Joint channel coding and detection for efficient communication over fading channels

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Outline

- Motivation
- Work completed
  – MCMC based joint detection and decoding for noncoherent channel
  – Nonbinary LDPC coded MIMO system
- Future work
  – Construction of nonbinary QC cycle codes
  – Low complexity nonbinary LDPC decoding
  – Rateless coding over fading channel with erasures

Goals of the work

- Capacity-approaching receiver strategies for various fading channels. (High spectrum efficiency)
- Low-complexity detection algorithms for noncoherent fading channels. (Low complexity)
- Hardware-friendly LDPC codes. (Low cost)
- Incremental redundancy retransmissions and rateless coding for wireless networks. (High quality)

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Motivation

- Channel estimation may be too expensive or infeasible
- Separate channel estimation and data detection is not capacity approaching
- Low complexity noncoherent detector needed
- The application of MCMC to coherent MIMO detection has been very successful [1]

[1] B. Farhang-Boroujeny, H. Zhu, and Z. Shi. Monte Carlo Markov chain techniques for CDMA and MIMO communication systems. IEEE Trans. Signal. Process., 54(5):1896–1909, May 2006.

Contribution

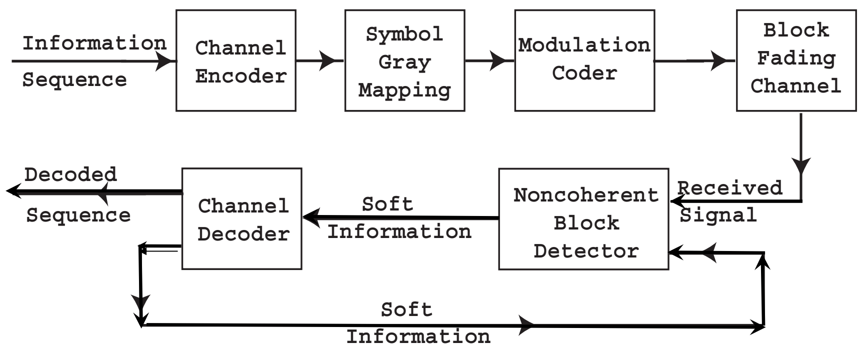
- Propose an important design criterion: information rate of modulation codes should be close to optimal channel capacity.
- Compare information rates of modulation codes used in SISO and DISO systems.
  - For certain modulation codes, SISO is better than DISO.
- Develop a low complexity noncoherent detector based on MCMC.
  - Very low complexity
  - No explicit amptitude estimation or phase quantization required

Contribution

[C1] "*Noncoherent detection based on Markov chain Monte Carlo methods for block fading channels*", Proc. IEEE Global Telecommunications Conference, 2005

[J1] "*Performance of Channel Coded Noncoherent Systems: Modulation Choice, Information Rate, and Markov Chain Monte Carlo Detection*" Submitted to IEEE Trans. Commun

Background

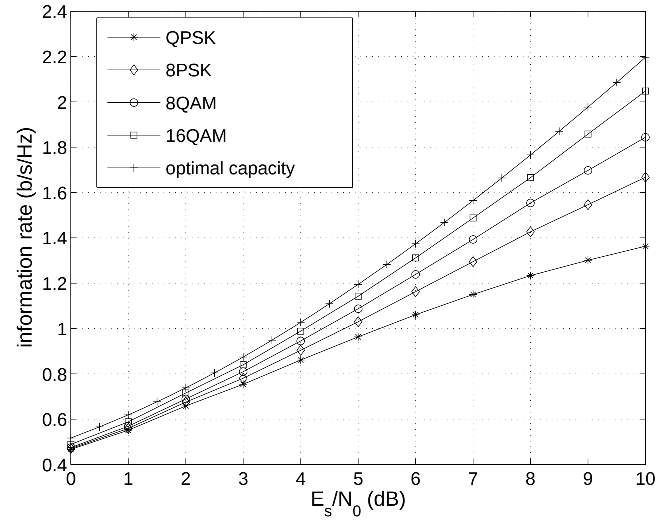


A schematic block diagram of the channel coded noncoherent system.

Noncoherent block fading channel

Noncoherent: neither Tx nor Rx know channel

Modulation choice – SISO system



SISO VS. DISO

- Capacity: DISO   SISO
  - Optimal input distribution unknown
  - Complex modulation code means complex detection
- Practical system
  - DISO system using unitary space time modulation (USTM) or Alamouti code achieve only a fraction of the optimal capacity
  - Mutual information rate is much lower than SISO system using 16QAM
- No need to waste a second transmit antenna when above modulation codes are used

MCMC detector

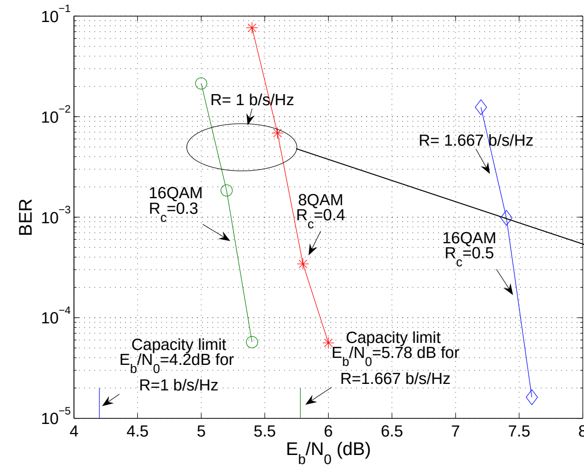
- MAP detector: complexity is exponential with

- Only those S with large (important vectors) contribute much to the summation (max-log: only the largest one)
- MCMC detector finds important vectors using Markov chain Monte Carlo

MCMC detector

- Compared to other existing noncoherent detector, MCMC detector achieves better performance at reduced complexity
- Noncoherent MCMC detector versus coherent MCMC detector: use noncoherent pdf instead of coherent pdf

Simulation results



SISO system using 16QAM achieve about 4dB gain over DISO system using USTM or Alamouti

Rate=1, 16QAM system is 0.5dB better 8QAM system

Performance comparisons of SISO system

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Motivation

- Optimal binary code has been designed to approach channel capacity.
  - Long codes
  - Irregular
- Nonbinary LDPC code design has been studied for AWGN and shows better performance than binary codes.
  - Shorter codes
  - More regular

Contribution

- Apply nonbinary LDPC codes to fading channels and MIMO channels and provide comparison with optimal binary LDPC coded systems
- Propose modified nonbinary LDPC decoding algorithm.
- Extend EXIT chart to nonbinary code design
- Propose parallel sparse encodable nonbinary code with low encoding and decoding complexity

Contribution

[C2] "*Application of nonbinary LDPC codes for communication over fading channels using higher order modulations*" Proc. IEEE Global Telecommunications Conference, 2006

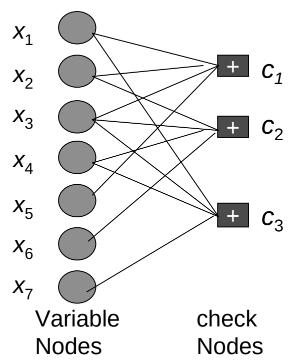
[C3] "*Good LDPC Codes over GF(q) for Multiple-Antenna Transmission*", Proc. IEEE Military Communication Conference, 2006.

[C4] "*Design of Nonbinary Quasi-Cyclic LDPC Cycle Codes*", Proc. IEEE Information Theory Workshop, 2007.

[J2] "*Application of nonbinary LDPC cycle codes to MIMO channels*", submitted to IEEE Trans. Wireless Commun., (Under minor revision)

Introduction of binary LDPC codes

- A subclass of linear block codes
- Specified by a parity check matrix $(n\text{-}k) \times n$
  - n: code length k: length of information sequence

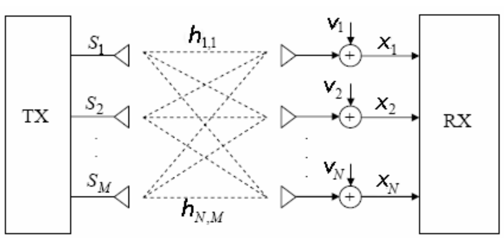


Definition of nonbinary LDPC codes

- For nonbinary codes, the ones in parity check matrix are replaced by nonzero elements in GF(q)

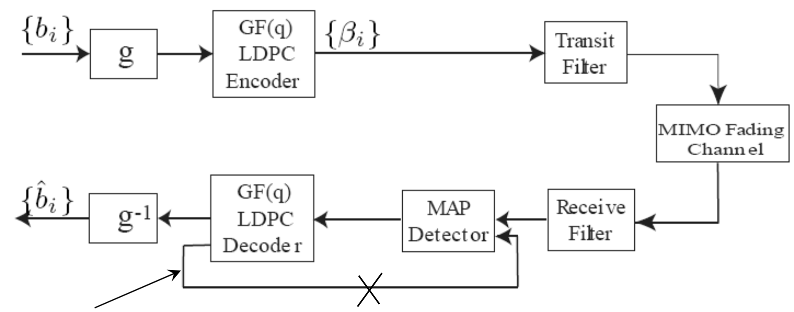
Application to fading channels

- Channel model



Assume each entry of channel matrix is independent, follows Rayleigh fading, and is known by receiver

System block diagram

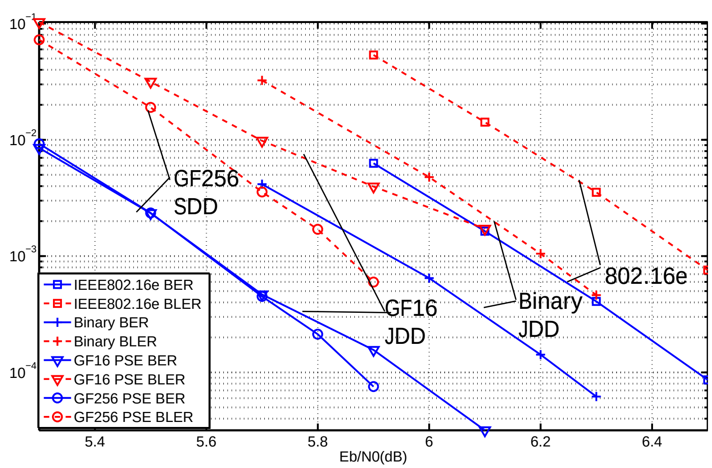


SDD: the detection is performed only once.

JDD: Soft messages are exchanged between detector and decoder iteratively.

R.-H. Peng and R.-R. Chen, "*Good LDPC Codes over GF(q) for Multiple-Antenna Transmission*", Presented on MILCOM 2006

Performance comparison



Performance: GF256>GF16> binary>802.16e

Complexity: GF16<GF256 802.16e<binary

Performance comparison of GF(256) SDD, GF(16) JDD and binary JDD system

Construction of Parallel sparse encodable codes

- Motivation
  - Low encoding complexity
  - Allow parallel implementation
- Parallel sparse encodable (PSE) codes = Qausi cyclic (QC) cycle codes + tree codes
  - QC codes: parallel implementation
  - Cycle code: Low encoding complexity

Quasi-cyclic construction

- Quasi-cyclic structure

- $A_{i,j}$ is a circulant: each row is a right cycle-shift of the row above it and the first row is the right cycle-shift of the last row
- The advantage of QC structure
  - Allow linear-time encoding using shift register
  - Allow partially parallel decoding
  - Save memory

A new QC structure for GF(q)

- $A_{i,j}$ is a *nonbinary multiplied circulant permutation matrix*

Cycle codes

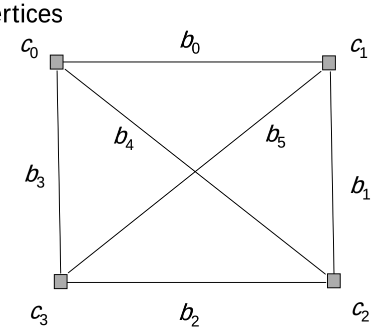
- With degree 2 variable nodes only
- Can be represented by normal graph, every vertex imposes one linear constraint
  - Columns => edges; rows => vertices

b_0 b_1 … b_5

c_0

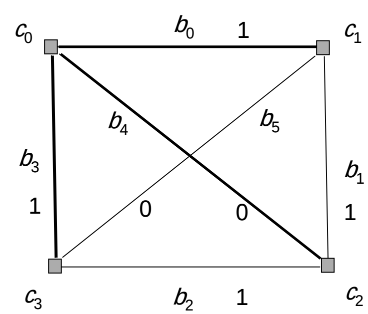
c_3

Parity check matrix



Normal graph representation

Encoding of Cycle codes



① Find the spanning tree:
b_0, b_3, b_4

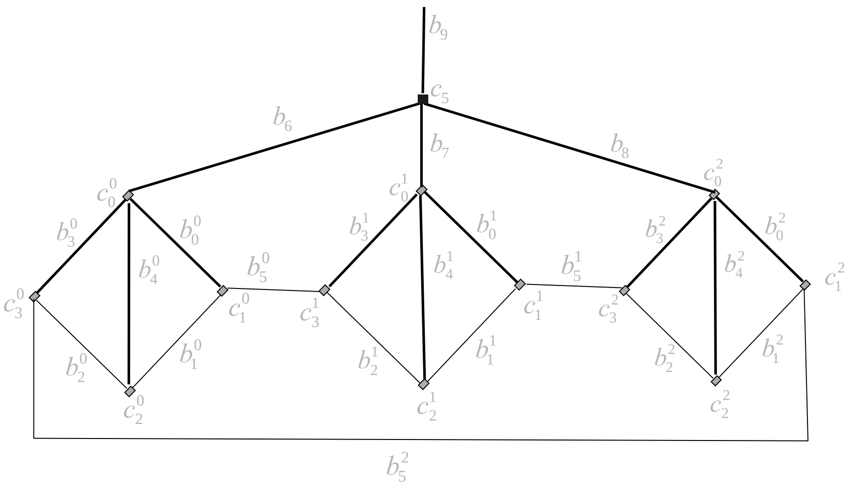
② Information bits => Edges outside SP
$b_1=1, b_2=1, b_5=0$

③ Compute coded bits
$b_3=b_2+b_5=1$
$b_4=b_2+b_1=0$
$b_0=b_1+b_5=1$

For binary code: check c_0 is always satisfied.
$b_0+b_3+b_4=0$

Not work for nonbinary cycle codes! Why?

PSE codes

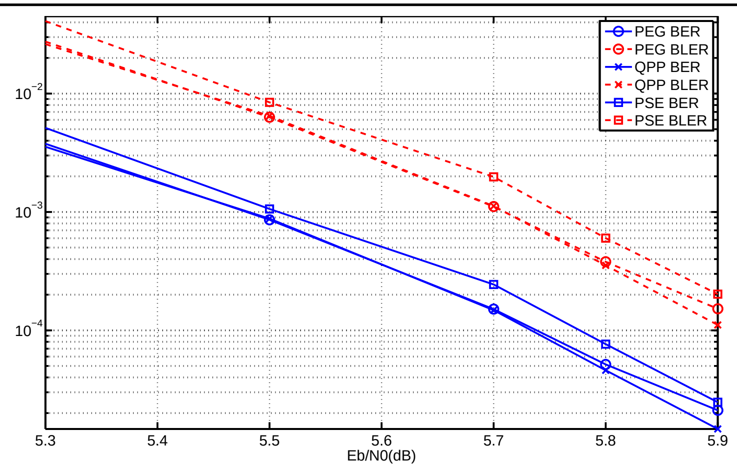


PSE codes = QC cycle codes + tree codes

Encoding of PSE codes

- Parity check matrix based encoding
- Parallel encoding for QC cycle subcode
- Much lower encoding complexity than normal LDPC codes using generator matrix based encoding because the generator matrix is usually dense

Simulation results



Performance comparison of PSE codes over GF(256) with QPP (QC) codes and PEG (non-QC) codes

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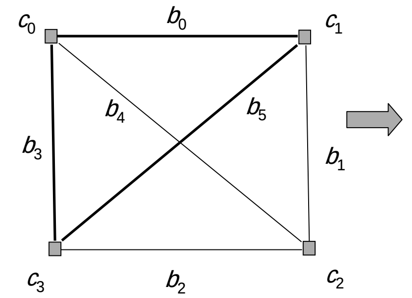
Motivation

- Small field size QC cycle codes have high error floor
  - Poor distance spectrum

Nonbinary QC cycle codes construction

- Full rank condition



Full rank = No codeword generated by the cycle

Nonbinary QC cycle codes construction

- To improve the distance spectrum
  - Increase the girth of the graph
  - Assign h_{ij} such that short cycles full rank
- QC properties
- Design an algorithm?

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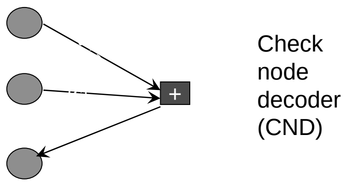
Motivation



Single parity check code

Horizon step:

Direct computation has huge complexity!

Nonbinary LDPC decoding

- Horizon step has room for improvement
- Only important vectors contributes much
- Can we use similar idea as MCMC to find important vectors?
- Changing one variable leads to the parity check not satisfied?
  - Solution: Select one variable as free variable

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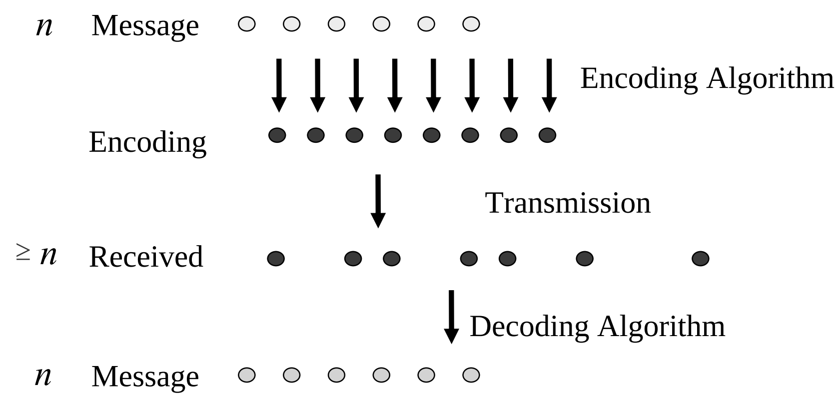
Motivation

- Wired internet: packet erasure channel
- Wireless communication system: fading channel
- Packed based wireless network: fading channel with erasures
- Current solution: error control coding in lower layer + error erasure coding in higher layer
- Codes correct both erasures and errors
  - Reed-Solomn codes
  - Rateless codes

Dealing with nonergodic channels

- Slow changing and block fading channels
- Finite length codeword
- Fixed length codes doesn't work well
- Solution:
  - Hybrid ARQ
  - Rateless coding

Rateless coding



Encoding of rateless codes

- Encoding process from source symbols
  - Randomly choose degree d from degree distribution
  - Choose, uniformly at random, d source symbols to set encoded symbols c_n equal to the sum of those d source symbols

Proposed work

- Apply rateless coding scheme to fading channel with erasures
- Challenges
  - Does rateless coding approach the capacity of the channel
    - How to prove it?
  - How to design good rateless codes
    - Find optimal degree distribution
      - EXIT chart, density evolution?
  - Stopping rule
    - When the receiver stop receiving and start decoding
      - Mutual information > K?
  - Throughput
    - Any throughput improvement over HARQ?

Thanks !