2D Coding for Future Perpendicular and Probe Recording

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1. INTRODUCTION

As the data density in data storage systems increases, different recording methodologies may be explored, including truly two-dimensional storage. Perhaps more imminent is the impact of the increase of the track density, leading to intertrack interference in addition to the down-track intersymbol interference. In either case, the measurements of data at one location may be influenced by recorded information in a two-dimensional neighborhood of that location, yielding two-dimensional (2D) intersymbol interference (ISI). Decoding in the presence of 2D ISI is significantly different from decoding in the presence of one-dimensional ISI, the standard model in magnetic recording. This interference invalidates assumptions in the Viterbi and related algorithms necessitating novel decoding strategies. We describe several approaches to encoding and decoding for 2D data storage systems that have 2D ISI. Our approach to the problem is two-fold: (1) to use existing equalization methods and combine them with error-correction coding to enhance system performance; (2) perform joint equalization and decoding using message-passing algorithms. Simulations demonstrate the potential for such systems [1]-[3].

2. JOINT EQUALIZATION AND DECODING FOR 2D ISI

The recording medium is modeled as a discrete, linear 2D ISI channel. User data is assumed to be binary and is encoded using an error-correction code prior to recording. The encoded data are modulated using BPSK and scanned into a matrix. The noise is modeled as additive white Gaussian noise (AWGN). The channel output is a matrix with elements,

$$\boldsymbol{r}(\boldsymbol{i},\boldsymbol{j}) = \sum_{\boldsymbol{k}_1,\boldsymbol{k}_2=0}^{\boldsymbol{L}-1} \boldsymbol{x}(\boldsymbol{i}-\boldsymbol{k}_1,\boldsymbol{j}-\boldsymbol{k}_2)\boldsymbol{h}(\boldsymbol{k}_1,\boldsymbol{k}_2) + \boldsymbol{w}(\boldsymbol{i},\boldsymbol{j}), \tag{1}$$

where $x(i,j)$ are the elements of the encoded data matrix, $w(i,j)$ are the realizations of AWGN, $\boldsymbol{h}$ is the channel point spread function and L represents the number of elements over which the ISI extends in each dimension. For error correction we use regular low-density parity-check (LDPC) coset codes.

A. MMSE Equalization and Decoding

The first decoding scheme uses a minimum mean squared error (MMSE) equalizer followed by LDPC decoder. The Wiener filter is designed subject to the input power constraint and is applied iteratively if decoding fails after a single application. In the iterative case soft information, the estimated mean of the codeword, is passed from the LDPC decoder to the Wiener filter [1]. The Wiener filter is space-invariant, using the same filter over the entire data.

B. Joint Equalization and Decoding using Message-Passing

The second method, called the "Full Graph" algorithm, is an *a posteriori* probability (APP) based algorithm [1]. This algorithm computes approximate APPs of the codeword bits given the observations by performing message-passing on the three-level graph of the LDPC code and the channel ISI. The upper two levels in this graph represent the LDPC code bipartite graph and the lower two levels depict how the ISI induces dependencies among the codeword bits.

The channel ISI graph has many short cycles which degrade the performance of the message-passing algorithm. We employ a modified message-passing schedule based on the idea of ordered subsets which is widely employed in image reconstruction algorithms. The idea is to partition the observations into subsets and use only one subset of the observations for each iteration of message-passing on the three-level graph. This algorithm is termed as the ordered subsets message-passing algorithm [3].

C. Row-Column Decoding Algorithm

This scheme is designed for the case when the channel response matrix is separable. A separable 2D ISI matrix is can be written as a product of two vectors thus allowing us to treat the 2D ISI as the concatenation of two one-dimensional (1D) ISI channels, a 1D row ISI followed by a 1D column ISI. This method performs equalization by using an iterative detector which employs MAP algorithms for the ISI in each dimension. Since the trellis of the 1D ISI in the column direction is not binary so a MAP algorithm for nonbinary trellises needs to be employed for column detection. Also the output of the row ISI is not observed directly necessitating modifications in the row detector. When used with LDPC codes, the iterative detector and the LDPC decoder form an iterative decoder with three constituent decoder/detectors [2].

3. RESULTS

The performance curves for the joint equalization and decoding schemes are shown in Fig. 1. The LDPC code used for our simulations is a blocklength 10000 regular (3,6) code. The leftmost curve is the performance of the LDPC code on an AWGN channel with no ISI. The encoded data is scanned into a *100x100* matrix and prior to transmission over the ISI channel a guard band of all 1's is added around the codeword matrix. The reason for using the guard band is to isolate sectors in 2D and also to provide termination for our algorithms. We use the following separable point spread function for our simulations:

$$\boldsymbol{h} = \begin{pmatrix} 1 & 0.5 \\ 0.5 & 0.25 \end{pmatrix} = \begin{pmatrix} 1 \\ 0.5 \end{pmatrix} \begin{pmatrix} 1 & 0.5 \end{pmatrix}. \quad (2)$$

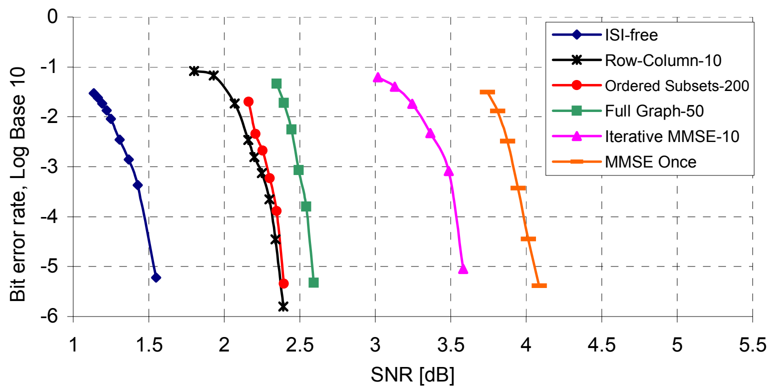

Fig. 1 Performance curves for the decoding schemes

From the curves we can see that the row-column decoder has the best performance. It also has a lower complexity than all the other schemes. These observations suggest equalizing a general 2D ISI to a nearby separable ISI and then using the row-column decoder. The ordered subsets message-passing algorithm has the best performance for a general 2D ISI. The use of ordered subsets brings about an improvement in performance over the full graph algorithm. Iterating soft information between the MMSE equalizer and the LDPC decoder brings about an improvement in performance over the case where equalization is performed only once.

REFERENCES

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