\mathrm{err\_}b_i$ as introduced above, then go to Step 1 with flipping the bits which have the value of $\mathrm{err\_}b_i$ is larger than one. Or a preset maximum number of iterations is reached (in this letter, we set the value to 3), the decoding should be stopped, and the present value of bits could be considered as the output of the decoding algorithm.

From the above 7 steps, we could find that the modified algorithm has almost the same complicity as the standard BF algorithm.

The BER curves of the standard BF decoding algorithm and the GBF decoding algorithm have been depicted in Figs. 3 and 4, respectively. The total maximum number of iterations is preset as 30. From the figure, it can be seen that when the PPM order number is 4, the modified algorithm could get more than 1dB coding gain with the value of BER is about 10^{-5}; when the PPM order number is 16, the modified algorithm could get more than 2 dB coding gain with the value of BER is about 10^{-5}. It could be expected that the modified algorithm could get more coding gain compared to the standard BP decoding algorithm as the PPM modulation number is increasing with the same decoding complexity. While it will have shorter decoding time at higher SNR values, due to the smaller value of BER, the less number of iterations is needed for error correcting.

In conclusion, the GBF decoding algorithm based on PPM signal has a better coding performance compared with the standard BF decoding algorithm with the same decoding complexity. When the value of M is 16, the GBF decoding algorithm gets more than 2 dB coding gain at the BER level about 10^{-5}, and gets more coding gain as the increasing of the modulation number. It provides guarantee for the high order number of PPM, and achieves both high energy efficiency and good error control. Although the simulation is based on the simplified AWGN channel, we expect the similar result on practical channel condition, and the performance of the system is improved when the block length of LDPC code is large.

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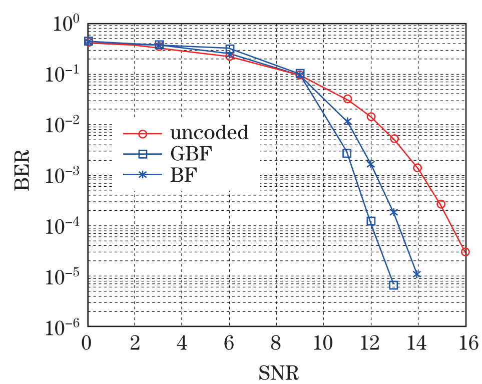

Fig. 3. BER versus SNR values for 4-PPM signals.

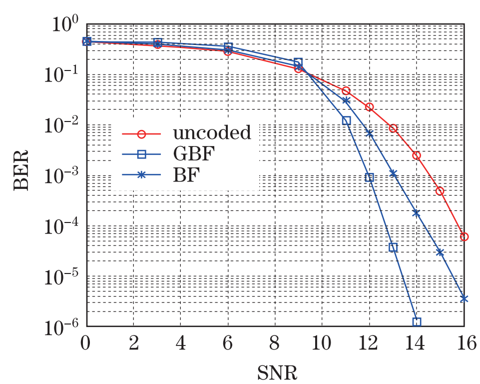

Fig. 4. BER versus SNR values for 16-PPM signals.

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References

1. V. W. S. Chan, J. Lightwave Technol. **24,** 4750 (2006).
2. F. Xu, M.-A. Khalighi, and S. Bourennane, J. Opt. Commun. Netw. **1,** 404 (2009).
3. Y. Shi, Q. Zhang, C. Yu, X. Xin, C. Jin, and R. Zhou, Chin. Opt. Lett. **9,** 080602 (2011).
4. B. Moision and J. Hamkins, Interplanetary Netw. Prog. Rep. **42-161,** 1 (2005).
5. M. F. Barsoum, B. Moision, and M. Fitz, in *Proceedings of IEEE ITW '07* 66 (2007).
6. R. G. Gallager, *Low-Density Parity-Check Codes* (Cambridge, MA: MIT Press, 1963).
7. T. J. Richardson, M. A. Shokrollahi, and R. L. Urbanke, IEEE Trans. Inform. Theory. **47,** 619 (2001).
8. S.-Y Chung, G. D. Forney, Jr., T. J. Richardson, and R. Urbanke, IEEE Commun. Lett. **5,** 58 (2001).
9. J. Hamkins, TMO Progess Report **42,** 1 (1999) .
10. D. J. C. MacKay, IEEE Trans. Inform. Theory **45,** 399 (1999).