Available online at www.iseec2012.com

I-SEEC 2012

Proceeding - Science and Engineering (2013) 244–246

Proceeding
Science and Engineering

www.iseec2012.com

Science and Engineering Symposium
4th International Science, Social Science, Engineering and Energy Conference 2012

Iterative Decoding for Bit-Patterned Media Recording Channels with Insertion/Deletion Errors

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Abstract

In bit-patterned media recording (BPMR) systems, the degraded system performance is often caused not only by the intertrack interference (ITI) and the intersymbol interference (ISI), but also by insertion/deletion errors. This insertion/deletion error is one of the major problems in BPMR systems. Therefore, we propose an iterative decoding scheme for a BPMR system to combat the insertion/deletion errors by using a marker code, a VT code, and turbo equalization. Simulation results indicate that the proposed scheme provides a significant performance improvement at a code rate of 0.821, if compared to the system without using an iterative decoding technique

Keywords: Bit-patterned media recording, Insertion/deletion, Marker code, Turbo equalization, VT code

1. Introduction

The perpendicular magnetic recording (PMR) technology is currently employed in hard disk drives. However, this PMR technology will soon reach its capacity limit at about 1 terabits per square inch (Tb/in^2), known as a superparamagnetic limit [1]. Therefore, to support a huge data storage demand, other technologies must be used to achieve an areal density beyond 1 Tb/in^2. Bit-patterned media recording (BPMR) system is one of these alternative technologies that can replace the PMR technology. In general, the BPMR system can achieve an areal density up to 4 Tb/in^2 by recording one data bit into one island surrounded by non-magnetic material [2]. However, there are many effects that degrades the performance of the BPMR system, including, intersymbol interference (ISI), intertrack interference (ITI), track mis-registration (TMR), media noise, and also insertion/deletion errors. This paper focuses on how to solve the problem of insertion/deletion errors in BPRM systems. Practically, the insertion/deletion error is caused by non-uniform islands and non-uniform write clocks, which results in write synchronization error [3]. Therefore, this paper proposes an iterative decoding scheme to deal with the insertion/detection errors by using a marker code [4], a VT code [5, 6], and turbo equalization.

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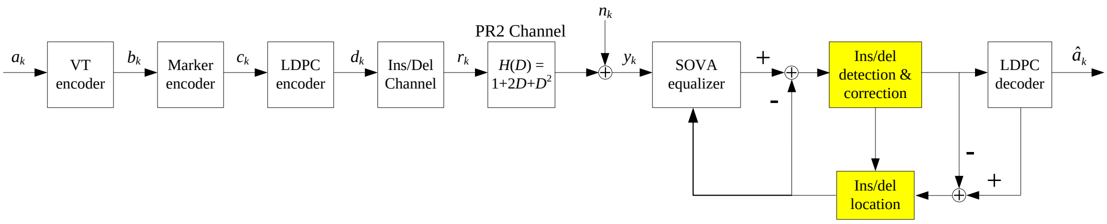

Fig. 1. A BPMR channel model with insertion/deletion errors

2. Channel Model

Consider a BPMR channel model with insertion/deletion errors shown in Fig. 1. The data input sequence $a_k \in \{0,1\}$ is encoded by a $VT_0(127)$ code [5, 6] (used to find insertion/deletion location and correct it) to obtain a sequence b_k and then is encoded by a (127, 130) marker code [4] (used to detect an insertion/deletion error) to obtain a sequence c_k. The sequence c_k of 3640 bits will be encoded by a regular (3, 27) low-density parity-check (LDPC) code to obtain a sequence d_k of 4095 bits. Then, a sequence d_k is independently corrupted by insertion and deletion errors with the probability of p_i and p_d, respectively. The sequence r_k is thus passed through the BPMR channel, represented by the channel response $H(D) = 1 + 2D + D^2$. The readback signal y_k can be written as

$$y_k = r_k * h_k + n_k \tag{1}$$

where h_k is the k-th channel coefficients, * is the convolution operator, and n_k is additive white Gaussian noise with two-sided power spectral density of $N_0/2$. Finally, the sequence y_k is fed to a turbo equalizer, which iteratively exchanges the soft information between the soft output Viterbi algorithm (SOVA) equalizer and the LDPC decoder, respectively.

3. Proposed Method

From Fig. 1, the "Ins/Del detection and correction" block consists of a maker decoder circuit and a VT decoder circuit. At the first iteration, the "Ins/Del detection and correction" block will find the location of the insertion/deletion errors and correct them. The proposed scheme will find this insertion/deletion location only once (at the 1st iteration) and store it in a buffer. Then, this data will be used to correct insertion/deletion errors at every iteration loop so as to reduce the complexity (because we found that using the detection process in every iteration loop yields similar performance).

If the insertion is detected in the soft information sequence, we will discard the data at that location. Likewise, if the deletion is detected, we will insert "0" in that location. Hence, the soft information at the output of LDPC decoder will be rearranged in the same manner so as to obtain the soft information that corresponds to a sequence y_k. This process will operate for every iteration.

4. Numerical Result

The energy-per-bit to noise ratio is defined as $E_b/N_0 = 10\log_{10}(\sum|h_k|^2/2R\sigma^2)$ in dB, where R is a code rate. Because we only investigate the effect of the insertion/deletion errors in this paper, we then ignore the ITI, media noise, and TMR in our simulation. We also assume that the insertion/deletion errors will not occur in the redundant bits of an LDPC code. The probability of insertion/deletion can be calculated from the length of a sequence d_k, which is 3460 bits. Figure 2 compares the system performance in terms of bit-error rate (BER) and sector-error rate (SER) at the probability of insertion/deletion of $p_i = p_d = 10^{-5}$, where the "with ins/del" and the "without ins/del" are referred to as the system with and without the insertion/deletion errors, respectively. In addition, the curve labeled "Proposed (5)" means the performance of the proposed scheme at the 5-th iteration, where “Proposed (1)” can be considered as the system without using an iterative decoding technique. Clearly, without the inserting/deletion detection and correction algorithm, the system performance is unacceptable. Furthermore, the proposed scheme yields a large performance gain if compared to the system without using an iterative decoding technique.

5. Conclusion

The insertion/deletion errors resulted from write synchronization error in BPRM channels can significantly degrade the system performance. Thus, the detection and correction method to reduce the effect of the insertion/deletion errors is very important to the BPMR channel. In general, the conventional iterative decoding scheme cannot solve this problem. Therefore, we propose the iterative decoding scheme to jointly perform marker decoding, VT decoding, and turbo equalization for the BPMR channel, which can provide a significant performance improvement at the code rate of 0.821, if compared to the system without using an iterative decoding technique.

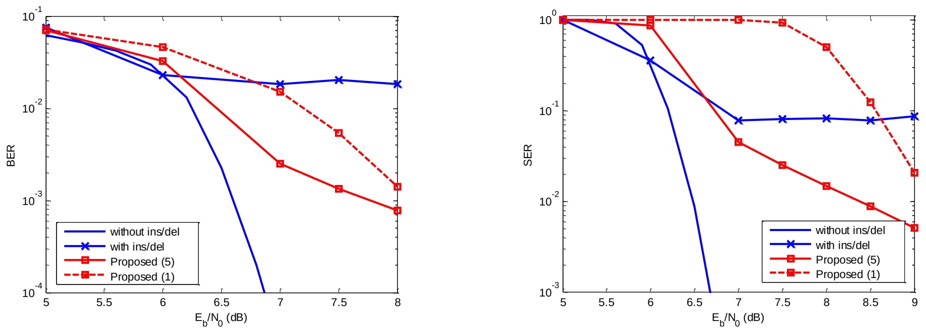

Fig. 2. Performance comparison at the probability of insertion/deletion of $p_i = p_d = 10^{-5}$

Acknowledgments

This project was supported by the Research and Development Institute, Nakhon Pathom Rajabhat University, Nakhon Pathom, Thailand.

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