Two-Dimensional Coding for Advanced Recording

N. Singla, J. A. O’Sullivan, Y. Wu, and R. S. Indeck
Washington University
Saint Louis, Missouri
Motivation: Areal Density
Performance: match medium, sensor, processing

Currently use continuous films with discrete ‘grains’; exchange decoupled; create bits from 1000 grains; make grains smaller

To increase areal bit density we need a medium that can sustain smaller, stable magnetic regions

Potential solutions:
- glue (via exchange) structure within region; discrete film; 1 bit per region
- couple magnetization within region via exchange; smooth film; ion beam modification; create discrete regions

✓ Want a manufacturable process!
Challenges with the Patterning of Media

- Fine features (<20nm)
- Large area coverage (many cm’s)
- High substrate throughput
- Complicated, non-rectangular irregular structures (tracks, sector, servo)

... conventional processing inadequate
Nanoimprinting
for patterning recording media
Ion Beam Modification

Terris: Hitachi
Nanoimprinting/Ion Modification

- Small-scale features (10 nm)
- Large-scale extensibility
- Smooth topography
- Suitable for irregular patterns
  - non-rectangular, sector and servo

...viable for patterning recording media, memory elements and sensors
Nanoimprinting

6 million-million bits/square inch!
Outstanding Issue: Two-Dimensional ISI

- Patterned media
  - interference from neighbors in both directions
- Conventional magnetic storage
  - reduce bit-aspect-ratio increases ITI
- Optical recording
  - laser spot spread; page oriented optical memories
- Probe recording
  - probe’s point spread function

Existing schemes (Viterbi, BCJR) cannot deal with 2D ISI
Joint Equalization and Decoding Schemes for 2D ISI

• General 2D ISI
  – using 2D MMSE equalization and decoding
  – using novel message-passing algorithms that take advantage of the 2D dependence

• Separable 2D ISI
  – using turbo equalization

Channel Model

- \( x(i,j) \in \{+1,-1\} \)
- Channel ISI is 2D and linear
- Noise assumed to be AWGN
2D Intersymbol Interference

Includes guard band

\[ r_{i,j} = x_{i,j} + 0.5x_{i-1,j} + 0.5x_{i,j-1} + 0.25x_{i-1,j-1} + w_{i,j} \]
1. MMSE Equalization

- Equalizer may or may not iterate with the LDPC decoder
- Soft information, estimated mean of the codeword, passed from LDPC decoder to equalizer
Performance

Block length 10000 regular (3,6) LDPC code

Iterative MMSE and decoding
2a. Full Graph Message-Passing

The sky is falling!

\[ h = \begin{pmatrix} 1 & 0.5 \\ 0.5 & 0.25 \end{pmatrix} \]

\[ r_{i,j} = x_{i,j} + 0.5x_{i-1,j} + 0.5x_{i,j-1} + 0.25x_{i-1,j-1} + w_{i,j} \]
Full Graph

Same as before – just a different representation
Performance

Full Graph Message Passing

Bit error rate in log10

SNR [dB]
Full Graph Analysis

- Length 4 cycles present which degrade performance of message-passing algorithm

From Check Nodes

2b. Ordered Subsets Message-Passing

- From Imaging – Data set is grouped into subsets to increase rate of convergence
- For Decoding – Observed data is grouped into subsets to eliminate short length cycles in the Channel ISI graph

Grouped ISI Graph

- Labeling of data nodes into 4 subsets
- For each iteration use data nodes of one label only

Performance

Ordered Subsets Message Passing

Bit error rate in log10

SNR [dB]

-6 -5 -4 -3 -2 -1 0 1 2 3 4 4.5

ISI-free
Ordered Subsets_200
Full Graph_50
Itr Wiener_10
Wiener
3. A Separable 2D ISI

• Advantages of separable 2D ISI
  – apply existing one-dimensional equalization methods
  – reduced detector complexity

\[ h = \begin{pmatrix} 1 & 0.5 \\ 0.5 & 0.25 \end{pmatrix} = \begin{pmatrix} 1 \\ 0.5 \end{pmatrix} \begin{pmatrix} 1 & 0.5 \end{pmatrix} \]

Row-Column Decoder Diagram

- Inputs to column detector are not binary

Performance

Row-Column Decoder

Bit error rate, log Base 10 vs SNR [dB]

- ISI-free
- Row-Column Decoder
- Ordered Subsets_200
- Full Graph_50
Conclusions

- Advanced recording schemes may give rise to 2D ISI
- Use joint detection and decoding for 2D ISI
  - MMSE equalization and decoding
    - good performance, moderate complexity
  - Message passing algorithms
    - full graph algorithm performance deteriorated due to short cycles
    - ordered subsets message-passing gives best performance for general 2D ISI
  - Separable ISI decoding
    - best performance
    - low complexity
    - approximate channel response by separable response