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

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Abstract

Bit-patterned media recording (BPMR) is one of the promising technologies for future hard disk drives. The insertion and deletion (Ins/Del) errors are a crucial problem for BPMR, which can cause an error burst in a data detection process. This paper proposes an iterative decoding scheme that can handle the ins/del errors. At each iteration, the Ins/Del errors are detected by the Marker code and the VT code is used to find the location and correct those errors. Numerical results show that the proposed scheme performs better than the conventional receiver, which performs the Ins/Del correction and the iterative decoding separately.

Keywords: Bit-patterned media recording, Insertion and deletion errors, Marker code, VT code.

1. Introduction

In BPMR, each data bit is stored into one magnetic island surrounded by non-magnetic material [1]. The mis-synchronization between the write clock and the island positions results in the insertion and deletion errors (denoted as Ins/Del), which can cause an error burst in the BPMR system. Moreover, the dead islands, the fluctuation of magnetic saturation, and a located random phase drift can also lead to the Ins/Del errors.

Several works have been recently proposed to combat the Ins/Del errors. For example, Sellers [2] proposed the Marker code to detect and correct these errors. This code is simple for encoding and decoding operation but it cannot find the exact location of the inserted or deleted bit. In [3], the VT code was invented to correct a single insertion or deletion bit. This paper proposes a method for jointly performing the tasks of a marker code, a VT code, and iterative decoding to mitigate the Ins/Del errors.

2. Channel Model

We consider a discrete-time BPMR channel model with Ins/Del in Fig. 1, and assume only two adjacent tracks cause most of intertrack interference. The data input sequence $a_{j,k} \in \{0,1\}$ with bit period T_x, where $j \in \{-1,0,1\}$ corresponding to the upper track, the main track and the lower track, respectively, is encoded by a VT code [3] and the Marker code [2] to obtain a sequence $c_{j,k}$. Next, a sequence $c_{j,k}$ is encoded by a low-density parity-check (LDPC) code and is corrupted by the Ins/Del errors to obtain a sequence $z_{j,k} \in \{-1,1\}$. Then, the readback signal can be written as

$$y_k = h_{j,k} \otimes w_{j,k} + n_k \qquad (1)$$

where $h_{j,k}$'s are the 2D channel response coefficients, $\otimes$ is the 2D convolution operator, and n_k is additive white Gaussian noise with zero mean and variance σ^2.

In a conventional receiver, the readback signal is sent to the Ins/Del suppression block followed by a turbo equalizer, which iteratively exchanges the soft information between a 2D soft-output Viterbi algorithm (2D-SOVA) and the LDPC decoder to obtain the estimate of $\{a_{0,k}\}$.

3. Proposed Method

The proposed method is illustrated in Fig. 1, where the Ins/Del detection and correction block is placed in between the 2D-SOVA and the LDPC decoder so as to perform the Ins/Del suppression and iterative decoding. Specifically, the Ins/Del detection and correction block consists of the Marker decoder and the VT decoder, where the Marker decoder is employed for the Ins/Del detection, and the VT decoder is used to find the exact location and to correct the Ins/Del errors.

To correct the insertion error, we ignore the k-th soft information bit when the insertion error is detected. Similarly, to correct the deletion error, we will insert a

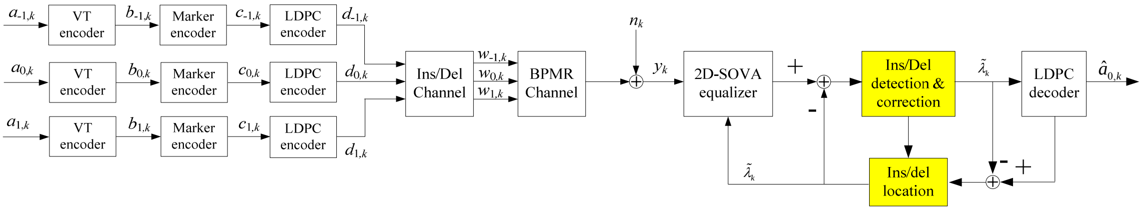

Fig. 1 A BPMR channel model with the insertion and deletion (Ins/Del) errors.

a dummy bit in the k-th soft information when the deletion error is detected. After correcting the Ins/Del errors, the corrected soft information is sent to the LDPC decoder and the Ins/Del error locations are fed to the Ins/Del location block.

The soft information from the LDPC decoder will be sent to the Ins/Del location block. Specifically, a dummy bit is inserted at the location where the insertion error was detected, the soft information is discarded at the location where the deletion error was detected. Thus, the adjusted soft information that corresponds to a sequence y_k will be sent to the 2D-SOVA for the next decoding iteration.

4. Numerical Result

Consider the BPMR system at an areal density of 2 Tbit/in^2, where the 3-by-3 channel matrix obtained by sampling the 2D pulse response at $T_x = T_z = 18$ nm is given by [1]

$$\mathbf{H} = \begin{bmatrix} 0.023 & 0.232 & 0.023 \\ 0.101 & 1 & 0.101 \\ 0.023 & 0.232 & 0.023 \end{bmatrix}. \qquad (2)$$

The signal-to-noise ratio (SNR) is defined as SNR = $10\log_{10}(1/R\sigma^2)$ in dB, where R is a code rate. For the Ins/Del model, some binary bits are inserted randomly within $\{d_{j,k}\}$ with probability p_i, whereas some bits are taken out from $\{d_{j,k}\}$ with probability p_d [5]. Here, we consider a rate-8/9 of the LDPC code, a rate-127/130 of the Marker code, and a rate-120/127 for VT code. Therefore, the overall code rate is $R = 0.82$.

Fig. 2 compares the performance of different systems, where we assume the probabilities of insertion and deletion errors are $p_i = p_d = 10^{-5}$, which are reasonable for a practical BPMR system [5]. Clearly, without the Ins/Del detection and correction algorithm, the system performance denoted as "with Ins/Del" is unacceptable, where the system without Ins/Del errors is referred to as "without Ins/Del." In addition, it is apparent that the proposed scheme performs better than the conventional receiver. Therefore, the method for Ins/Del detection and correction is essential for BPMR systems.

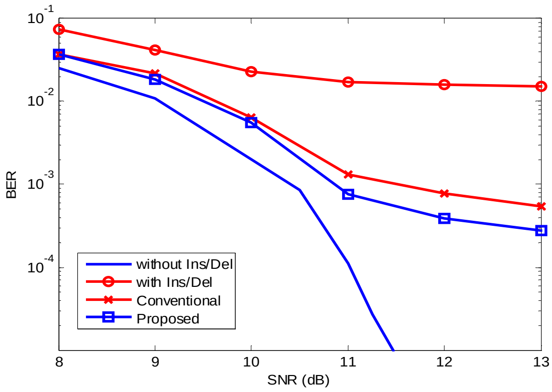

Fig. 2 BER performance for $p_i = p_d = 10^{-5}$ at 5 iterations.

5. Conclusion

In BPMR, the insertion and deletion errors can cause an error burst in data detection, which could easily exceed the correction ability of error-correction codes, leading to a sector failure. Hence, the Ins/Del detection and correction algorithm is crucial in the BPMR system. Simulation results showed that the proposed method yields better performance than the conventional one in terms of BER.

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