Unequal Protection Approach for RLL-constrained LDPC Coded Recording System Using Deliberate Flipping

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***Abstract*—For alleviating Run-Length-Limited (RLL) code, the deliberate flipping approach imposes some bit errors before recording in order to meet the RLL constraint. However, high coding rate of recording system limits the correcting capability of RLL flipping errors. In this paper, we propose a decoding scheme using Unequal Protection (UEP) Low-Density Parity-Check (LDPC) code by means of regular inter-leaver to confine the occurrence of flipping errors into a section of codeword. Specified section with flipping errors are attributed to the high degree nodes with high error protection capability. Iterative decoding within several iterations can solve the hard errors at the reading side. Experimental results reveal that our approach has a better BER performance compared to the recording system with RLL code. Experimental results show that our proposed scheme can efficiently exploit the correction capability to recover flipping bits.**

I. Introduction

According to classic binary (2-level) recording system with Run-Length-Limited (RLL) constraints [1], there is an equalizer at the reading side followed by a RLL decoder and a Low-Density Parity-Check (LDPC) decoder which is known by ECC-RLL scheme. Since a RLL decoder is located between the equalizer and the decoder, it is hardly efficient to perform turbo equalization in the ECC-RLL scheme. This leads to a limited error correction performance. The reverse-concatenation scheme presented in [2] and [3] can be adopted to construct RLL codes with error-correcting capability, where the data is first encoded through the RLL encoder and then the LDPC encoder. The reverse-concatenation scheme has the disadvantage of rate loss resultant from the RLL code. Therefore, an optimal RLL code approaching [4] is proposed to achieve the highest possible code rate of RLL code. Turbo equalization can be carried out by non-binary LDPC code [5] but this approach is suffered from high complexity of the reading side.

In this paper, we proposed a decoding scheme using UEP LDPC code with regular inter-leaver to confine the occurrence of flipping errors into a section of codeword. Specified section with flipping errors are attributed to the high degree nodes with high error protection capability. Therefore, the flipping errors can be recovered by the proposed UEP LDPC coded system. Since the proposed scheme can make the RLL encoder less complex, the iterative equalization and decoding can be operated more efficiently. Experimental results show that our approach can achieve improved BER performance compared to the system with RLL code. In addition, the binary LDPC decoder has a lower complexity than non-binary decoder which is used in M-level system with RLL code.

This paper is organized as follows. In section II, we discuss the two proposed schemes. In section III, experimental results over optical recording channel are presented to compare different schemes. In section IV, the conclusion is presented.

II. A RLL-constraint LDPC Coded Recording System using UEP Technique

A. Signal labeling for unequal protection technique

We present 4-level Pulse Pulse-Amplitude Modulation (PAM) as an example to show the proposed scheme. For 4-level PAM, the corresponding two bits signal labeling are denoted as (Z_1, Z_2). We define the average Euclidean weight enumerator (AEWE) as

$$\Delta_e^2(X) = (1/M)\sum_z X^{||f(z)-f(z\oplus e)||^2} \tag{1}$$

where e is the error vector $e = \overline{r} \oplus \overline{z}$ and there are M pairs of signal vectors $\overline{r}$ and $\overline{z}$ such that $\overline{z}$=$\overline{r} \oplus e$. The AEWE of natural mapping and Gray mapping are shown in Table I.

TABLE I: The AEWE of gray mapping and natural mapping.

e	Gray mapping$\Delta_e^2(X)$	Natural mapping$\Delta_e^2(X)$
00	X^0	X^0
01	$X^{0.8}$	$X^{0.8}$
10	$\frac{1}{2}X^{0.8} + \frac{1}{2}X^{7.2}$	$X^{3.2}$
11	$X^{3.2}$	$\frac{1}{2}X^{0.8} + \frac{1}{2}X^{7.2}$

B. Unequal Protection Allocation Technique

The proposed technique regularly interleaves the binary storage data to form a half of codeword with flipping errors and another half without flipping errors. Therefore, we design UEP LDPC code with two classes of different error correcting capability and allocate the flipping errors on the strong part of code bits. We propose the UEP scheme type I for designing strong part of code bits with short-distance flipping. We also propose UEP scheme type II for designing strong part of code bits with long-distance flipping.

III. Experimental Results

We present the performance evaluation in this section to show the proposed UEP LDPC code for the flipped bit system. Based on the optical channel, we consider the optical channel with AWGN noise only without jitter noise. First, the performance of proposed type I and II are evaluated. As illustrated in Fig. 1, we set the outer iteration to $U_o = 15$ and the inner iteration to $U_i = 1$. For Curve (A) to Curve (D), we observe that the flipped system using UEP scheme type I can achieve similar BER performance compared to the Non-flipped system. Consequently, Curve (C) and Curve (D) show that strong ECC bit with less nearest neighbor labeling can enhance the BER performance. Thus, the flipped system using UEP scheme type II also performs better than UEP scheme type I.

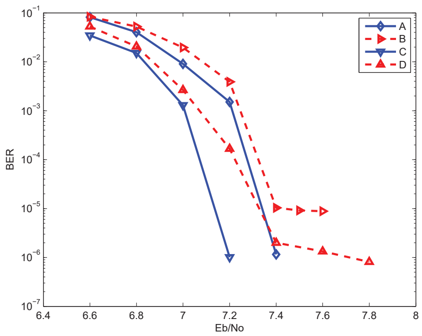

Fig. 1: BER results for a 4-level $(0, 3)$ RLL constraint for proposed system over optical recording channel with AWGN noise only using PEG-LDPC code $VND = [2, 5]$ with λ_k=[0.5,0.5] and $CND = [10, 11]$ with $\gamma = [0.9707, 0.0293]$ (A) Non-flipped type I system; (B) Flipped system type I system; (C) Non-flipped system type II system; (D) Flipped system type II system.

As the code rate of the system is increased, the corresponding capability becomes weaker, the results for which are illustrated in Fig. 2, where the proposed scheme type II is applied. For Curve (A) and (B), (4608,3000) LDPC with rate 0.65 and code parameter is $VND = [2, 5]$ with λ_k=[0.5,0.5] and $CND = [10, 11]$ with $\gamma = [0.9707, 0.0293]$. Curve (C) and Curve (D) show that the flipped system using $(4608, 3456)$ LDPC code rate 0.75 and code parameter $VND = [2, 5]$ with $\lambda_k = [0.5, 0.5]$ and $CND = [13]$ with $\gamma = [1]$ is close to the non-flipped system by 0.1dB. For the higher code rate 0.8, Curve (E) and Curve (F) with rate 0.8 and code parameter is $VND = [2, 5]$ with $\lambda_k = [0.5, 0.5]$ and $CND = [16, 17, 18]$ with $\gamma = [0.0163, 0.9230, 0.0607]$. It also illustrates satisfactory performance. The method of [6] is shown in Curve (G) and (H). The results show that this approach has the stronger error correcting capability over the irregular code in the non-flipped system. However, an error floor region is revealed in the flipped system illustrated by Curve (H). For comparing with the system using RLL code [7] Curve (I), results show that this approach is suffered from the error propagation from the input of the RLL decoder to its output.

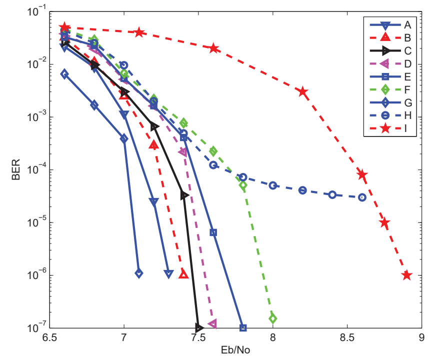

Fig. 2: BER results for a 4-level $(0, 3)$ RLL constraint over optical recording channel with AWGN noise only using the proposed scheme type II. (A) Non-flipped system with rate 0.65; (B) Flipped system with rate 0.65; (C) Non-flipped system with rate 0.75; (D) Flipped system with rate 0.75; (E) Non-flipped system with rate 0.8; (F) Flipped system with rate 0.8; (G) Non-flipped system in [6] with rate 0.65; (H) Flipped system in [6] with rate 0.65; (I) ECC-RLL scheme using RS code in [7] with rate 0.89.

IV. Conclusion

In conclusion, we propose an efficient approach to exploit unequal protection property. Experimental results show the merit of our proposed system and the convincing performance of the proposed schemes to the non-flipped system.

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