Joint Detection and Decoding Schemes for Two Dimensional Data Storage Systems

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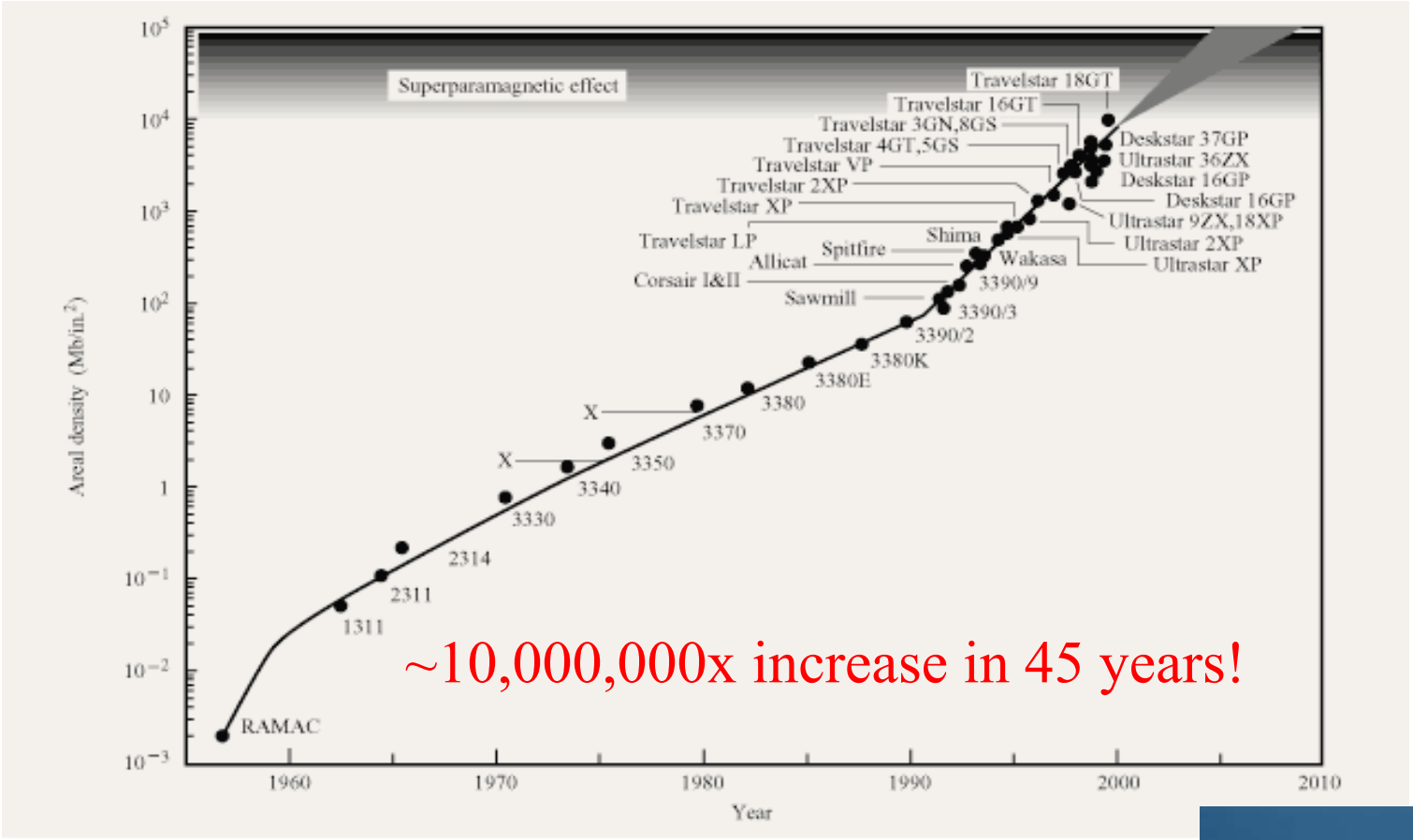
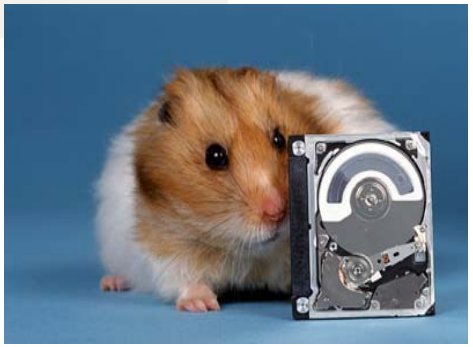
Enabling Technology: Disk Drives

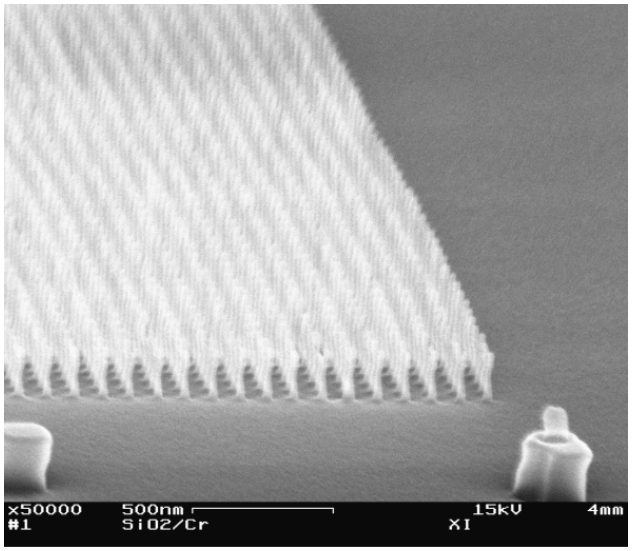


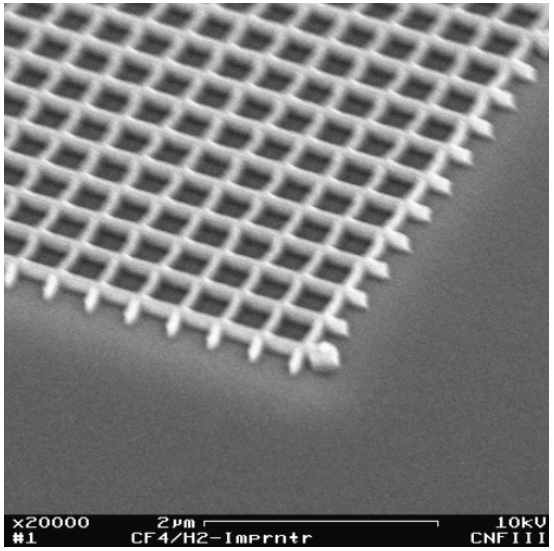
Magnetic disk storage areal density
vs. year of IBM product introduction
(From D. A. Thompson)



Problem Description

- Reliable data retrieval from channels having 2-D ISI
  - Advanced storage media: Patterned media
  - As bit aspect ratio reduces inter-track interference becomes significant
  - Optical memories

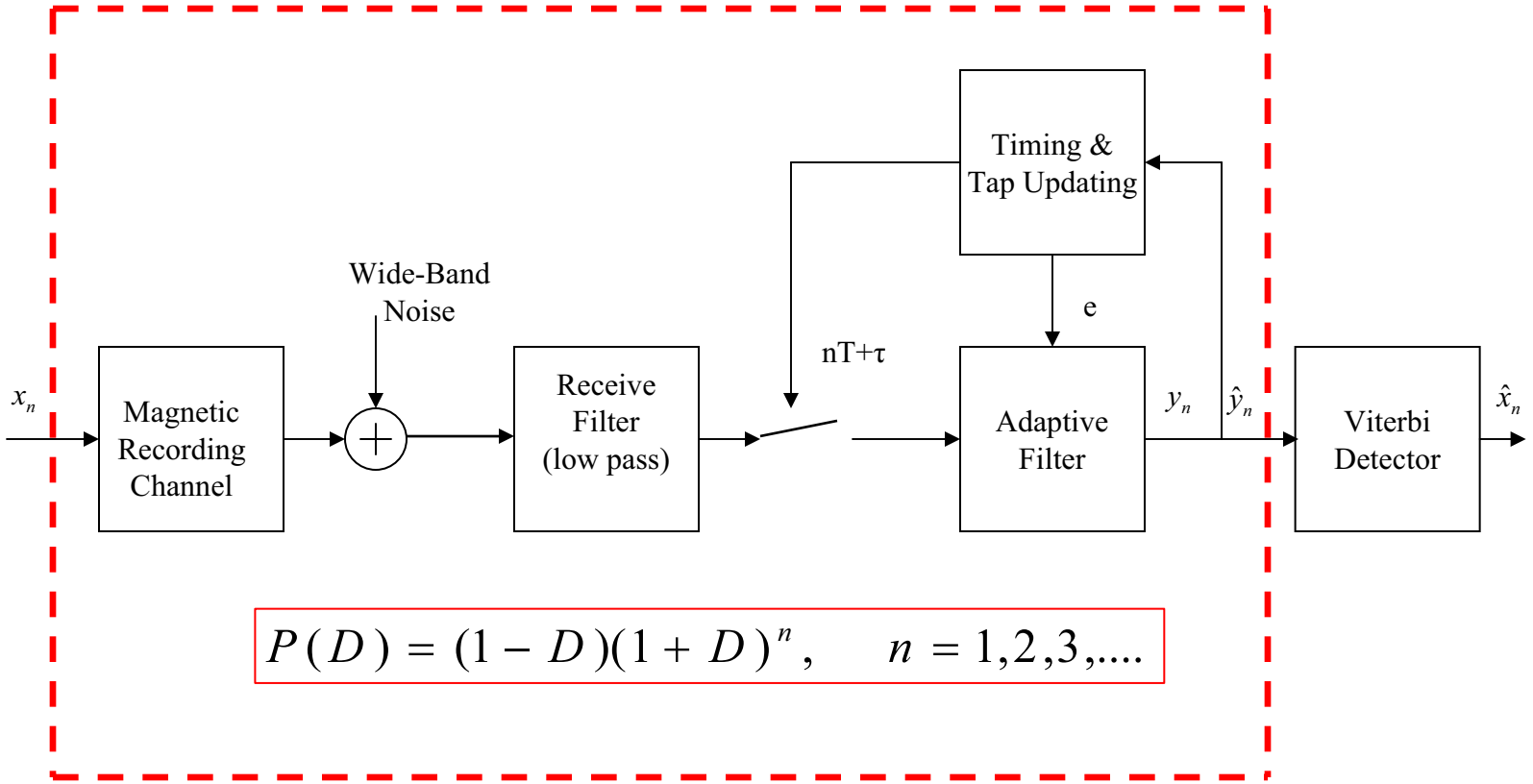




Science enables:

6 million-million bits/square inch!

Conventional PRML System



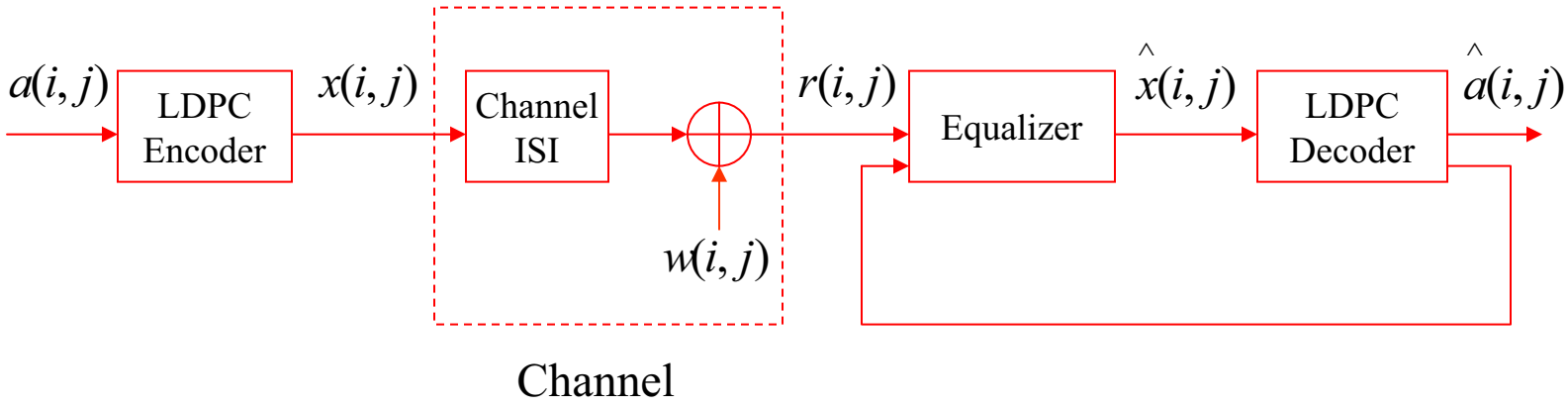
No generalization to 2D

Joint Equalization and Decoding Schemes

- 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

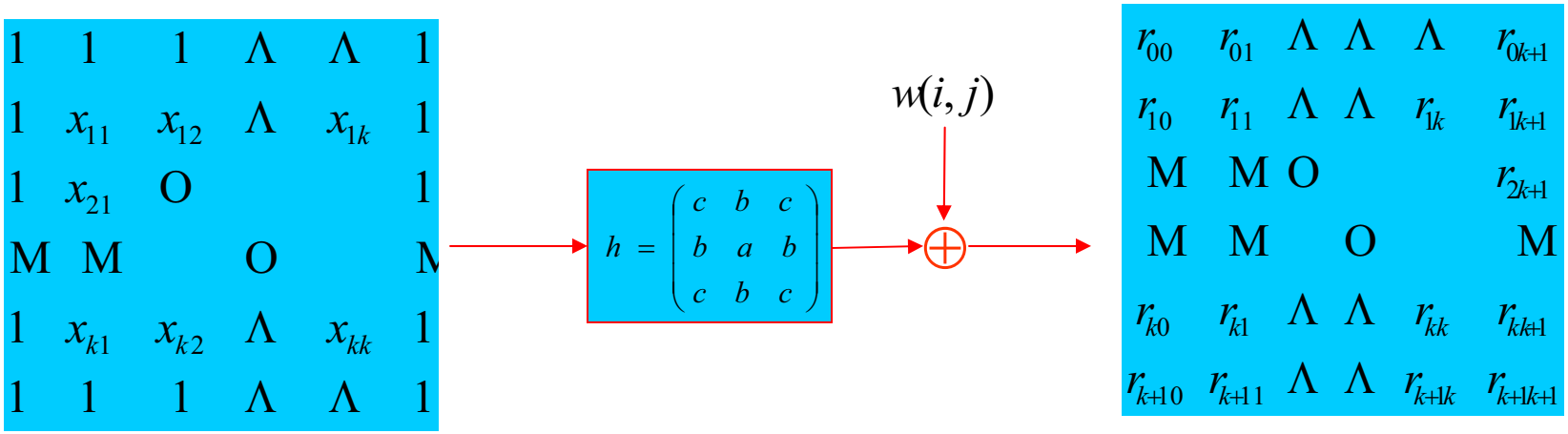
Singla *et al.,* "Iterative decoding and equalization for 2-D recording channels," *IEEE Trans. Magn.*, Sept. 2002.

Channel Model



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

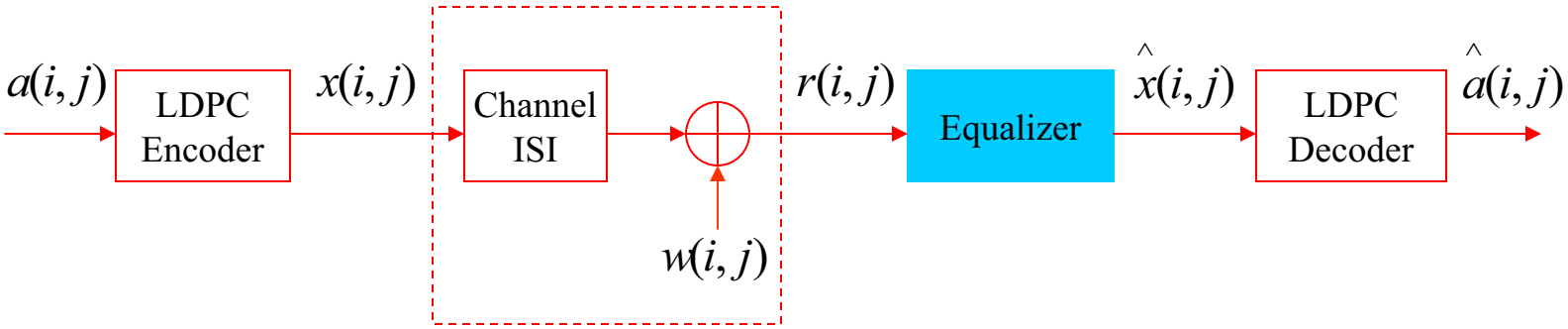
2D Intersymbol Interference



GUARD BAND

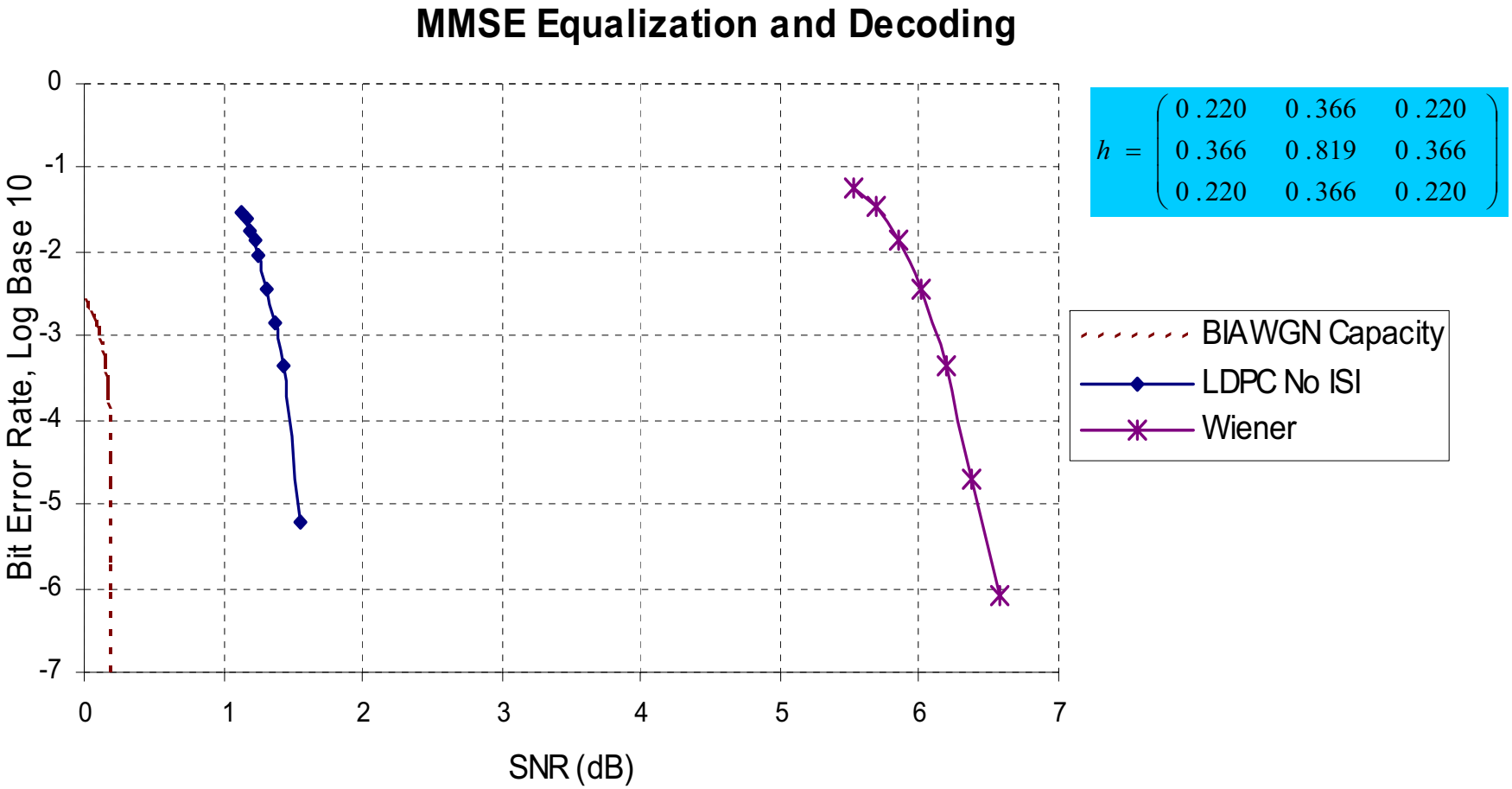
$$r(i,j) = \sum_{m,n=0}^{2} x(i-m, j-n)h(m,n) + w(i,j)$$

MMSE Equalization and Decoding

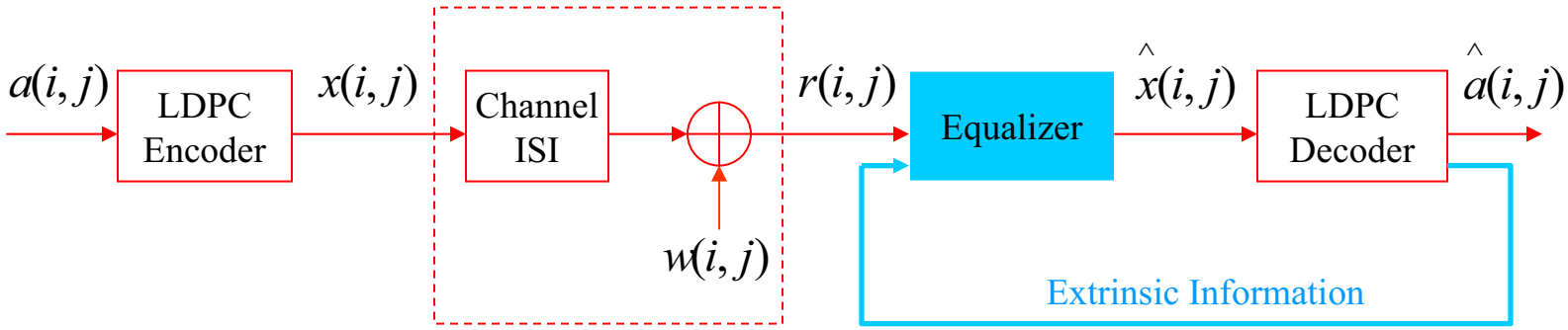


- Equalizer designed assuming inputs to be Gaussian

Performance



Iterative MMSE Equalization and Decoding

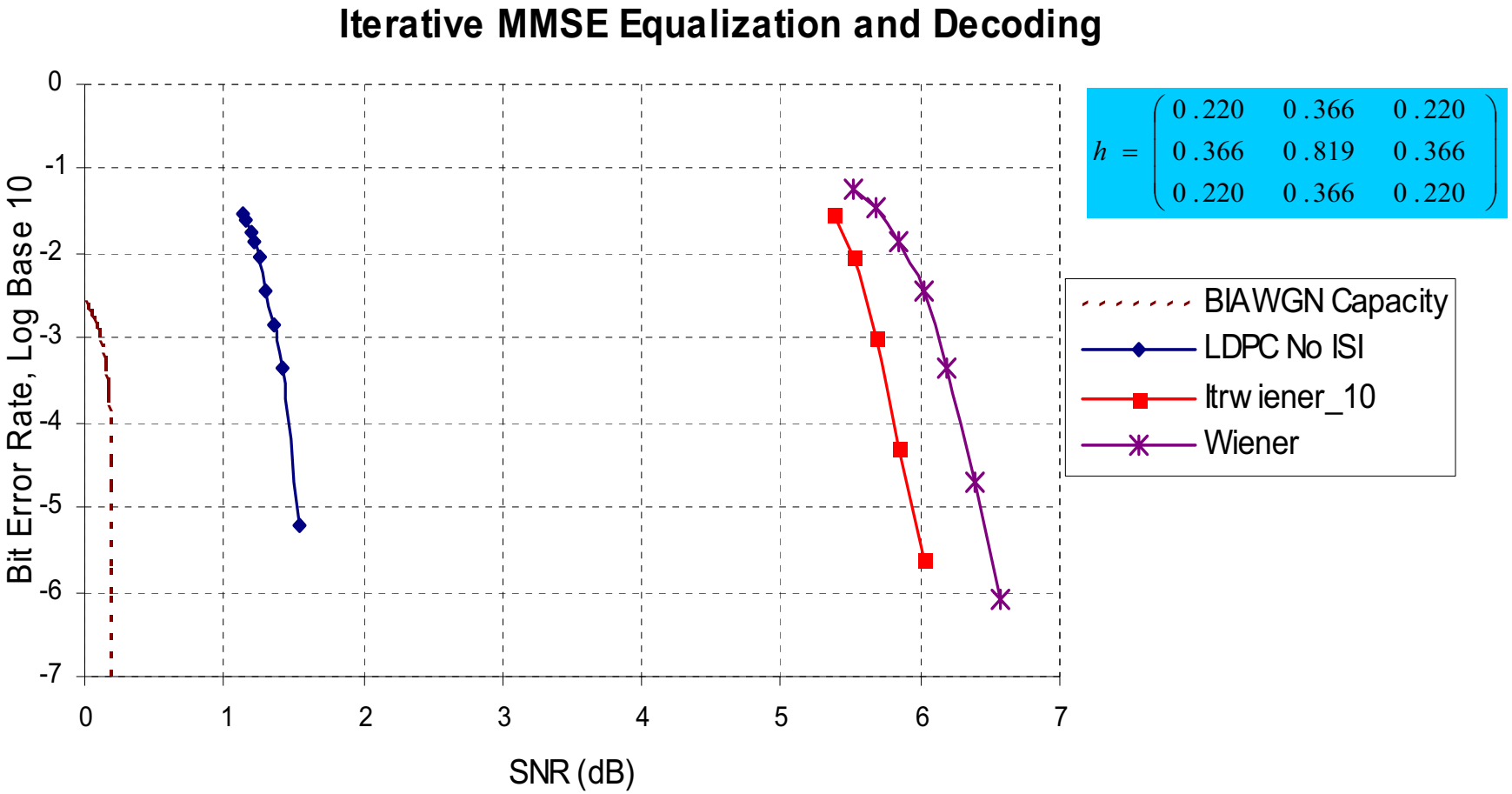


- Soft information, estimated mean of the codeword, passed from LDPC decoder to equalizer

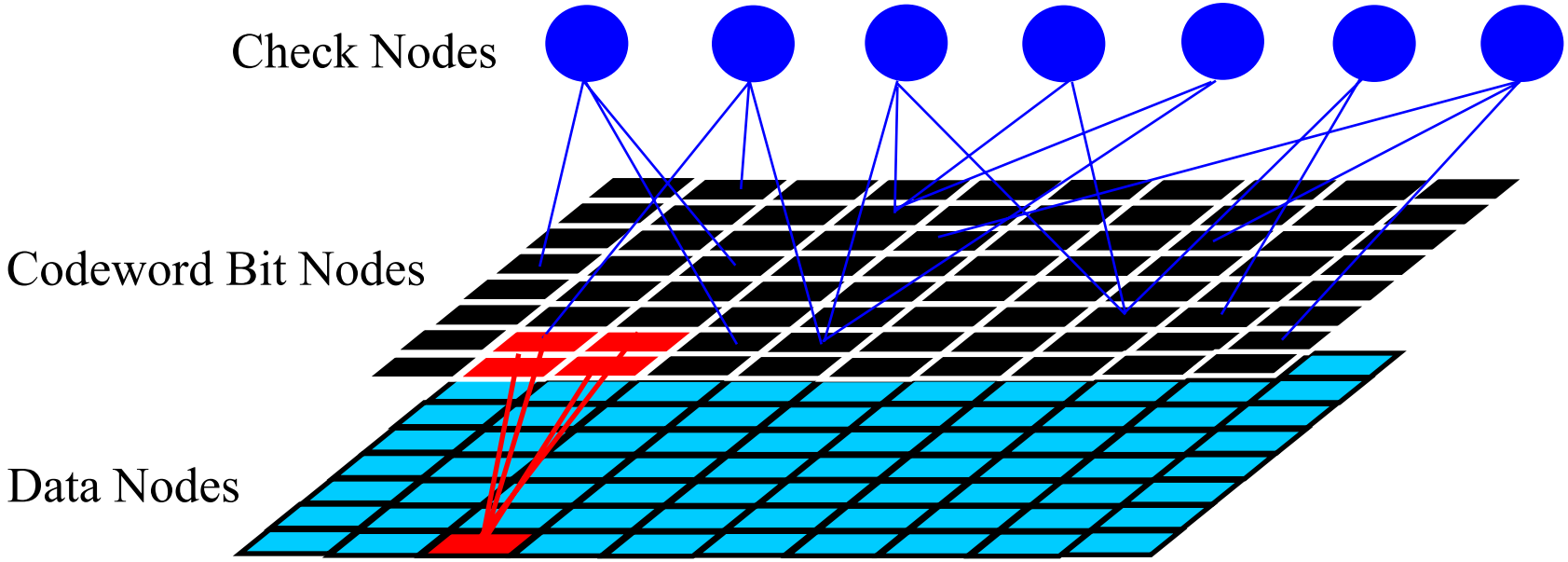
$$E[x] = \Pr(x=1) - \Pr(x=-1)$$

$$\hat{x} = E[x] + W^{**}[r - h^{**}E[x]]$$

Performance



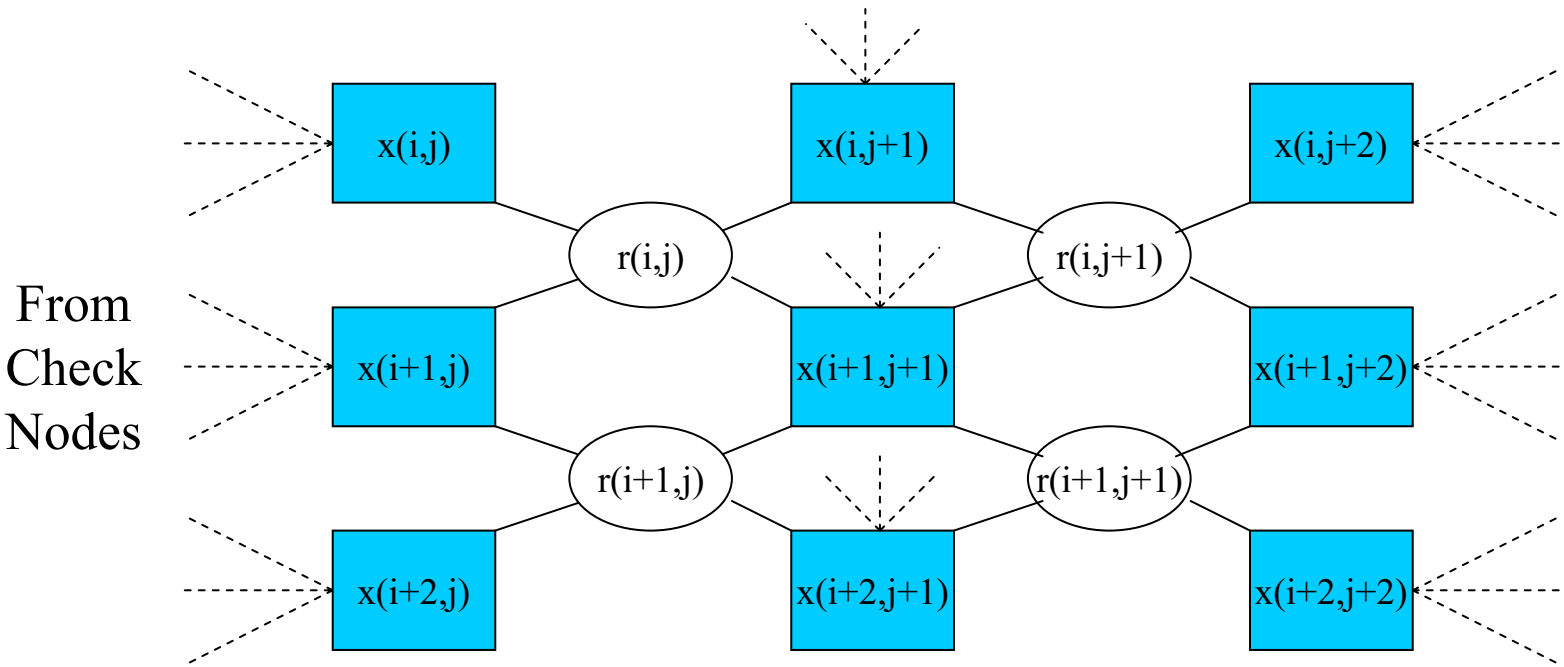
Full Graph Message-Passing



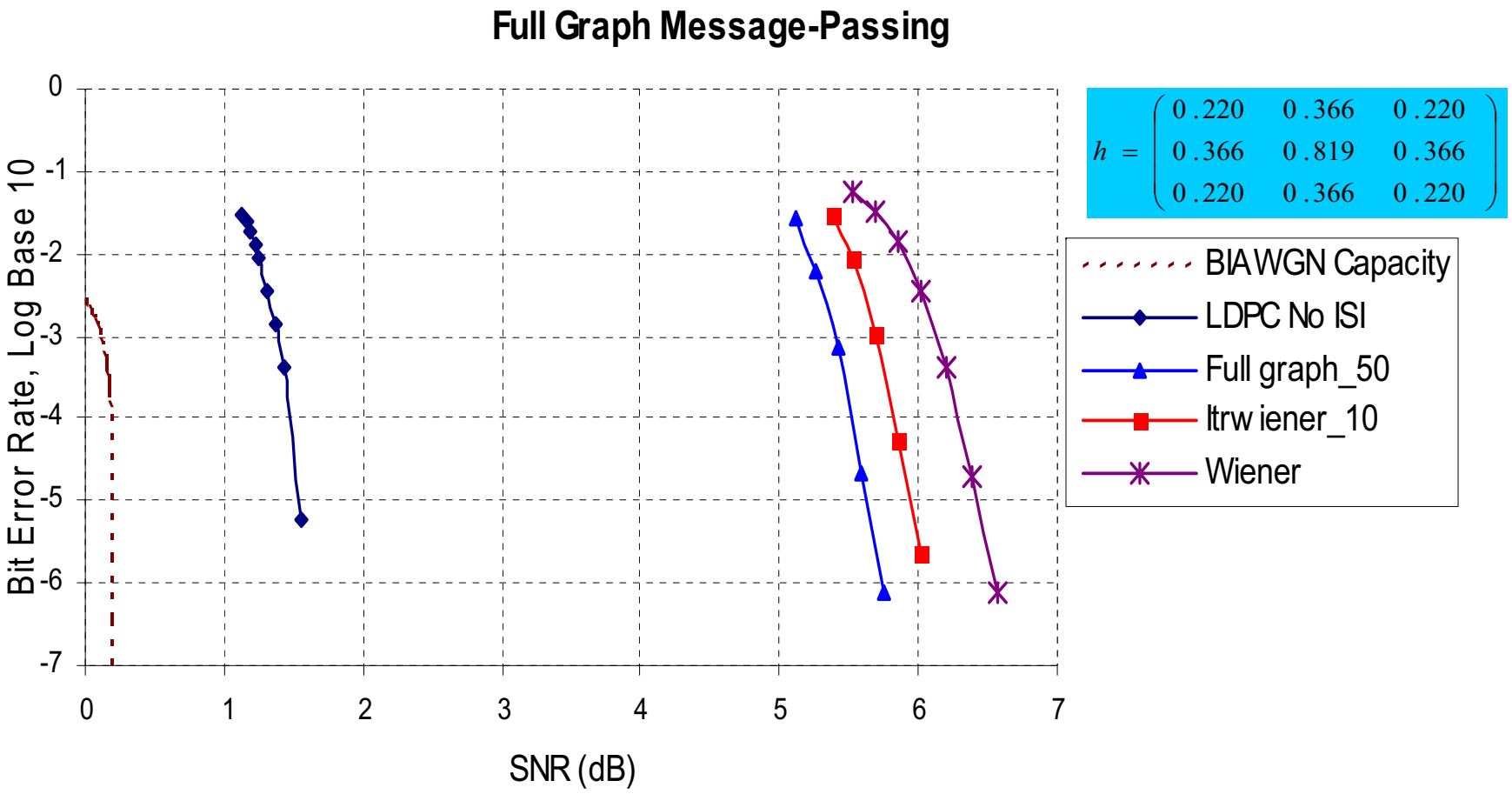
$$h = \begin{pmatrix} 1 & 0.5 \\ 0.5 & 0.25 \end{pmatrix}$$

$$r_{i,j} = x_{i,j} + 0.5x_{i-1,j} + 0.5x_{i,j-1} + 0.25x_{i-1,j-1} + w_{i,j}$$

Full Graph

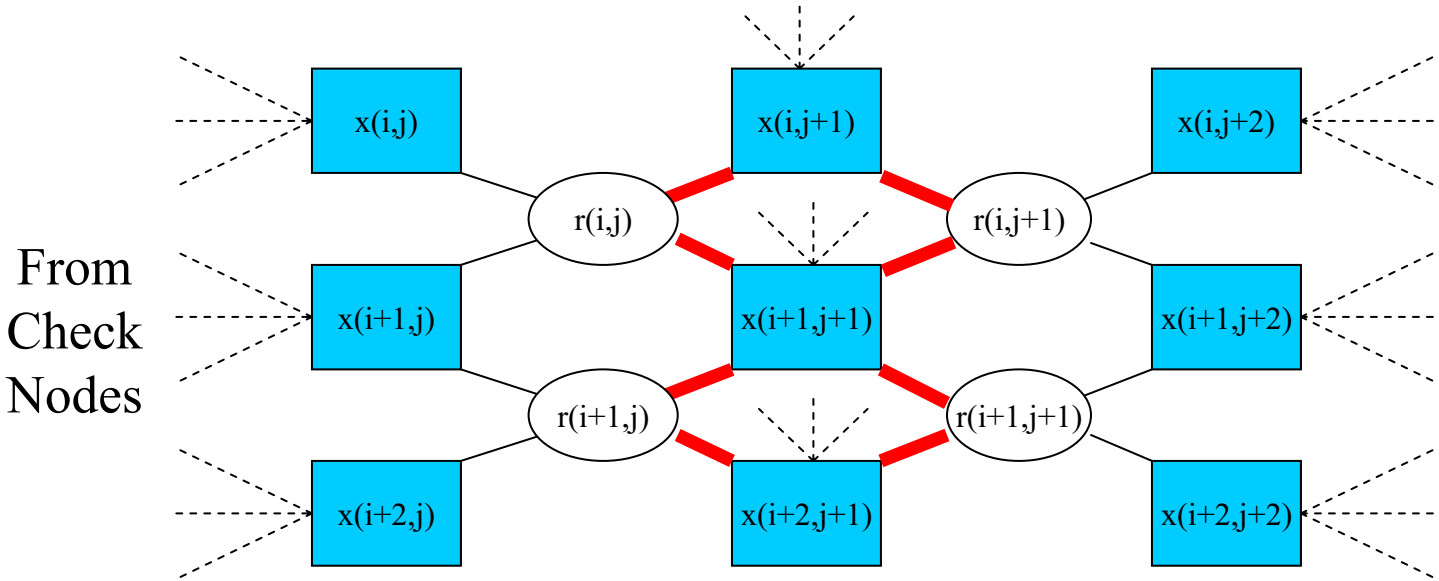

From
Check
Nodes
x(i,j)
x(i,j+1)
x(i,j+2)
r(i,j)
r(i,j+1)
x(i+1,j)
x(i+1,j+1)
x(i+1,j+2)
r(i+1,j)
r(i+1,j+1)
x(i+2,j)
x(i+2,j+1)
x(i+2,j+2)

Performance



Full Graph Analysis

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



Kschischang *et al*., "Factor graphs and the sum-product algorithm," *IEEE Trans. Inform. Theory*, Feb. 2001.

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

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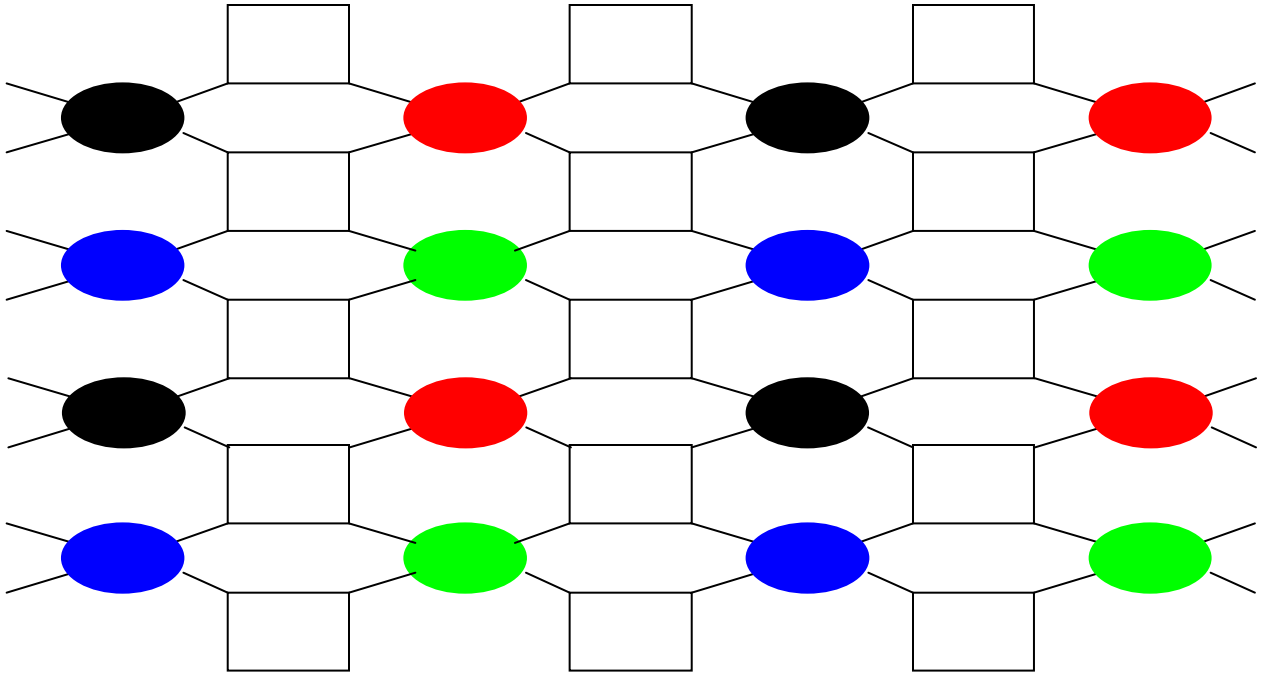
H. M. Hudson, and R. S. Larkin, "Accelerated image reconstruction using ordered subsets of projection data," *IEEE Trans. Medical Imaging*, Dec. 1994

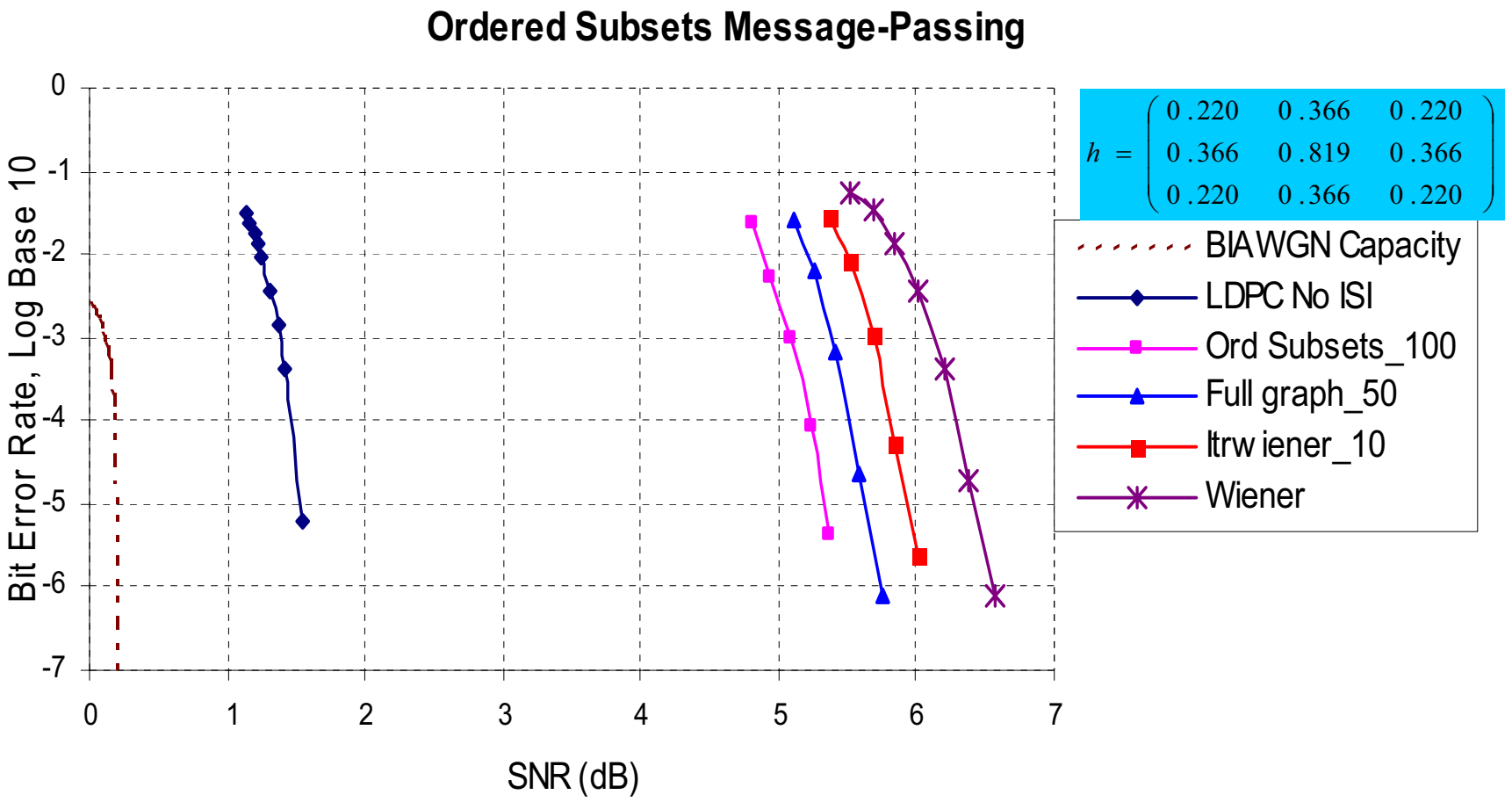
Grouped ISI Graph



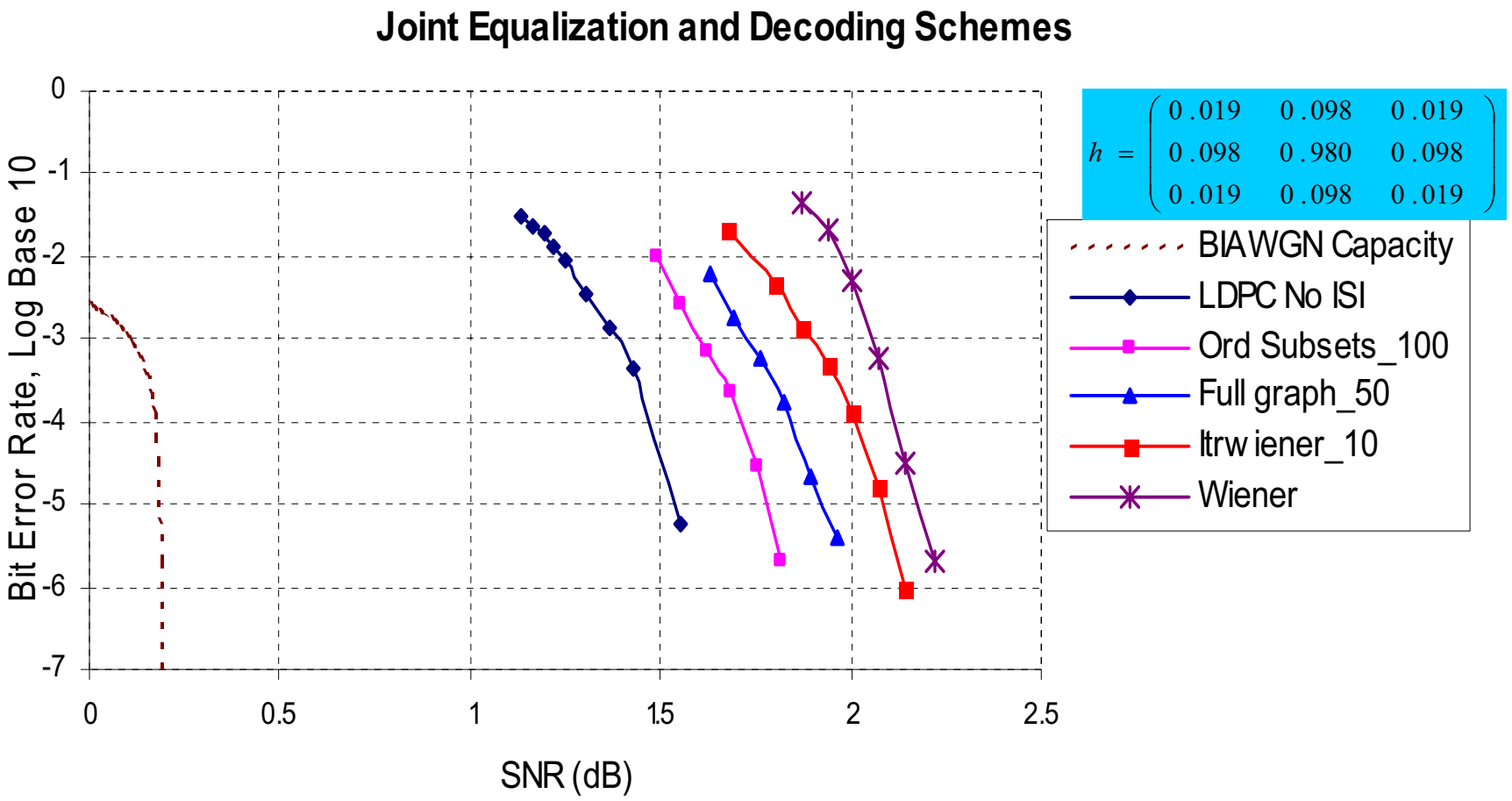
- Labeling of data nodes into 4 subsets
- For each iteration use data nodes of one label only

J. A. O'Sullivan, and N. Singla, "Ordered subsets message-passing," Submitted to *Int'l Symp. Inform. Theory* 2003.

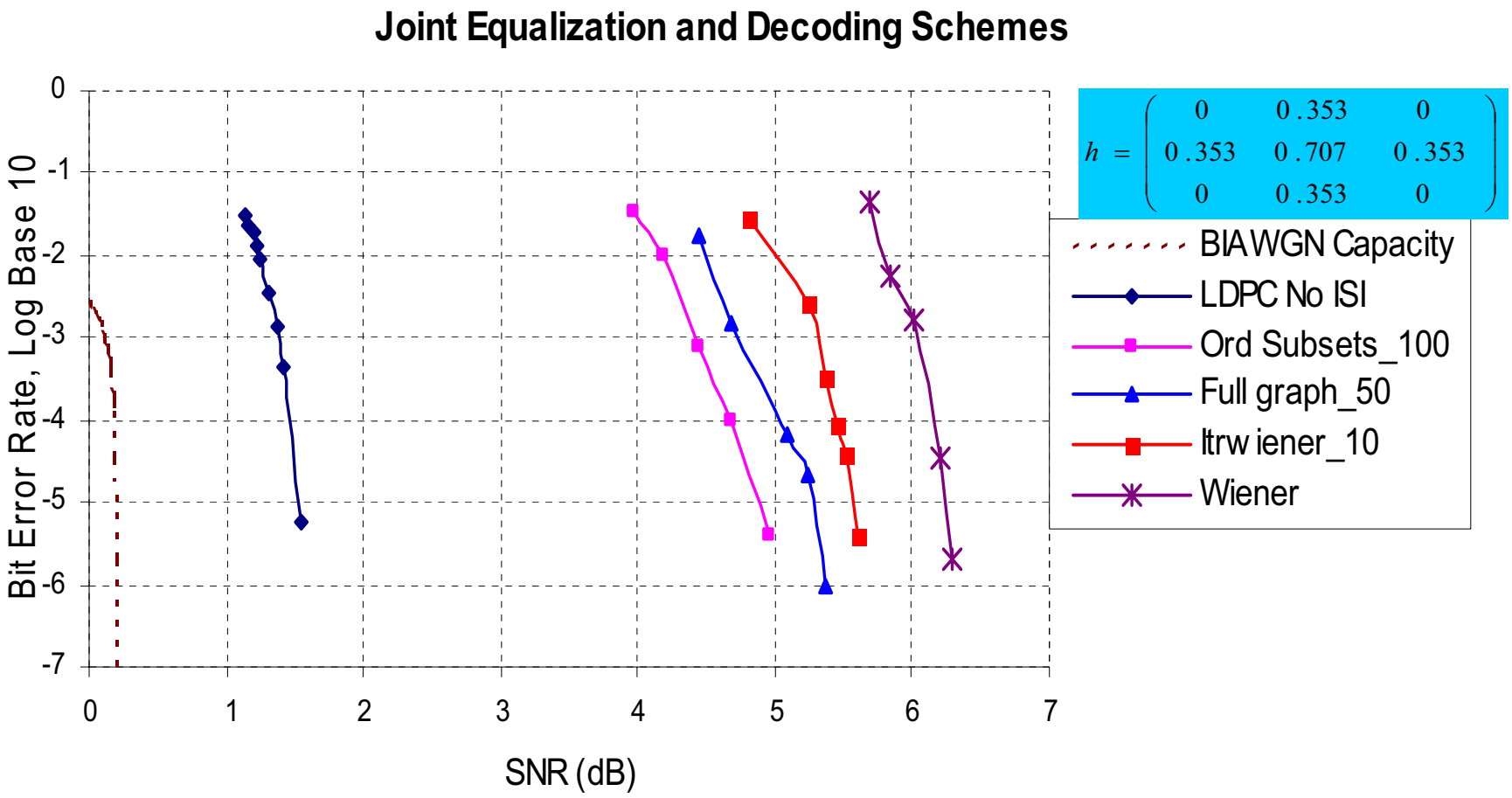
Performance



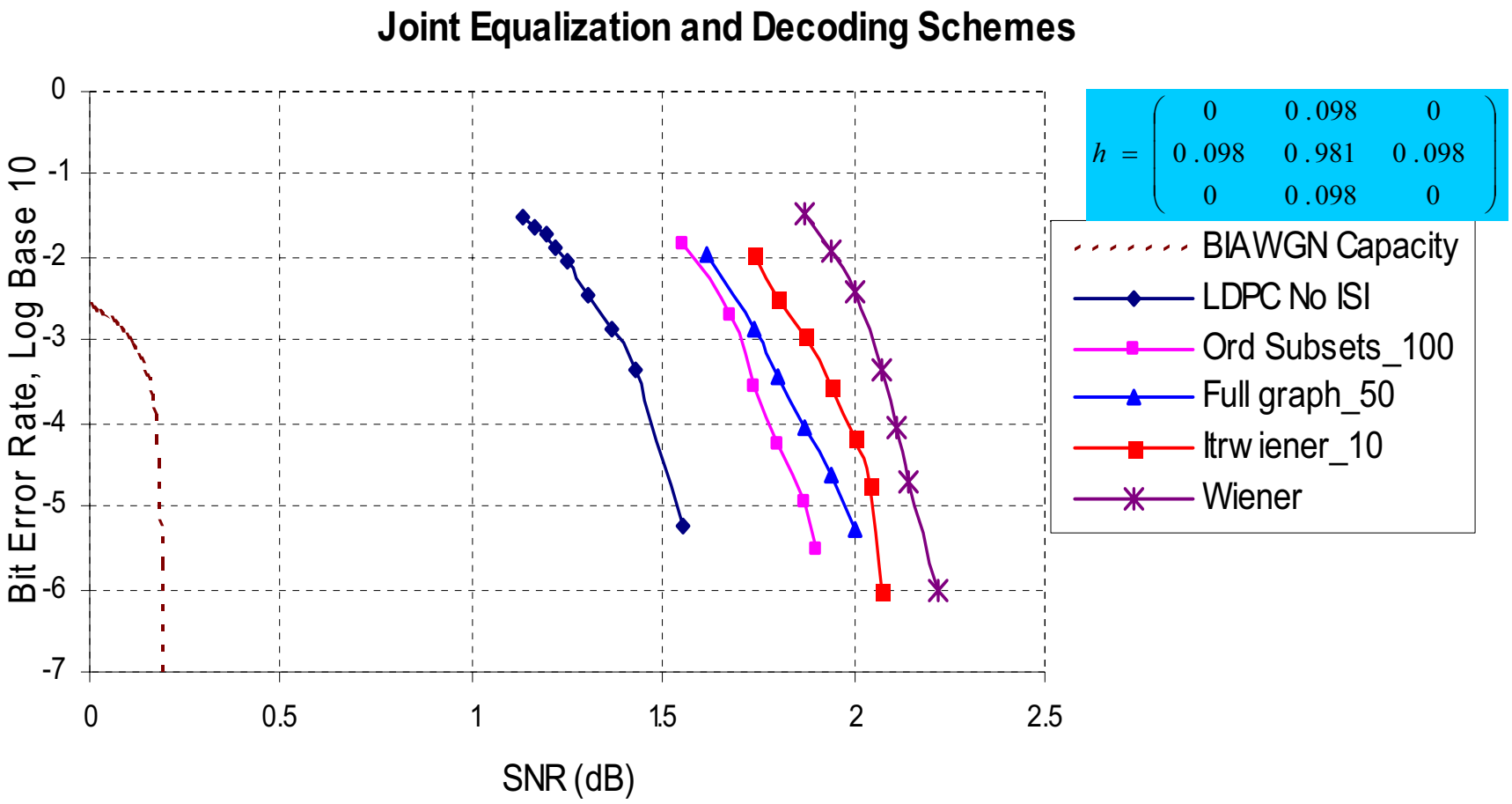
Performance



Performance



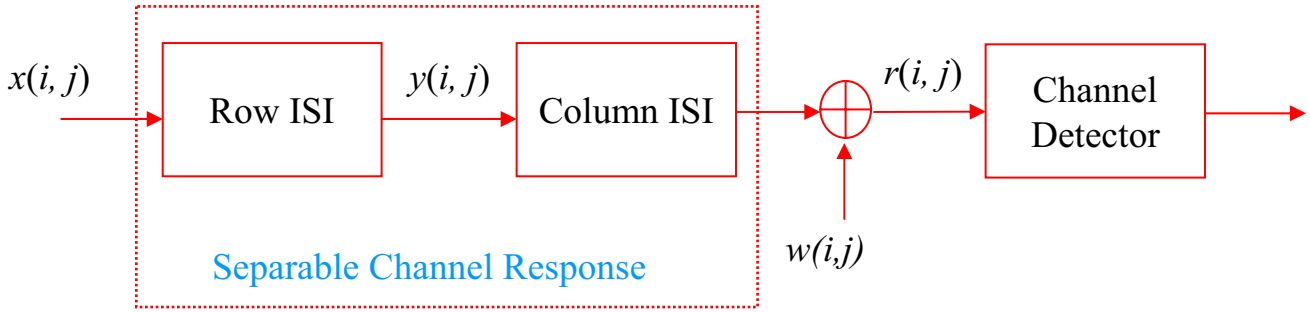
Performance



Consider Separable 2D ISI

Wu *et al.,* "Iterative detection and decoding for separable two-dimensional intersymbol interference" Submitted to *IEEE Trans. Magn.*, June. 2002.

A Separable 2D ISI

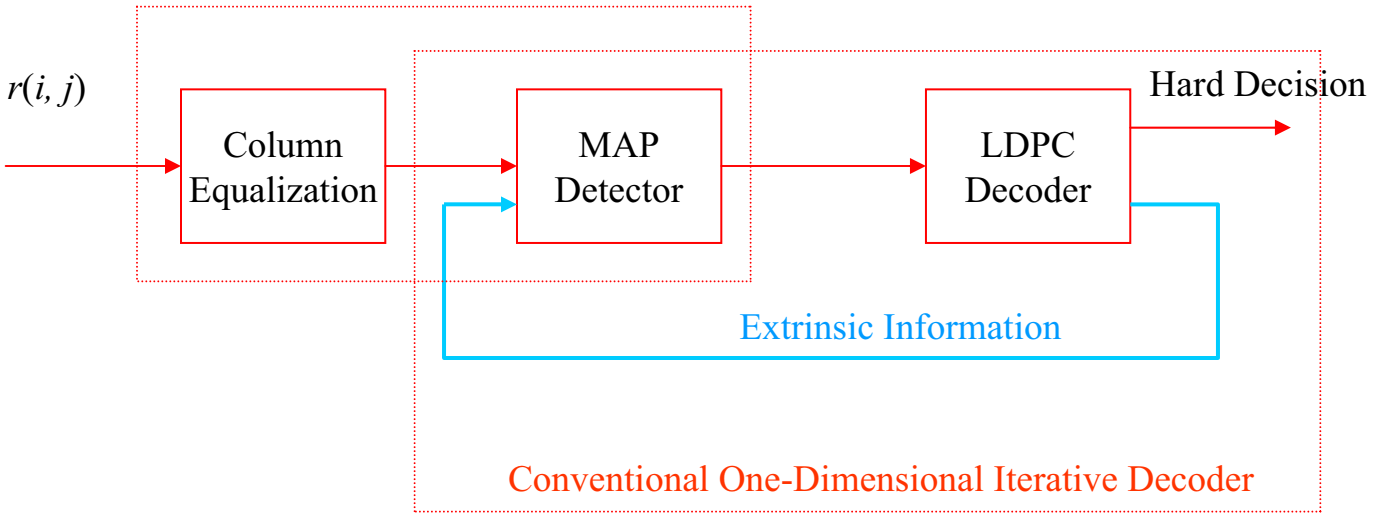


$$h = \begin{pmatrix} 1 & 0.5 \\ 0.5 & 0.25 \end{pmatrix} = \begin{pmatrix} 1 \\ 0.5 \end{pmatrix} \begin{pmatrix} 1 & 0.5 \end{pmatrix}$$

- Advantages of Separable 2D ISI
  - Apply existing one-dimensional equalization methods
  - Reduced Detector Complexity

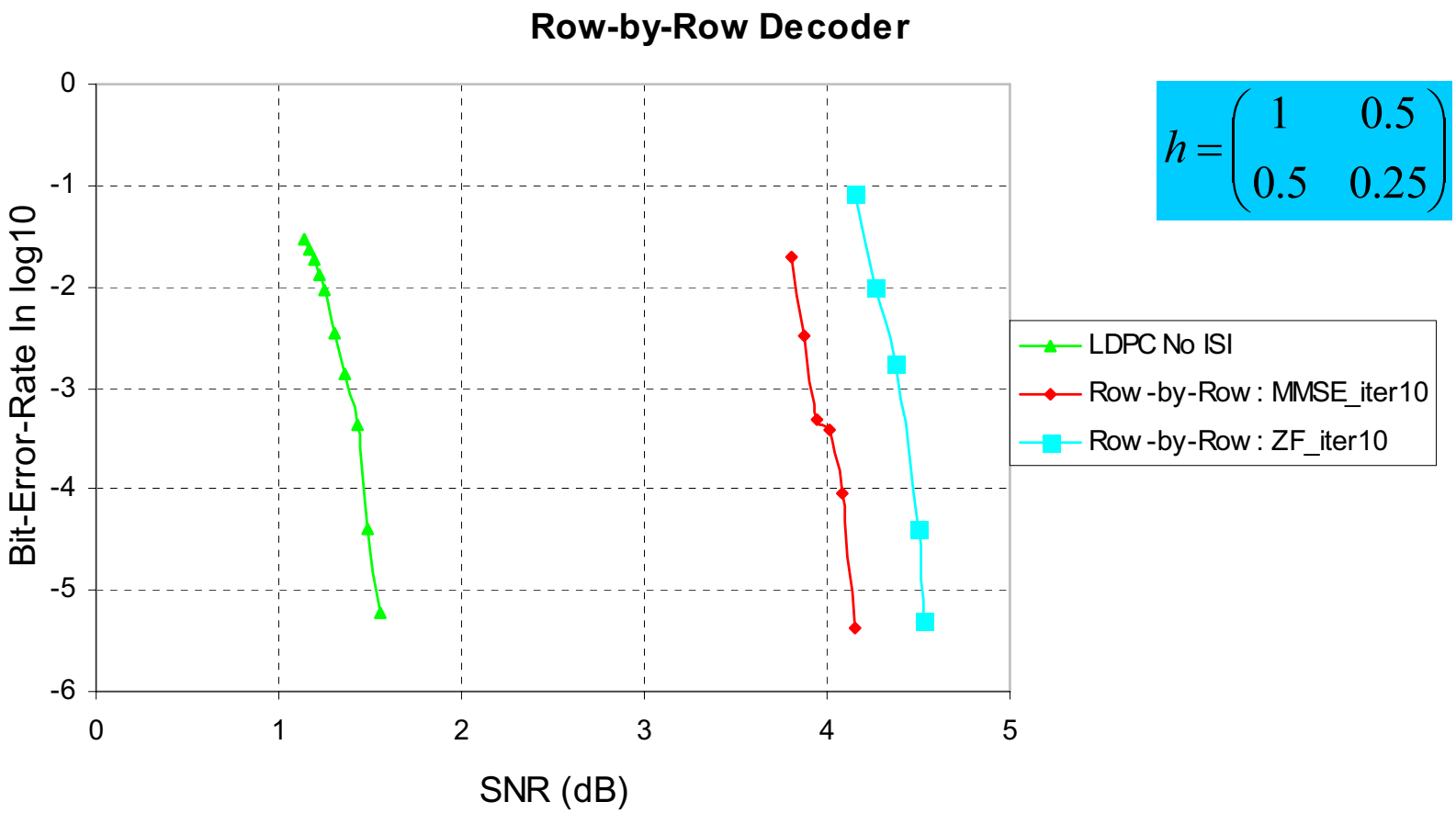
Tüchler *et al*., "Turbo equalization: principles and new results," *IEEE Trans. On Comm*., May 2002.

Row-by-Row Decoder



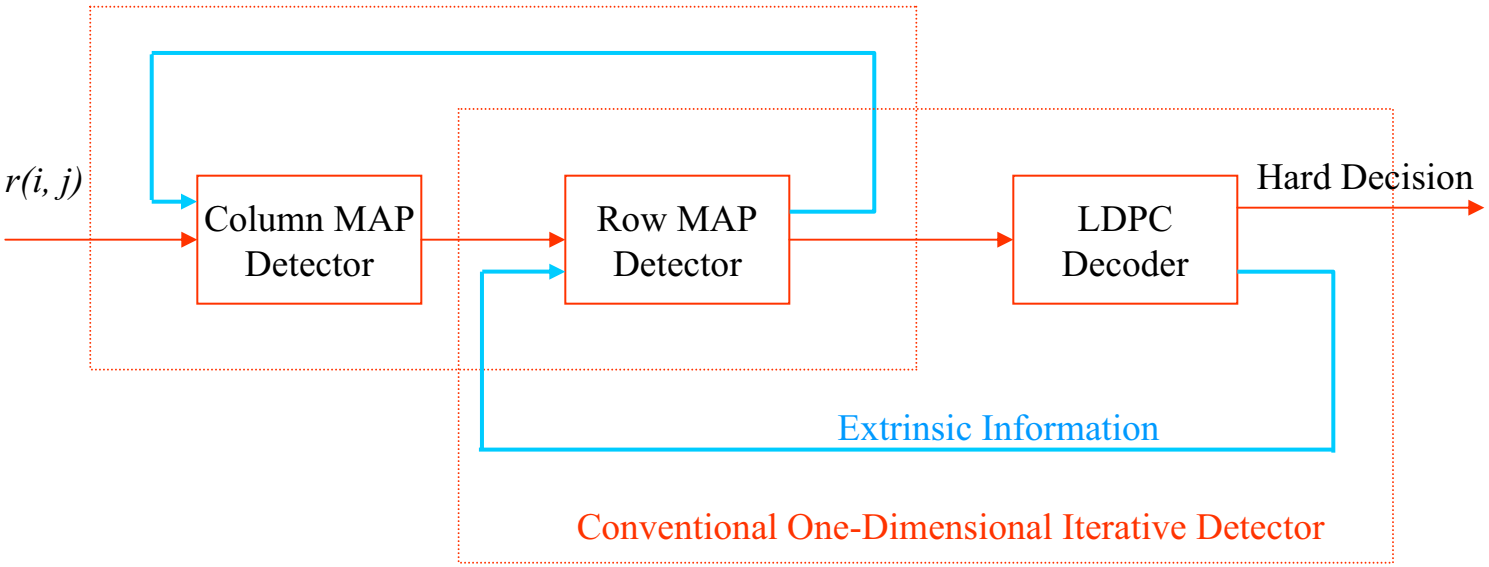
- MMSE and Zero-forcing criteria used for Equalization

Performance



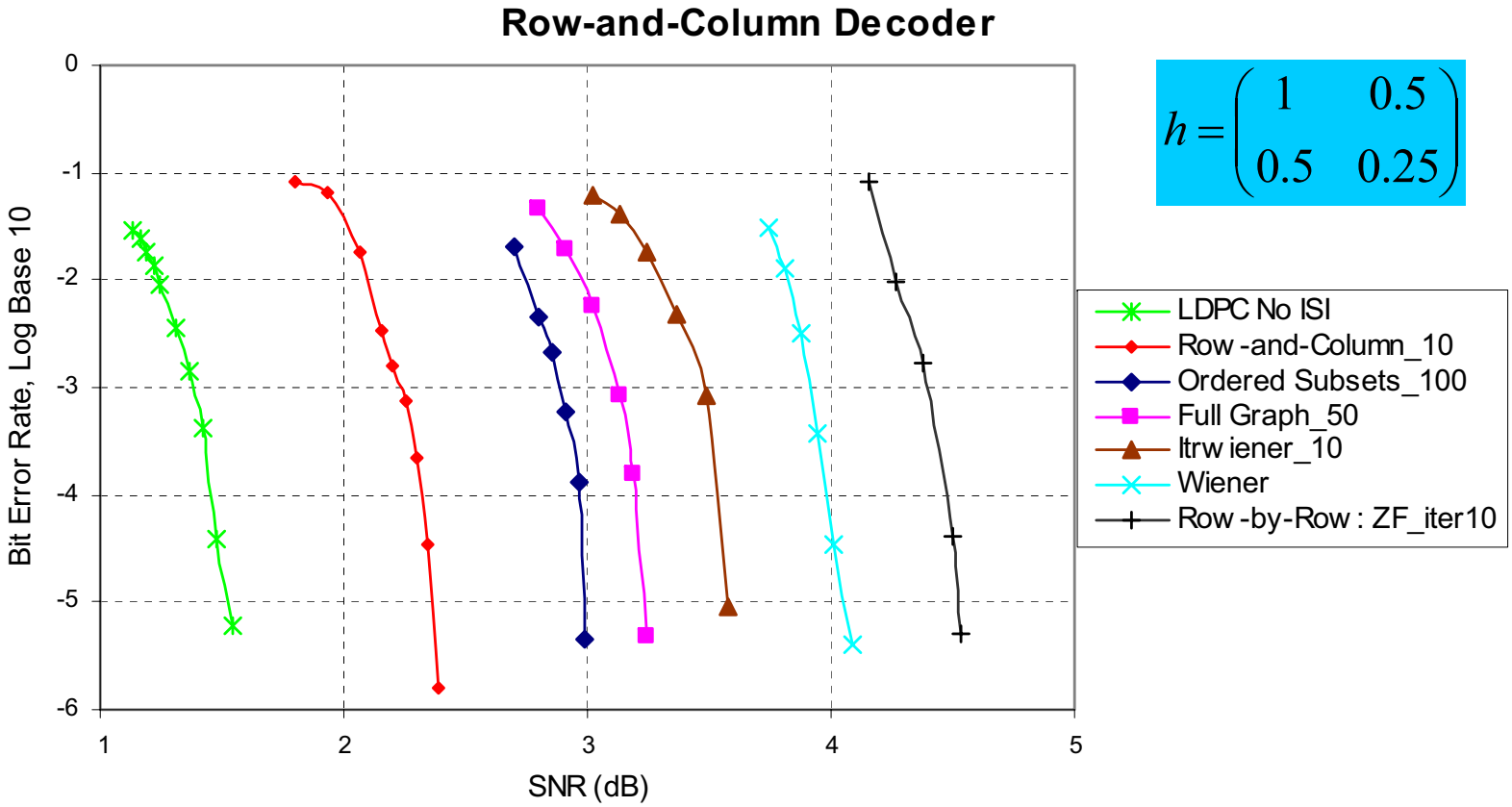
$$h = \begin{pmatrix} 1 & 0.5 \\ 0.5 & 0.25 \end{pmatrix}$$

Row-and-Column Decoder



- Inputs to column detector are not binary

Performance



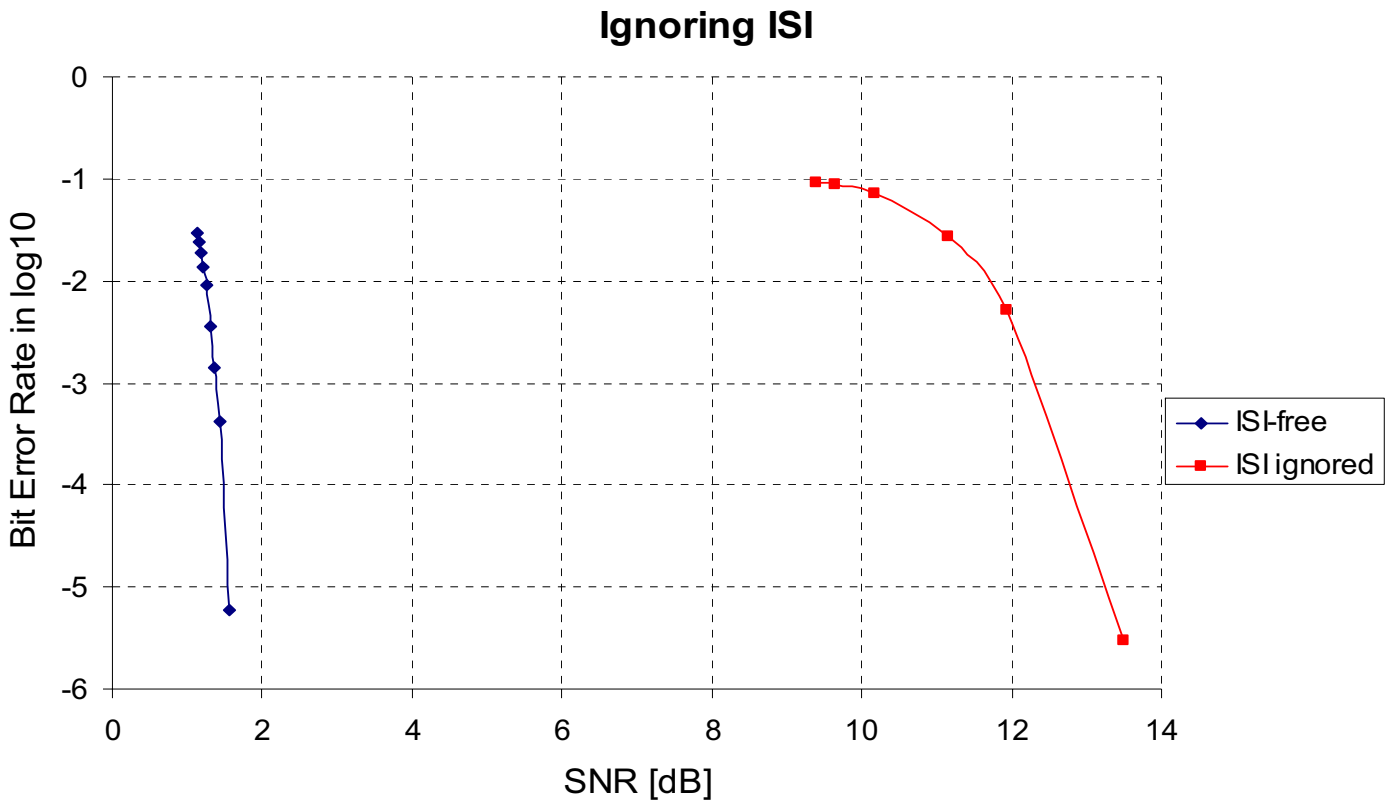
$$h = \begin{pmatrix} 1 & 0.5 \\ 0.5 & 0.25 \end{pmatrix}$$

Conclusions

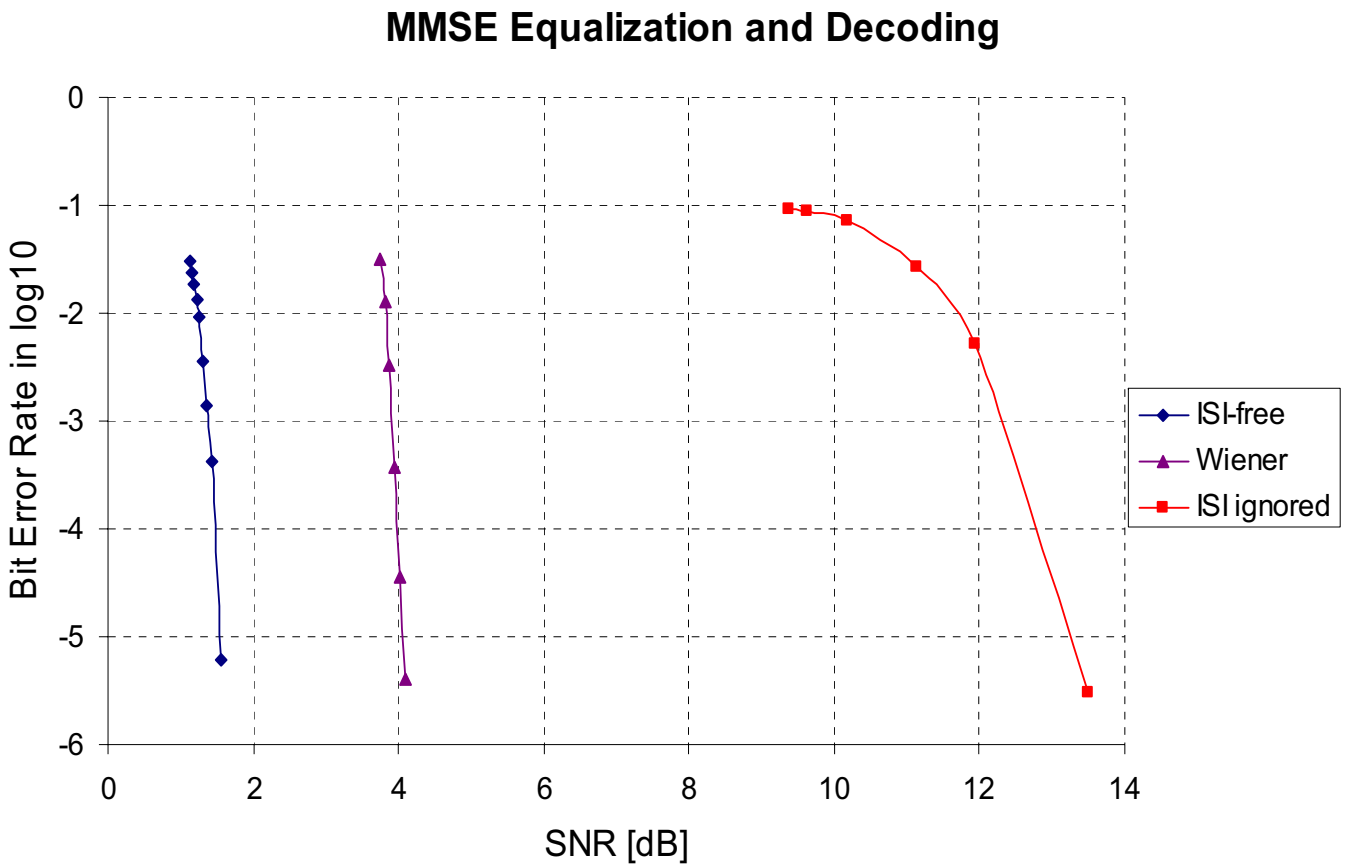
- MMSE equalization and decoding
  - Good Performance with Iterative Equalization
- Message-passing algorithms
  - Full graph algorithm performance deteriorated due to short cycles
  - Ordered subsets message-passing gives best performance for general 2D ISI
- Separable ISI decoding
  - Best performance for separable 2D ISI
  - Low complexity
  - Approximate channel response by separable response

Performance

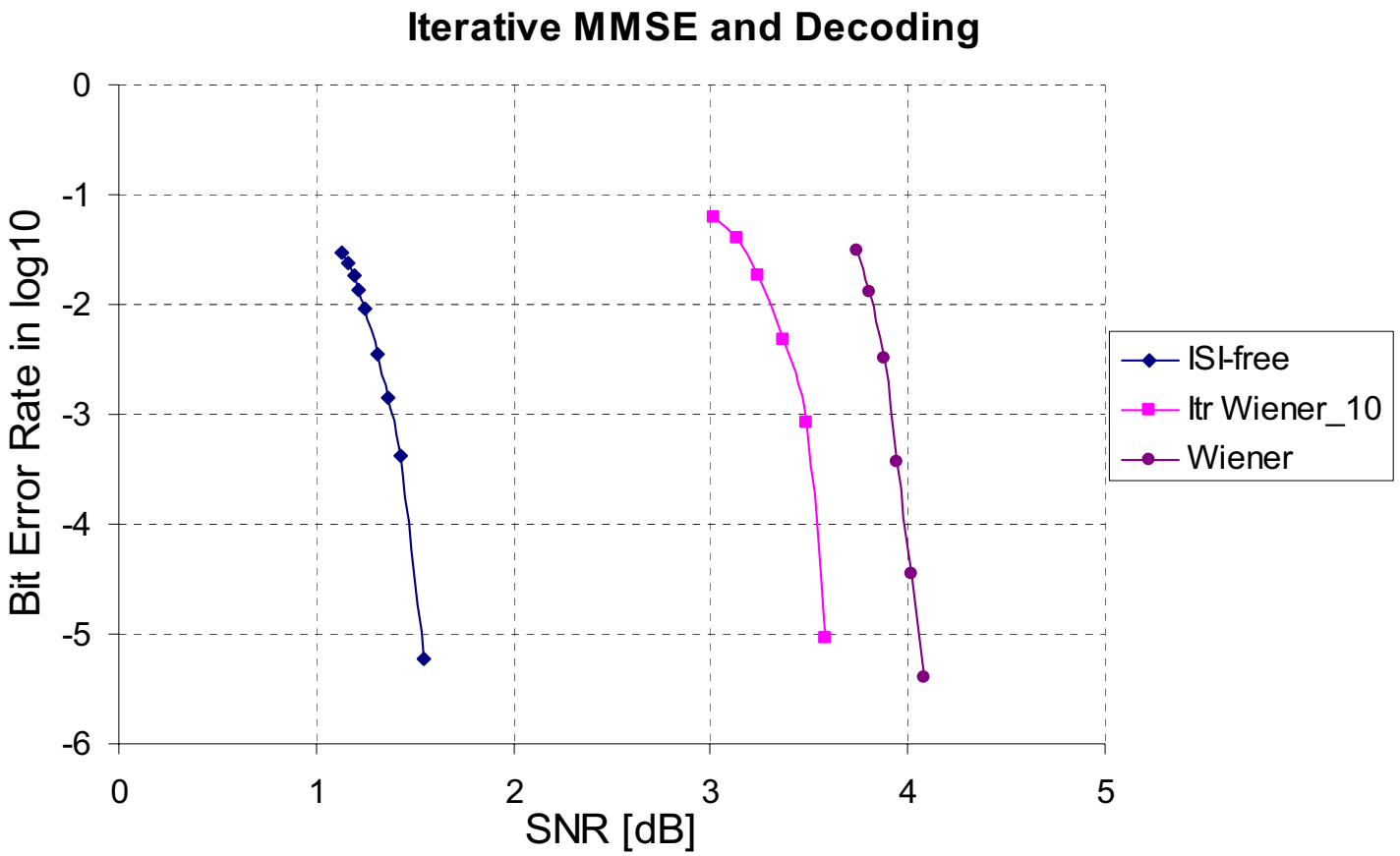
Block length 10000 regular (3,6) LDPC code



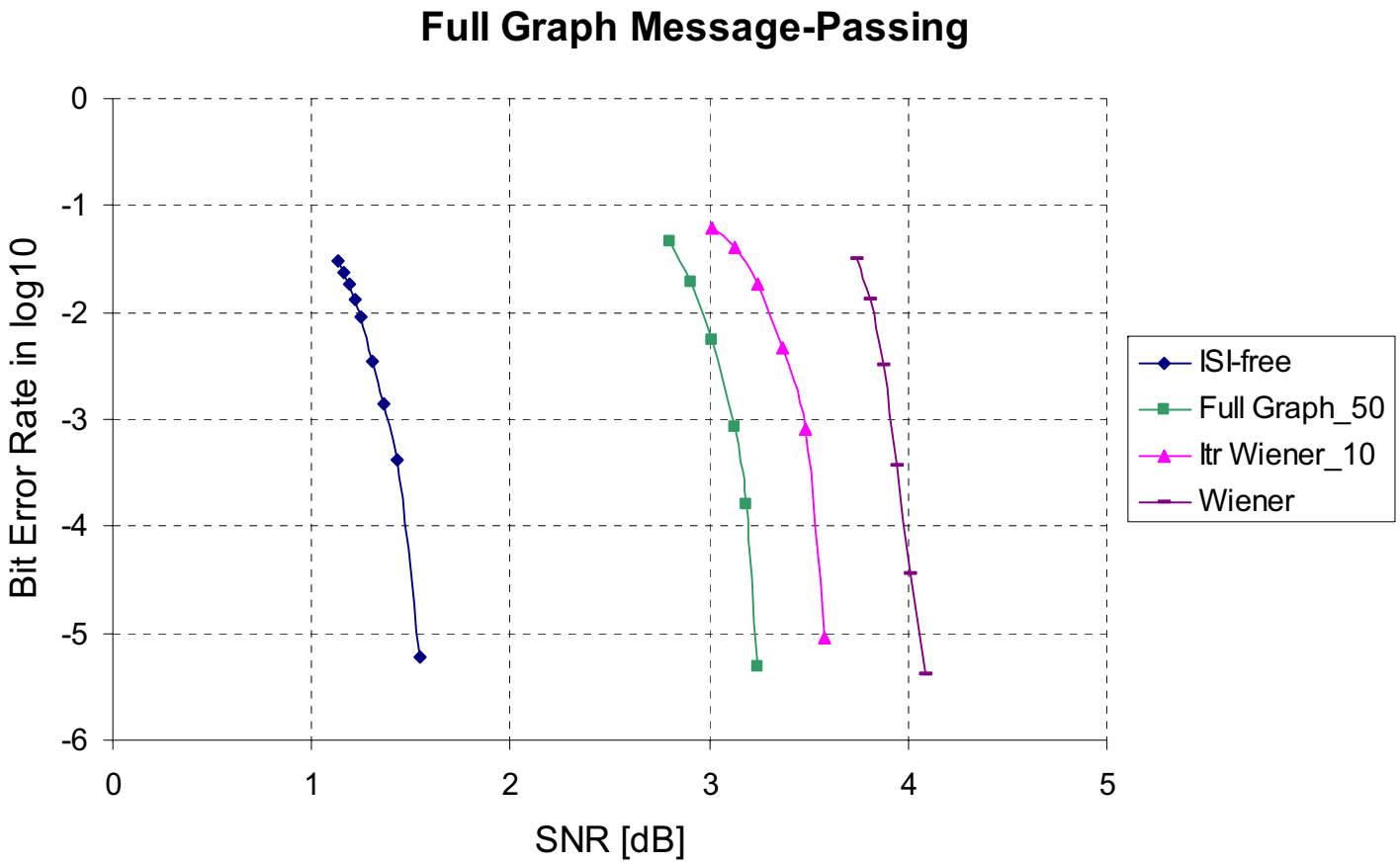
Performance



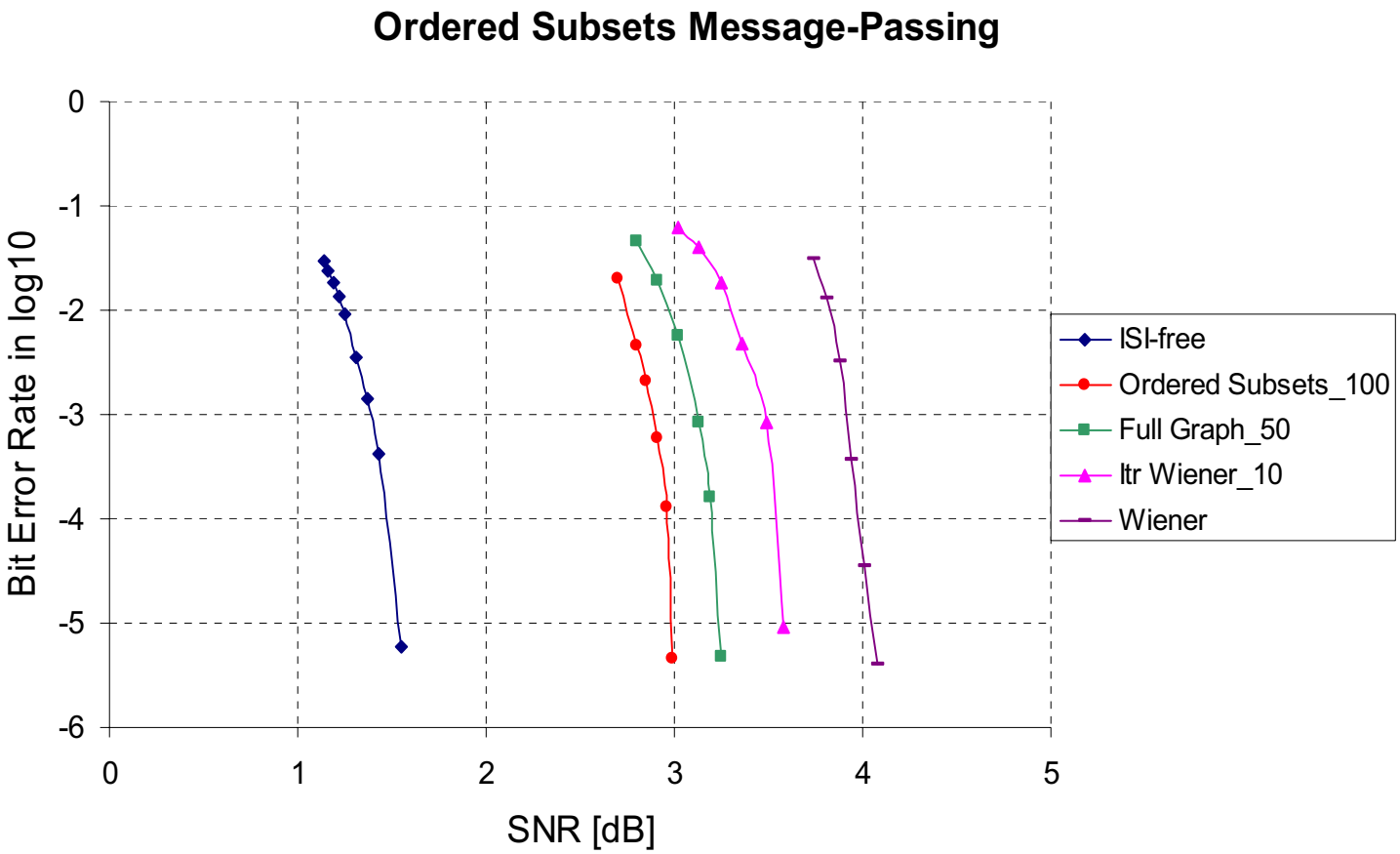
Performance



Performance



Performance



Advanced Media