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High Speed Optical Networking: Task 3
FEC Coding, Channel Models, and Evaluations

Joel M. Morris, PhD

Communications and Signal Processing Laboratory (CSPL)

UMBC/CSEE Department

1000 Hilltop Circle, Catonsville, MD 21250

morris@umbc.edu 410.455.3503

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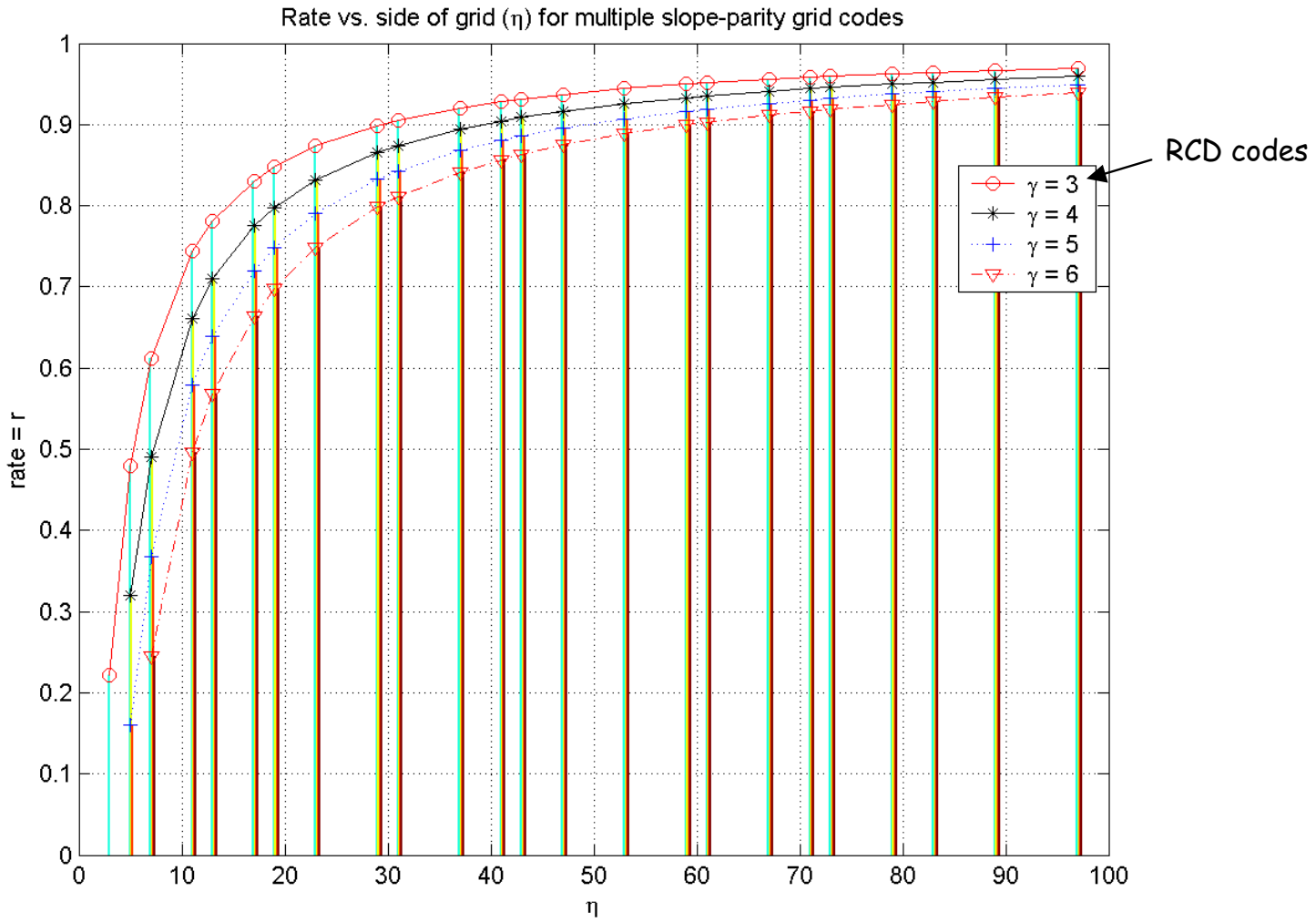
FEC Coding: RCD Codes

- Subset of Regular LDPC Codes
- Decodable via Variety of Decoder Schemes
  w/ Choice Driven by Performance vs. Technology Trade-offs
  - Majority-Logic (MLG) Decoding
  - Iterative Hard-Decision Decoding (Bit-Flipping)
  - Iterative Soft-Decision Decoding (SPA)
- High Code Rates (Low Overhead) Possible
- Weakly Random-like

Multiple slope-parity codes code-rate vs η



FEC Coding

Weight enumerator function (WEF) for RCD Codes

➡ WER/BER performance bounds

- Upper & lower bounds on BDD for BSC
- Union bound as upper bound on ML decoding

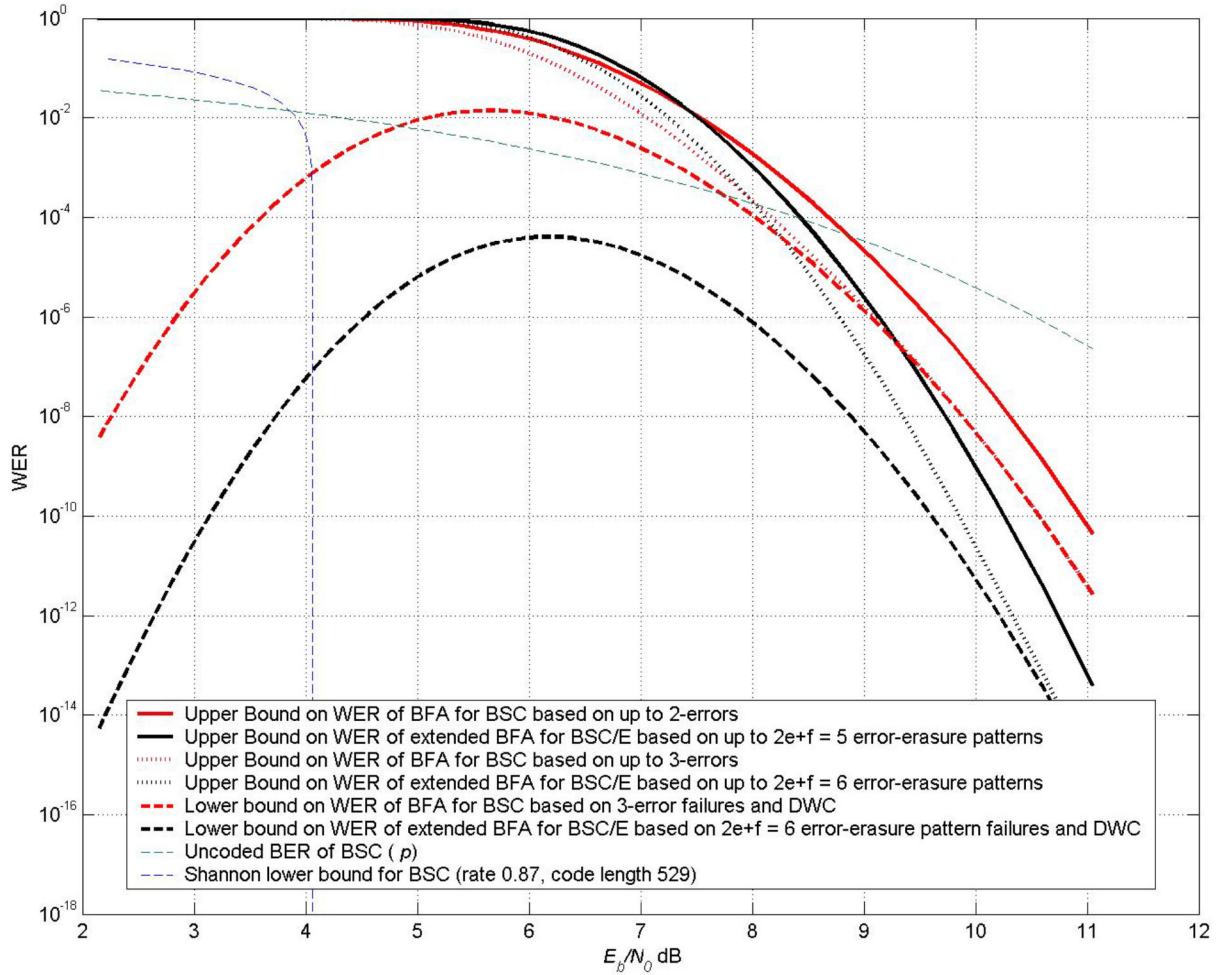
BFA decoding of RCD codes for decoding 3 & 4 error patterns on BSC

- Exhaustive enumeration and classification of 3 & 4 error patterns for various η

  ➡ Expression conjectured for 3 errors, $\forall \eta$

- FPGA design of BFA for (255,175) LDPC code

WER performance bounds for $\eta = 23$ RCD code under BFA for BSC and EBFA for BSC/E



Channel Models

BAC model ~ chi-squared *pdf* based

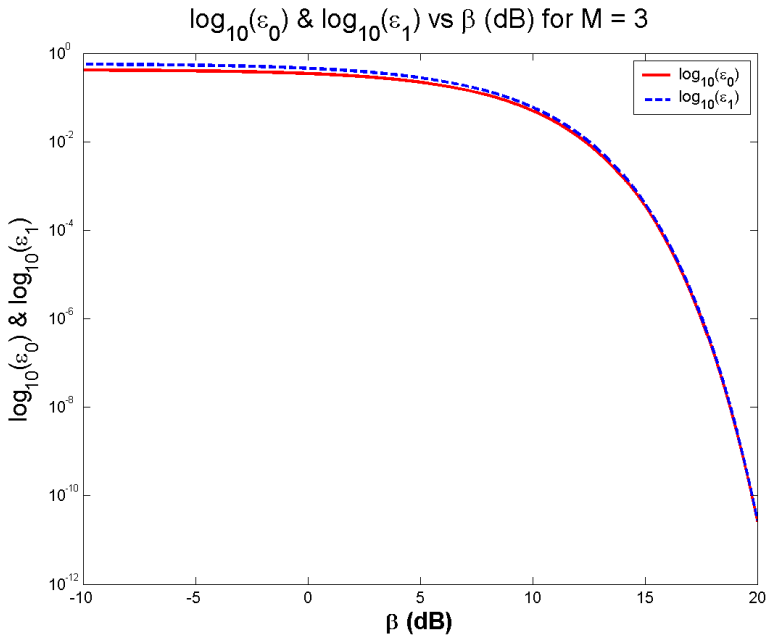
- Shannon limit expression & plots
- Channel capacity expressions & plots
- WER lower bound curves & plots
- Optimal crossover errors close to BSC errors $\forall M$
- BSC model obtained via threshold settings

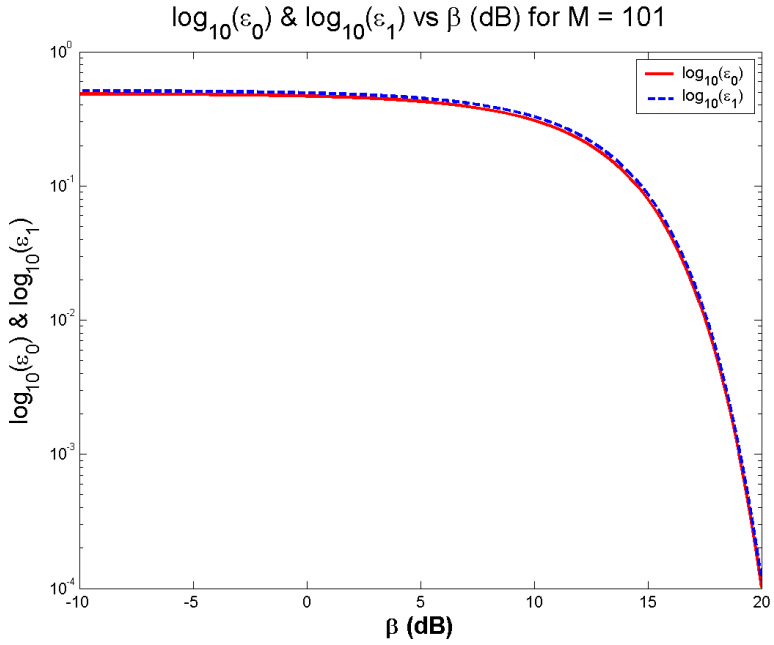
BSC/E model yields significant improvement over BSC

- Using EBFA on BSC/E for RCD codes
- Using extended BDD on BSC/E for LDPC codes
- Channel capacity and Shannon limit comparisons w/BSC

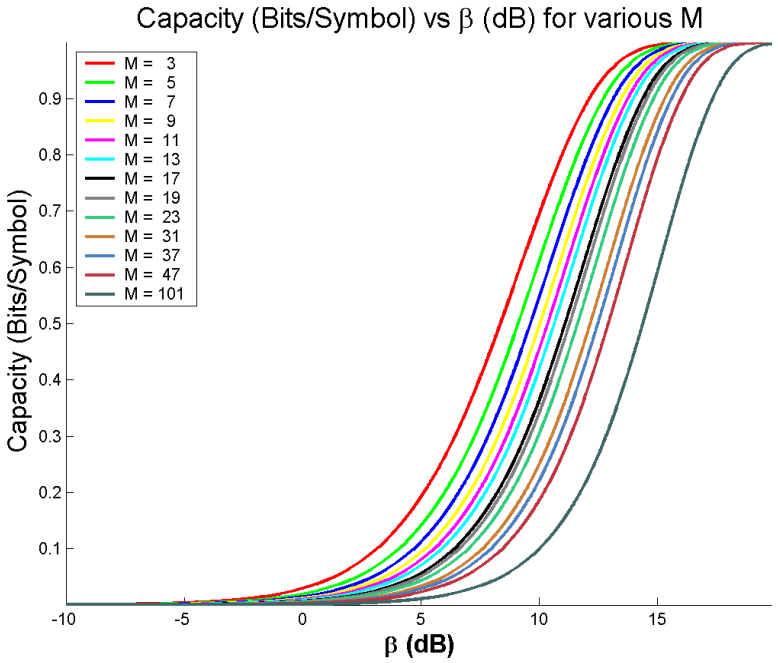
BAC transition probabilities ε_0 and ε_1 vs β for M =3 and M =101

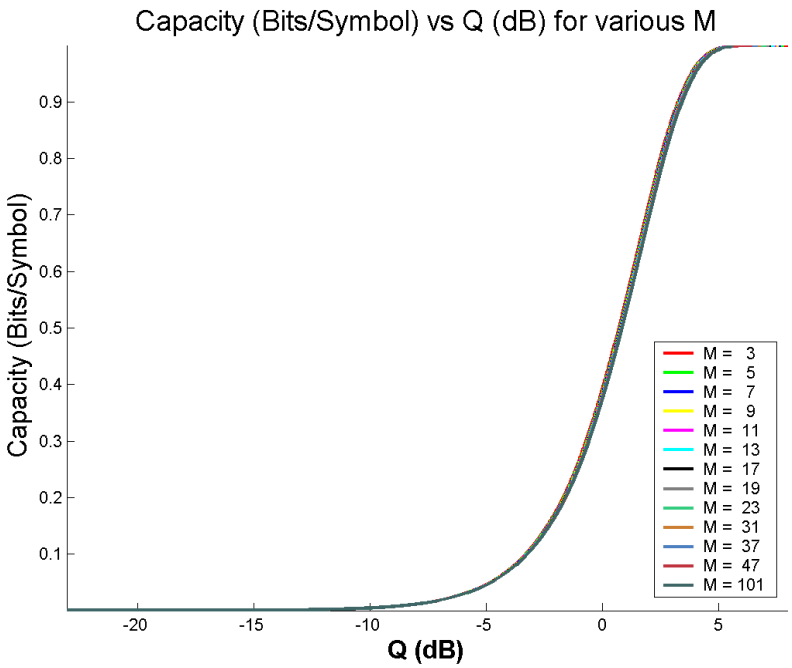
$$\beta = R_c E_b / N_o$$





BAC capacity vs β and Q for various M

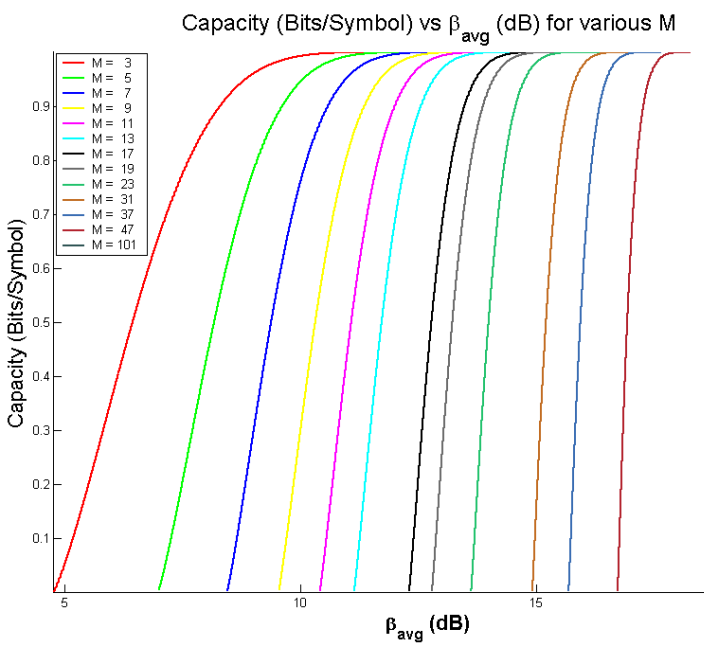


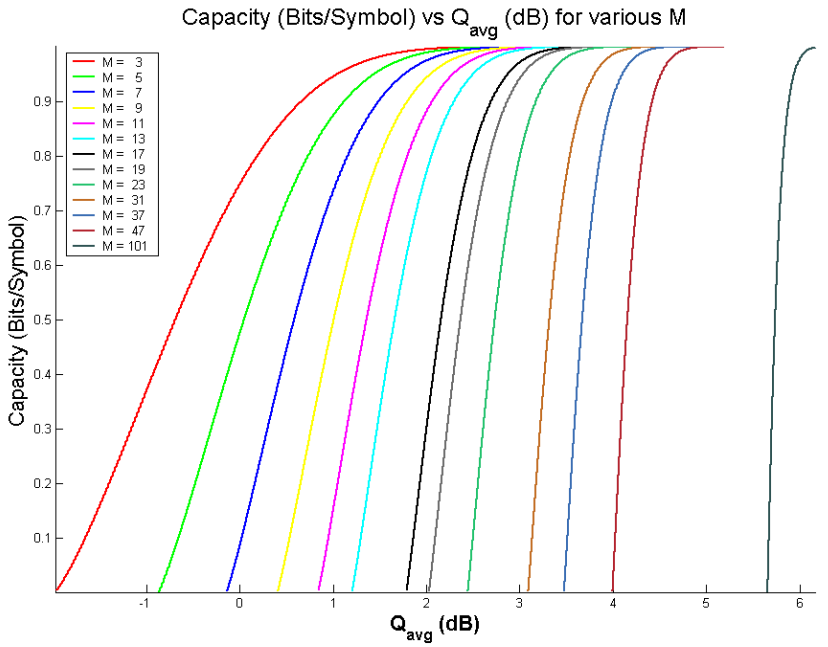


$$\beta = R_c E_b / N_o \qquad Q = (\mu_1 - \mu_0)/(\sigma_1 + \sigma_0) = \beta \Big/ \left(\sqrt{M} + \sqrt{M + 2\beta}\right)$$

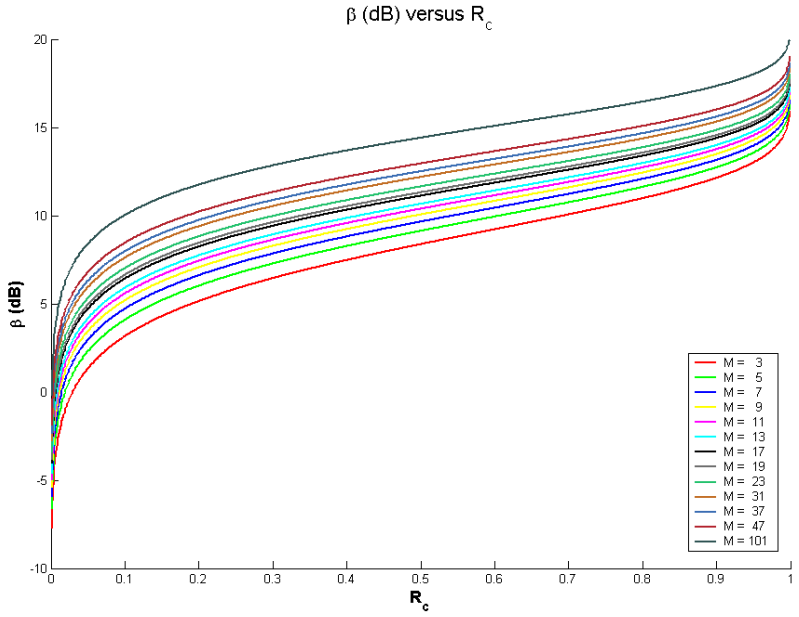
BAC capacity vs β_{avg} for various M

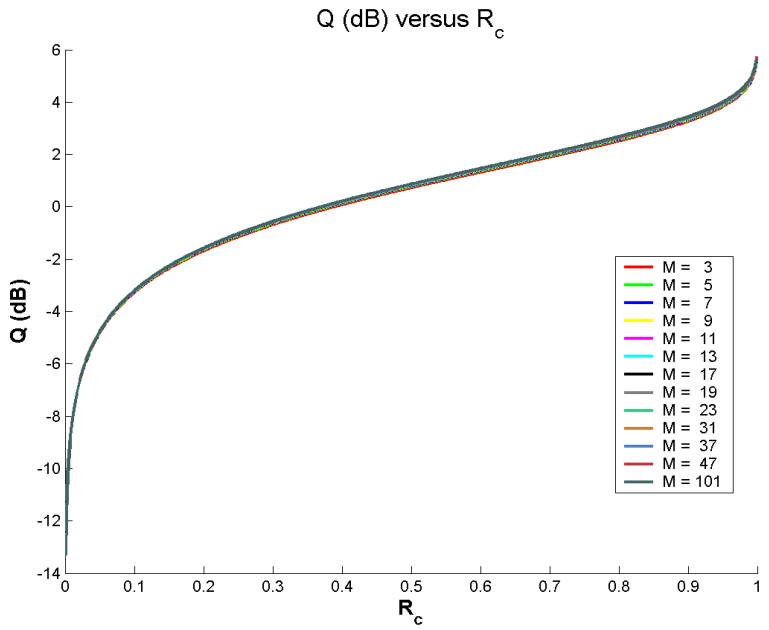
$$\beta_{avg} = \frac{1}{2}\left[\frac{\mu_0^2}{\sigma_0^2} + \frac{\mu_1^2}{\sigma_1^2}\right] = \frac{2M^2 + 4\beta M + \beta^2}{2M + 4\beta}$$



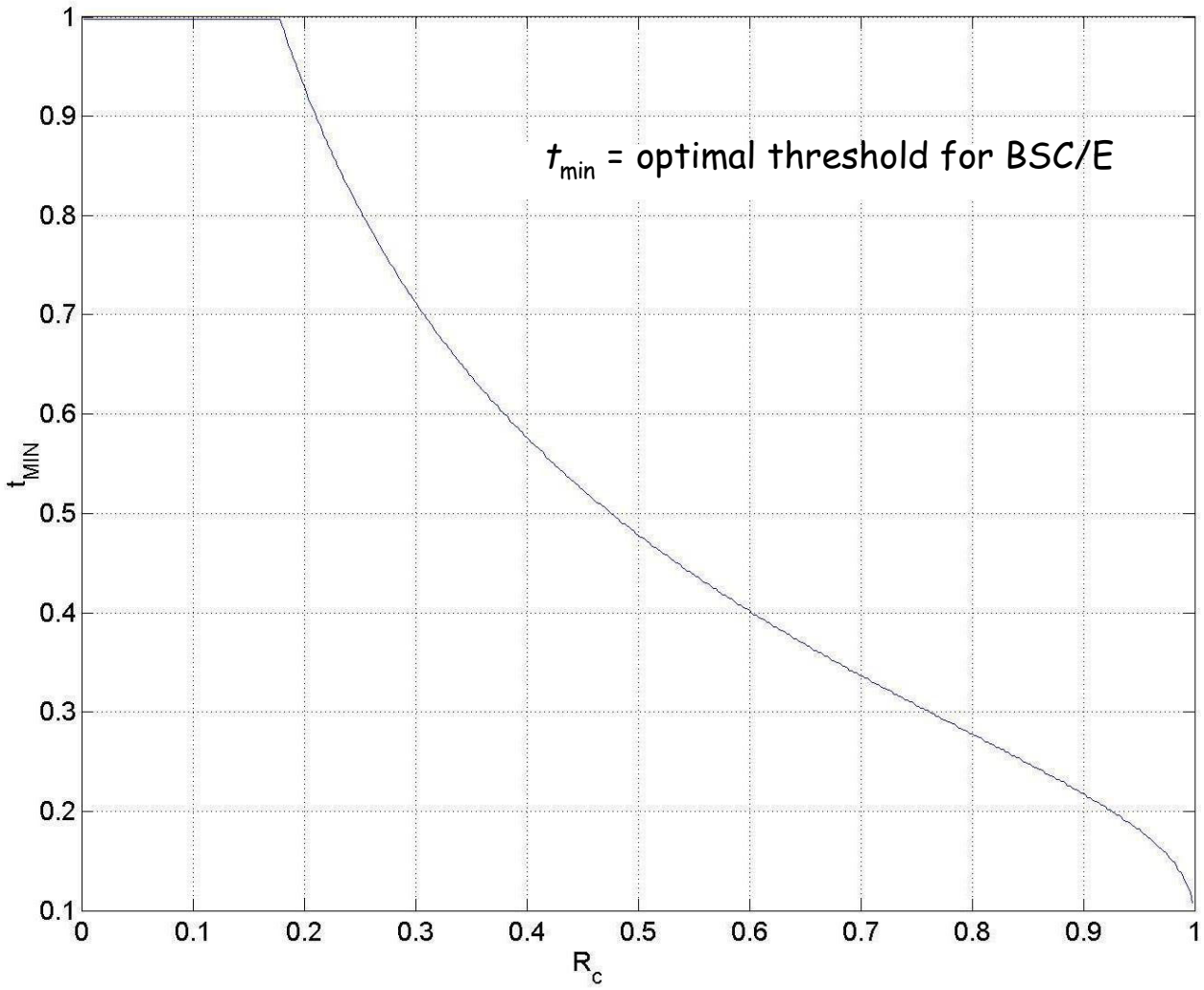


BAC Shannon limit of β and Q vs R_c for various M

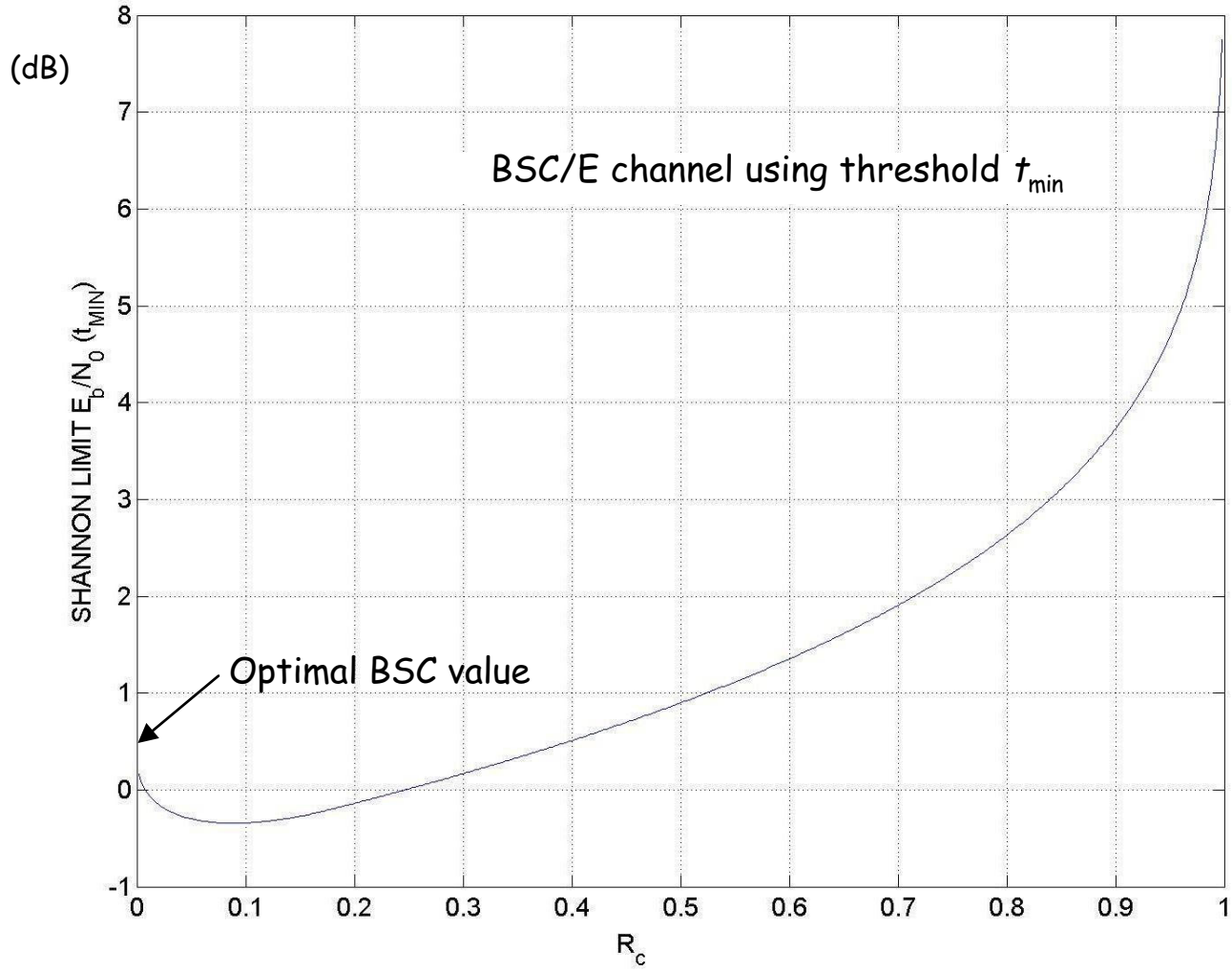




Optimal threshold t_{min} vs R_c for BSC/E channel



Shannon limit E_b/N_o vs R_c using t_{min} for BSC/E channel



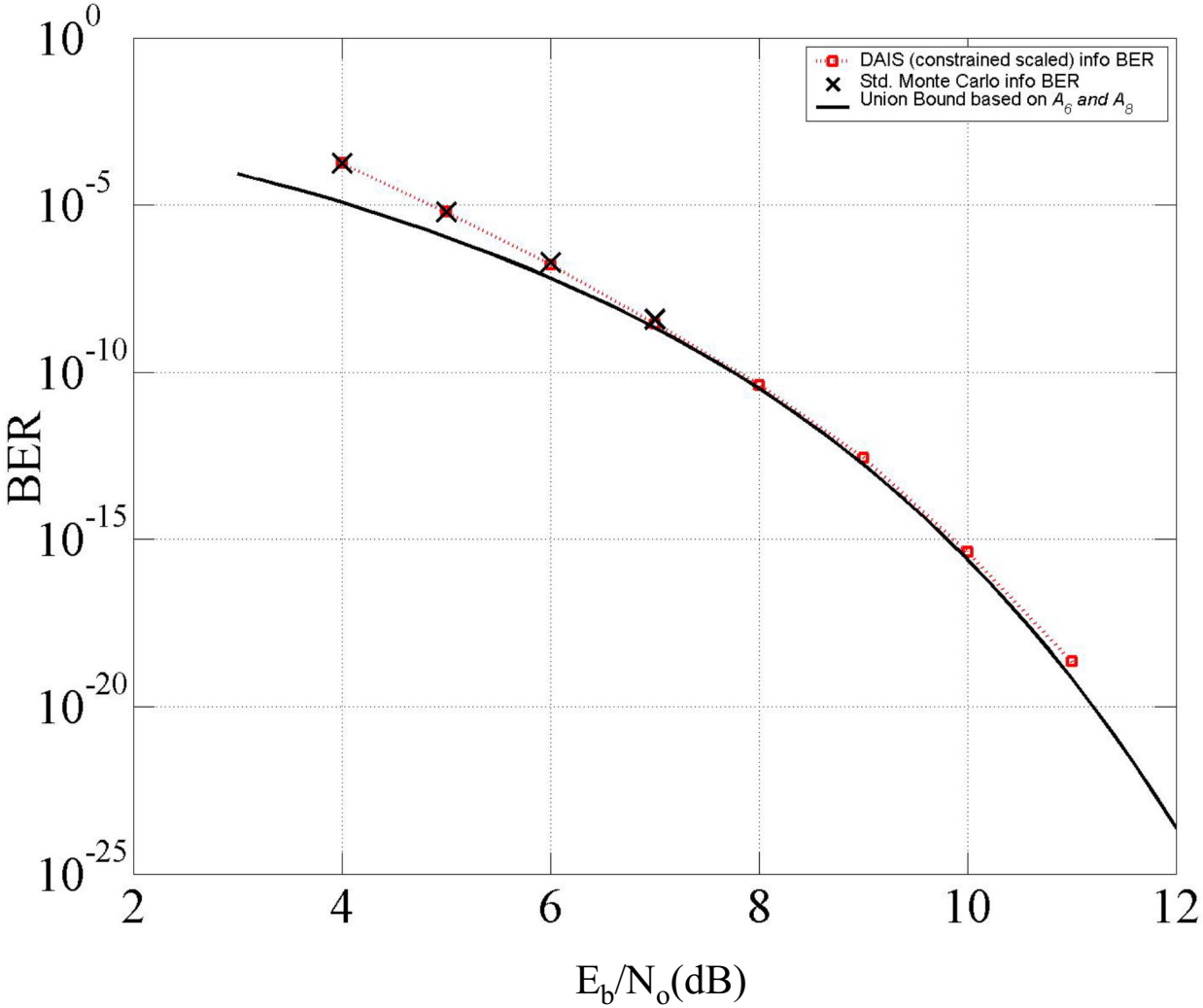
Evaluations

- Sensitivity of SPA decoding of LDPC codes to noise σ^2 variations
- P_{DWC} as a lower bound on WER for class of hard decision decoders for BSC

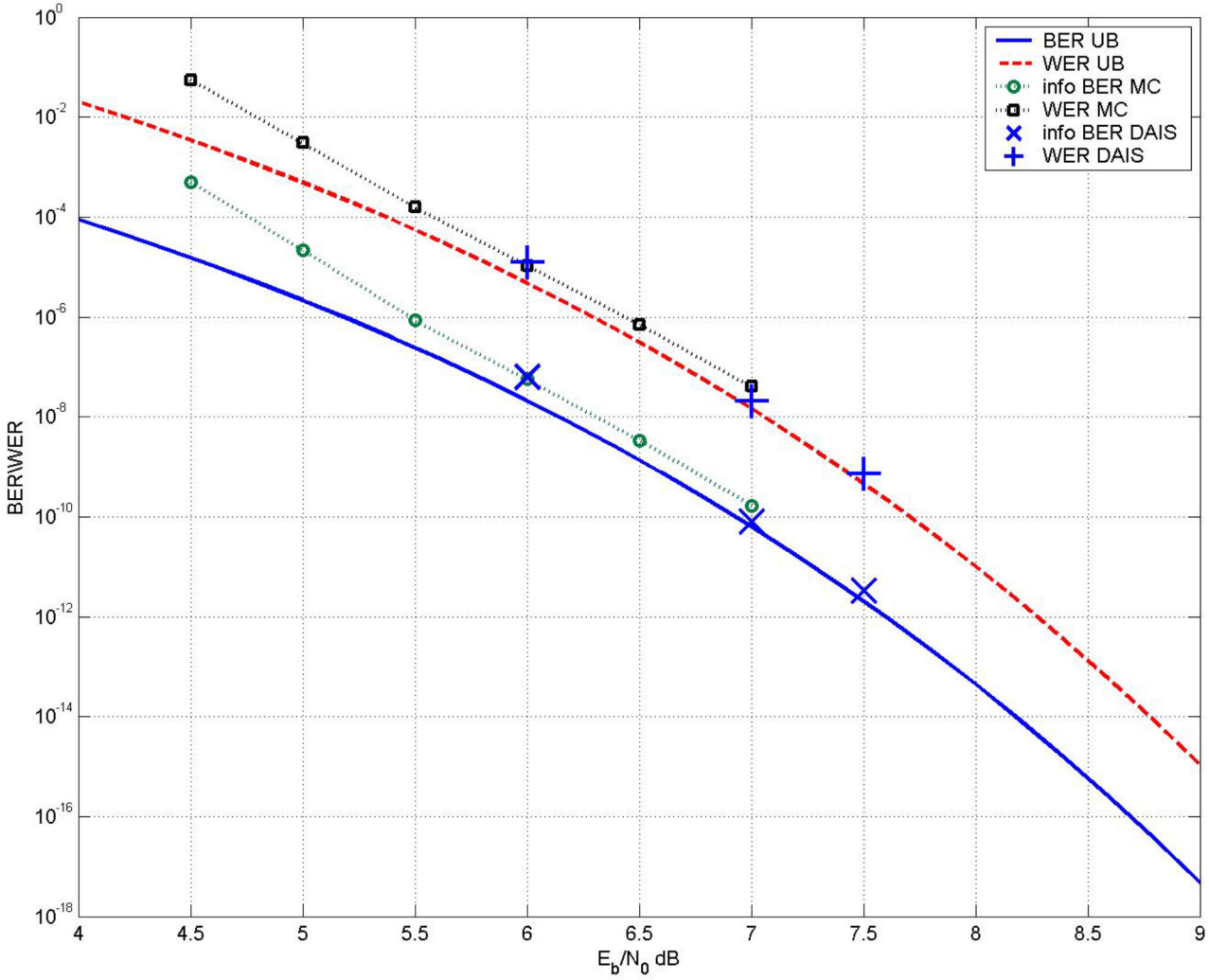
  ➡ extendable to soft-decision decoding

- DAIS ~ joint development of adaptive IS algorithms & software for simulation evaluation of FEC systems at very low BERs
  - AWGN-BPSK channel initially
  - Conceptually extendable to other channel models
  - Provisional patent application obtained

BER for (96,50) LDPC code under SPA decoding via DAIS



WER/BER for $\eta = 37$ RCD code under SPA decoding via DAIS



Papers, Presentations, Dissertations, etc.

Mamtora, D., Mahadevan, A., and Morris, J. M., "A Performance Surface Characterizing Sensitivity to Incorrect Channel Noise Statistics for SPA Decoding of LDPC Codes for M-QAM", *Proc. 3rd Int'l. Symp. Turbo Codes and Related Topics*, Brest, France, 1-5 Sept. 2003, pp. 559-562.

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Martin, W. and Morris, J. M., "The RCD Array Code is a Weakly Random-Like Code", *Proc. 3rd Int'l. Symp. Turbo Codes and Related Topics*, Brest, France, 1-5 Sept. 2003, pp. 351-354.

William R. Martin, "The Weight Enumerator Function for the RCD Array Codes: A Class of LDPC Codes", Ph.D. Dissertation, CSEE Dept/UMBC, Dec. 2003.

Mahadevan, A. and Morris, J. M., "On the Bounded-Distance Decoder's Probability of Decoding to a Wrong Codeword as a Lower Bound on WER for a Class of Decoders", submitted to *IEEE Trans. Information Theory*, 2004.

Mahadevan, A. and Morris, J. M., "On Minimum-WER Performance of FEC Codes for the BSC/E Based on BPSK-AWGN Under Extended Bounded Distance Decoding", submitted to *IEEE Trans. Communications*, 2004.

R. Holzlöhner, A. Mahadevan, C. R. Menyuk, J. M. Morris, and J. Zweck, "Evaluation of the Very Low BER of FEC Codes Using Dual Adaptive Importance Sampling", to appear *IEEE Communication Letters*, 2004.

Amitkumar Mahadevan., "On RCD Codes as a Class of LDPC Codes: Properties, Decoding, and Performance Evaluation", PhD Dissertation, CSEE Dept/UMBC, Dec. 2004 (expected).

___, Mahadevan, A., Menyuk, C. R., Morris, J. M., ___, "Dual Adaptive Importance-Sampling Technique for Estimating Probabilities of Very Rare Events in Coded Communication Systems", Provisional Patent Application #60/486,970, 14 July 2003.

Proposed Future Topics

- Extension of RCD codes to codes having ≥ 4 slope (diagonal) sets
- Hardware (FPGA) implementation of BFA, and test via Carter's testbed
- P_{DWC} as WER lower bound for soft-decision decoders
- Additional channel models with erasures (2-thresholds): BAC/SE & BSC/AE
- Channel models incorporating DPSK modulation/demodulation
- DAIS used for sensitivity studies & non-BSC channel models
- DAIS patent & further development for commercial licensing
- Quantum channel models and error correction