On the Universality of the Block Markov Superposition Transmission

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Outline

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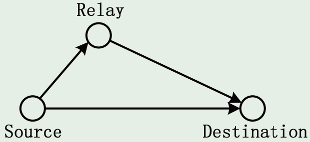
1. Superposition Block Markov Encoding in the Relay Channel
2. Block Markov Superposition Transmission
3. General Behavior of BMST
4. BMST with BPSK
5. BMST with High-order Modulations
6. BMST with Continuous phase modulation (CPM)
7. BMST with Spacial Modulation (SM)
8. Conclusions

Superposition Block Markov Encoding in the Relay Channel

Gaussian Relay Channel Model



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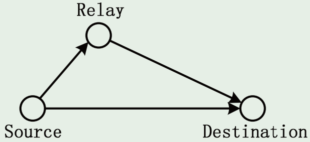

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- The Gaussian relay channel is given by

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where Z_1 and Z_2 are independent zero-mean Gaussian random variables with variance N_1 and N_2, respectively;

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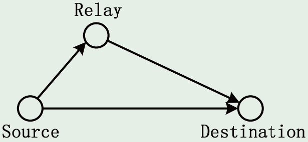

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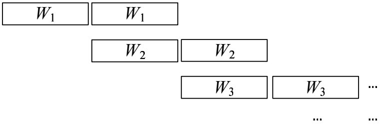
Achievable rate of the Gaussian Relay Channel

The decode-forward achievable rate is

$$C = \max_{0 \leq \alpha \leq 1} \min\left\{C\left(\frac{P + P_1 + 2\sqrt{\overline{\alpha}PP_1}}{N_1 + N_2}\right), C\left(\frac{\alpha P}{N_1}\right)\right\},$$

where $\overline{\alpha} = 1 - \alpha$.

Superposition Block Markov Encoding (SBME) - Decode-Forward (DF) Strategy



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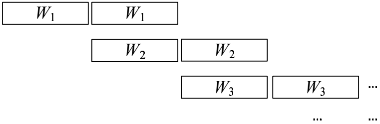

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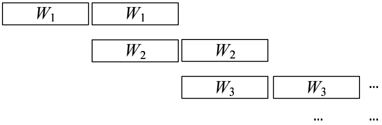

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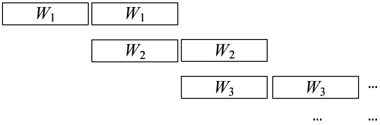

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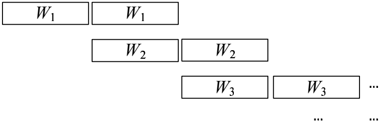

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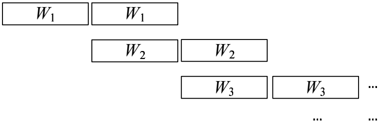

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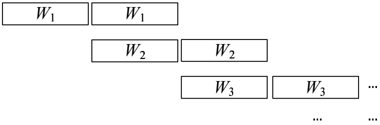

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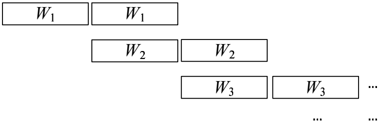

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- We apply a similar strategy (SBME) to the single-user communication system, resulting in the block Markov superposition transmission (BMST) scheme.

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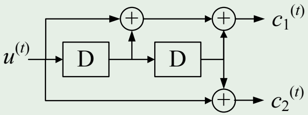
Short Convolutional Codes

Convolutional codes with short constraint lengths: e.g.,



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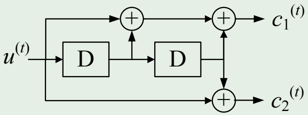

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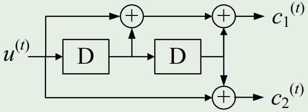

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Actually, short codes can be any code that has fast encoding algorithm and soft-in soft-out (SISO) decoding algorithm.

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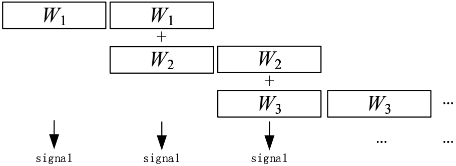

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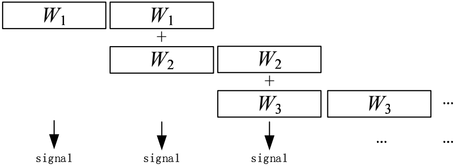

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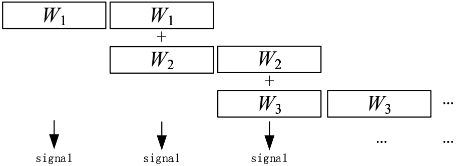

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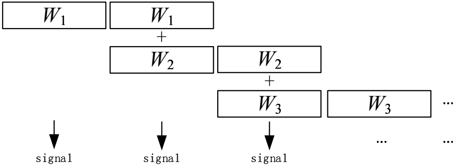

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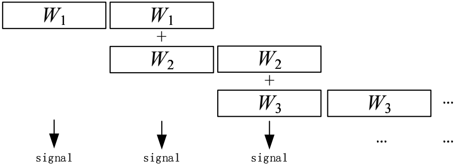

BMST Scheme (Continued)

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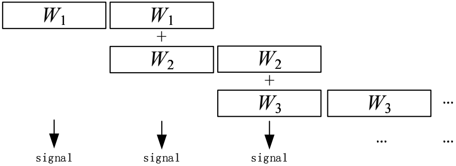

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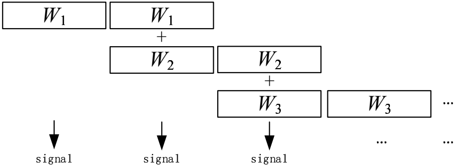

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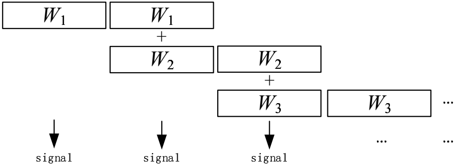

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- Repetition increases reliability.
- Superposition keeps rate unchanged.

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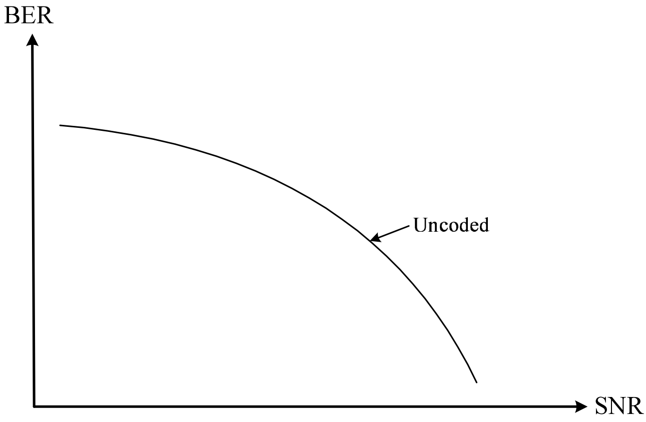

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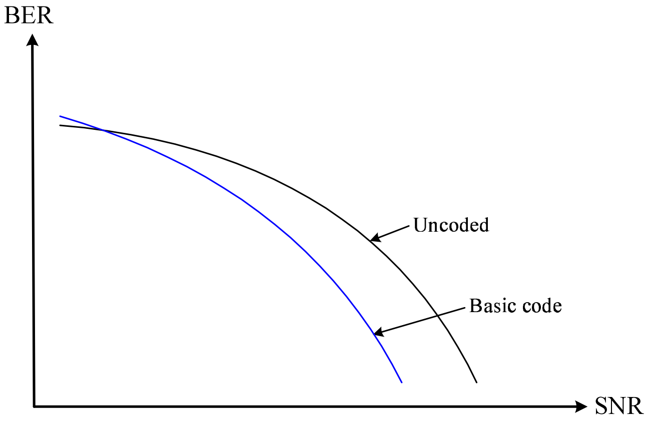

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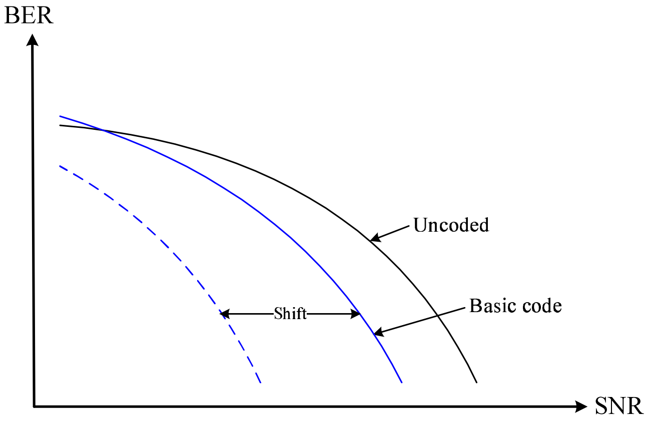

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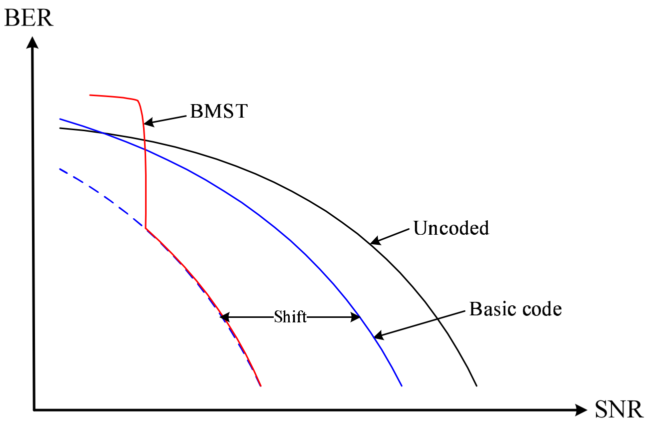

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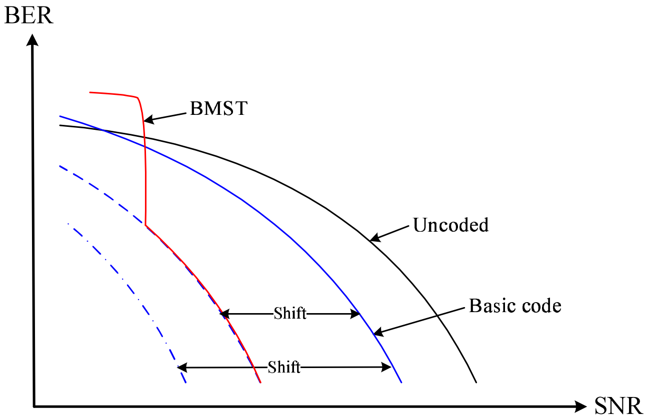

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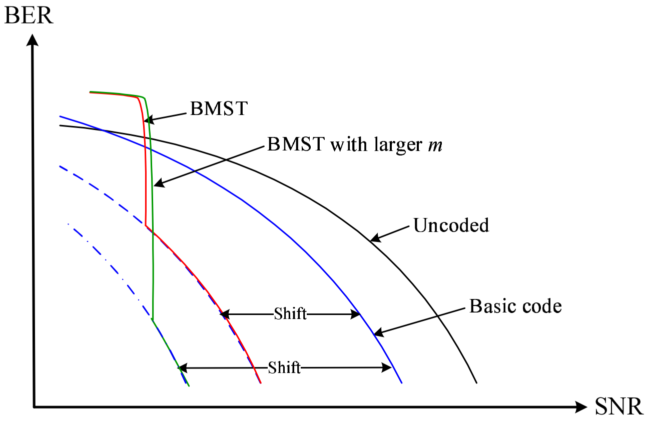

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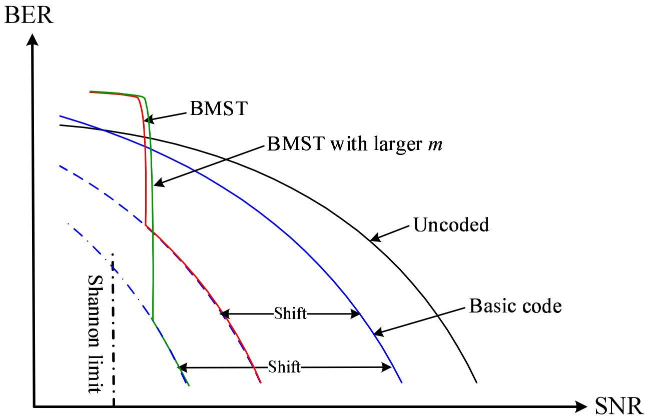

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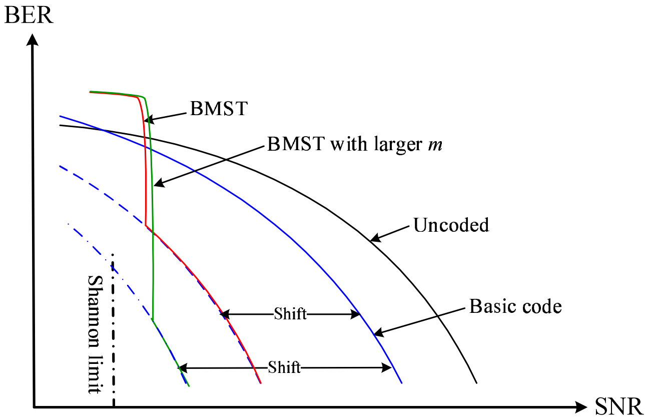

The maximal coding gain for a BMST system with memory m compared with the basic code can be $10\log_{10}(m+1)$.

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BMST with BPSK over AWGN channels

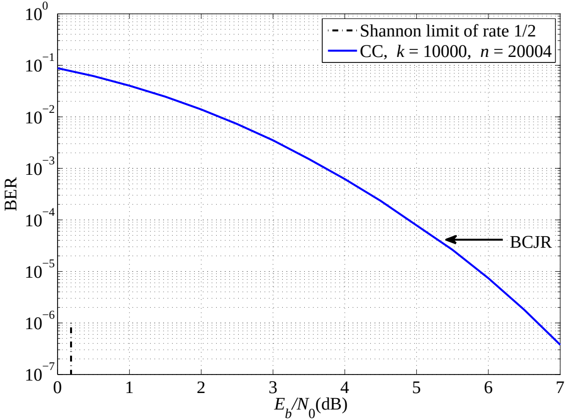

Figure: The basic code is a terminated 4-state $(2,1,2)$ convolutional code defined by the polynomial generator matrix $G(D) = [1 + D^2, 1 + D + D^2]$. The system encodes $L = 1000$ sub-blocks of data and the iterative sliding-window decoding algorithm is performed, where the encoding memories and the decoding delays are specified in the legends.

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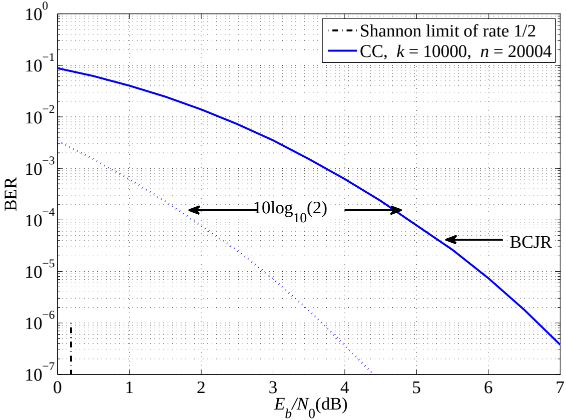

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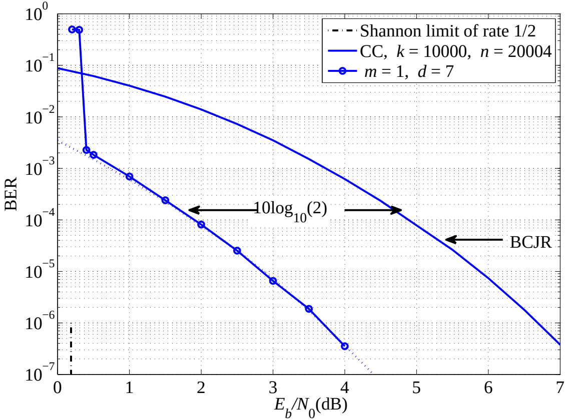

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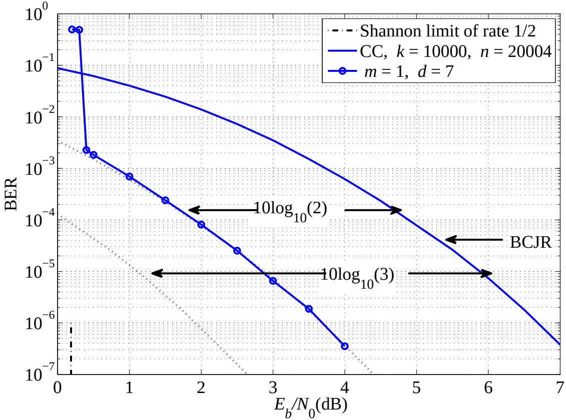

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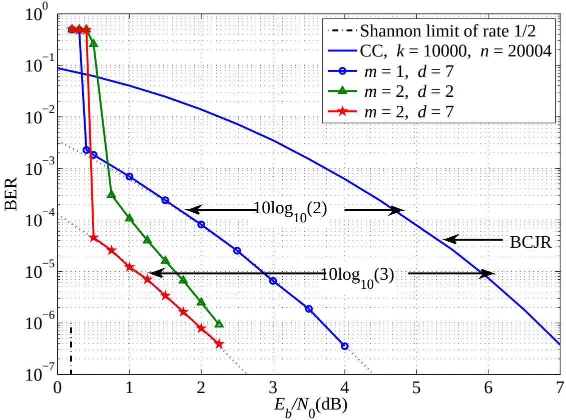

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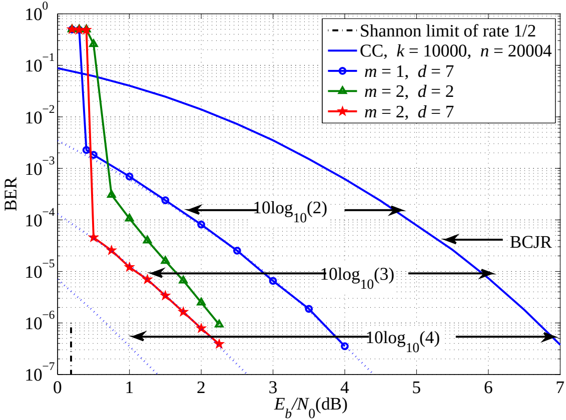

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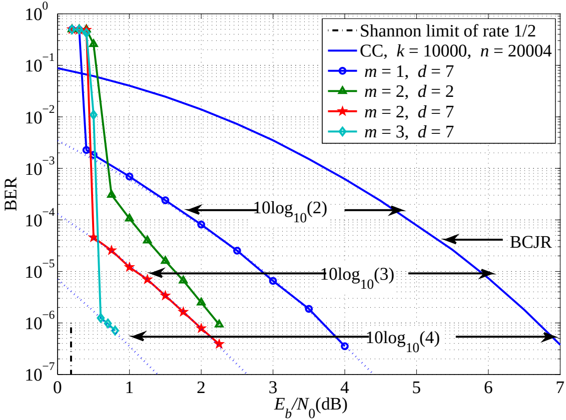

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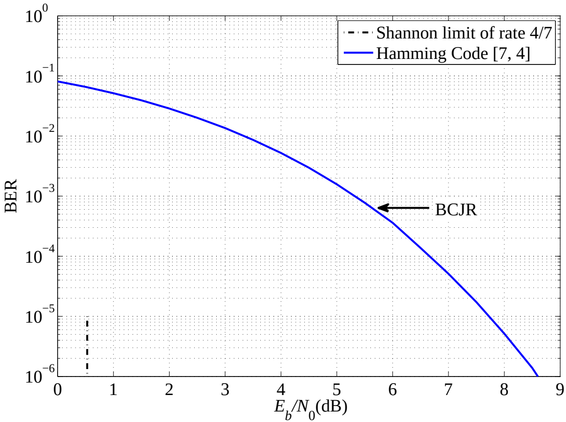

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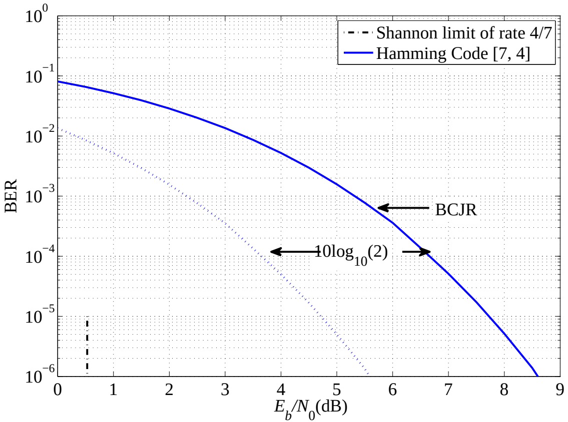

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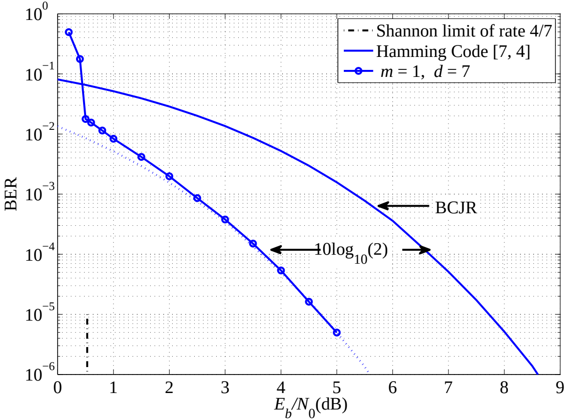

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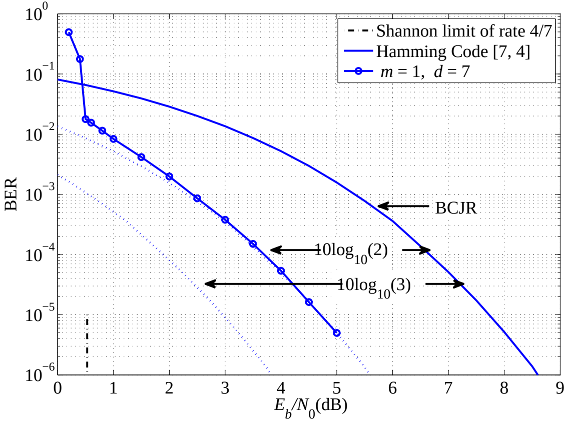

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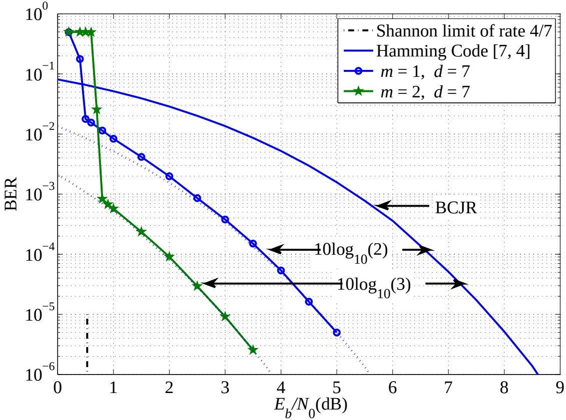

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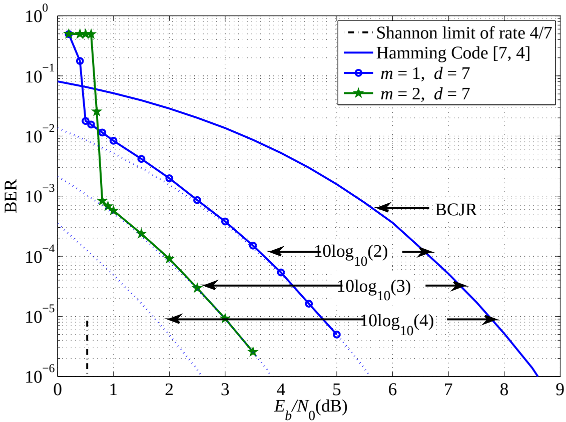

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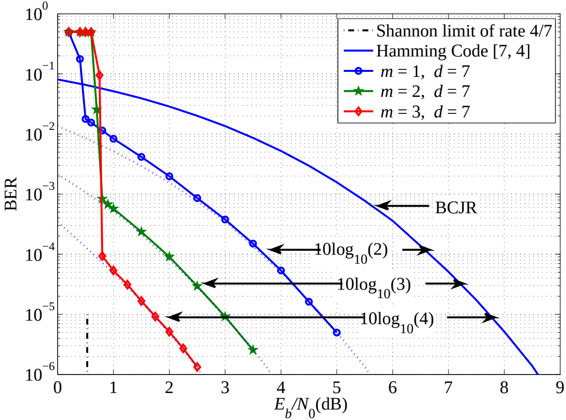

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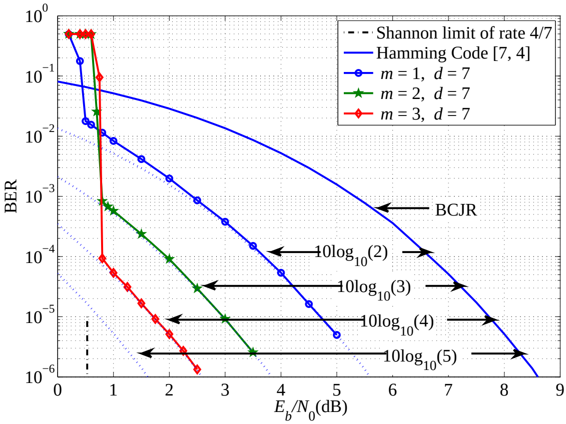

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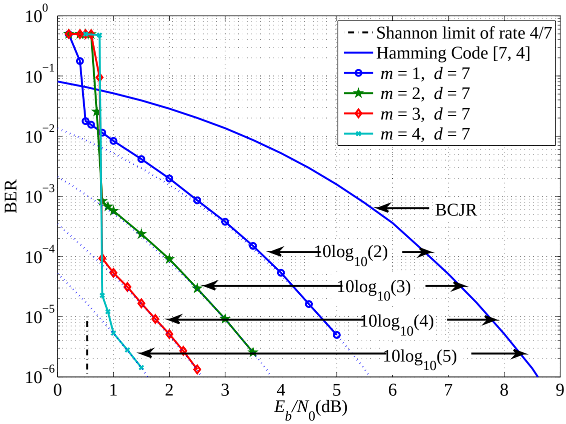

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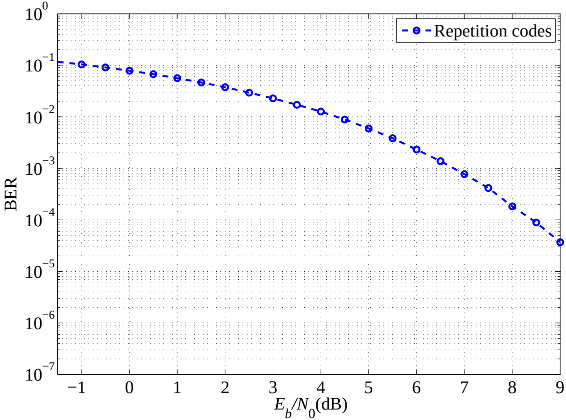

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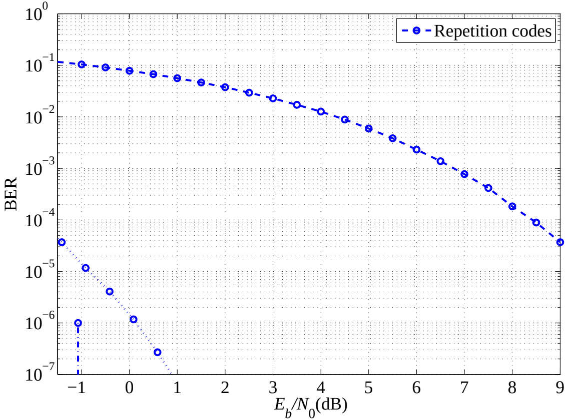

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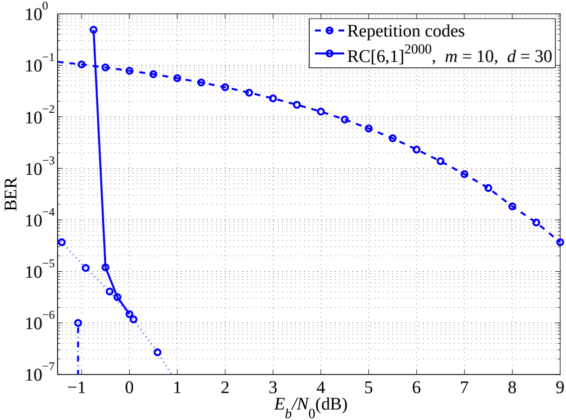

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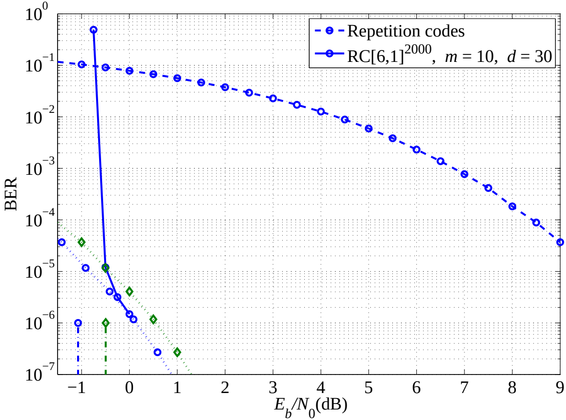

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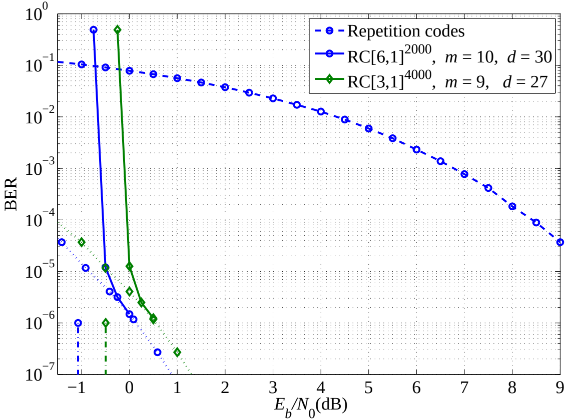

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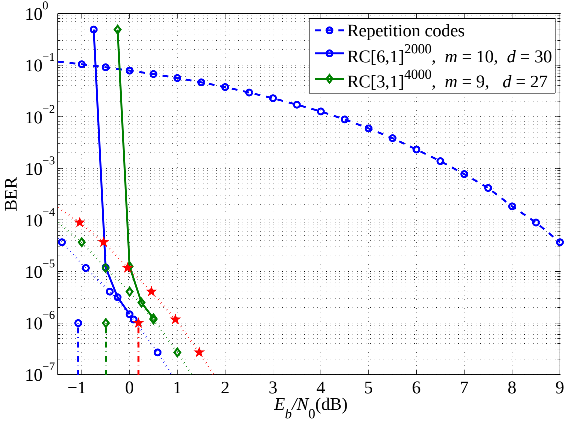

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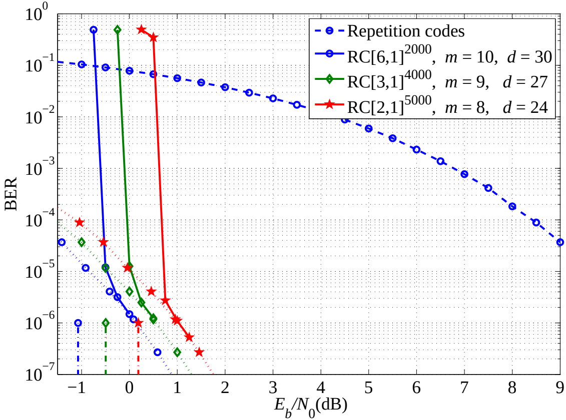

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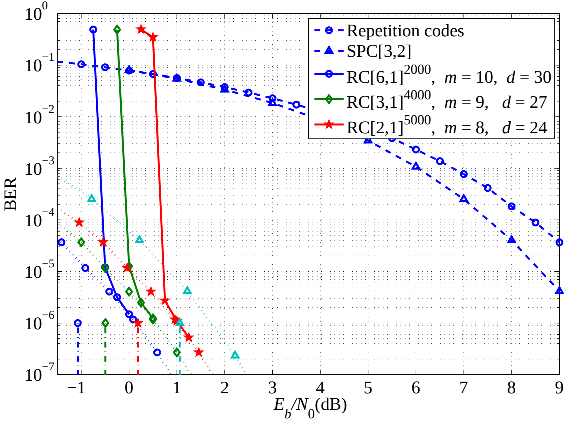

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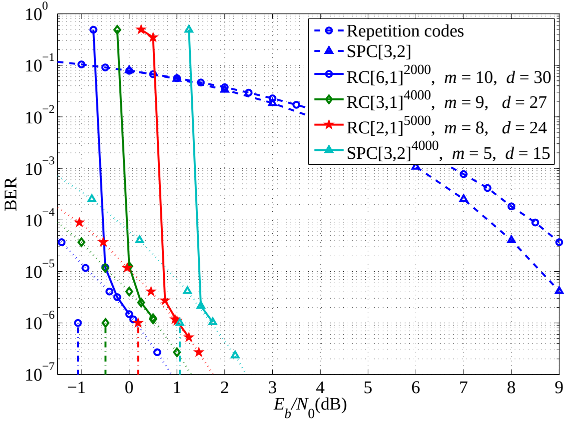

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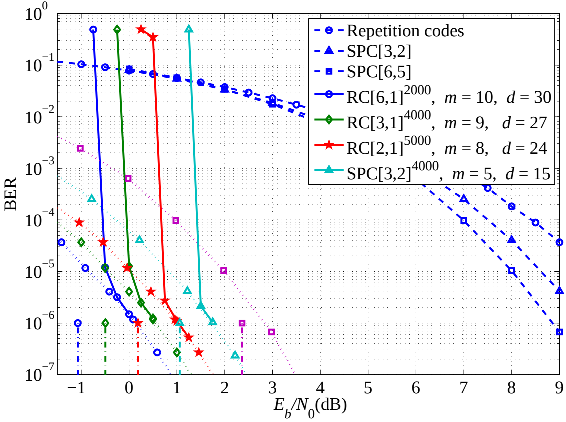

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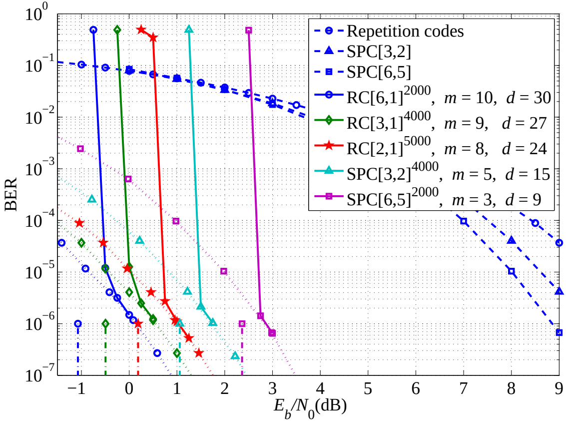

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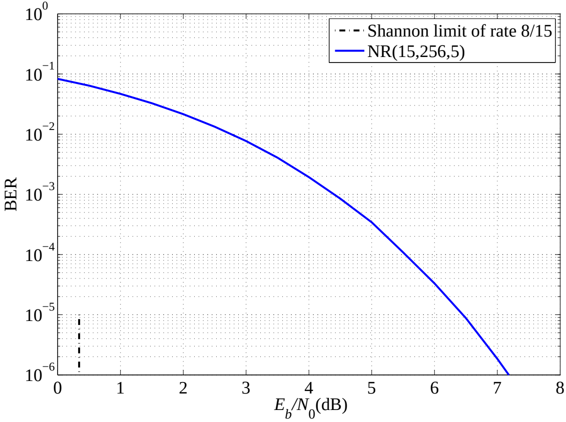
BMST with Nonlinear Basic Codes



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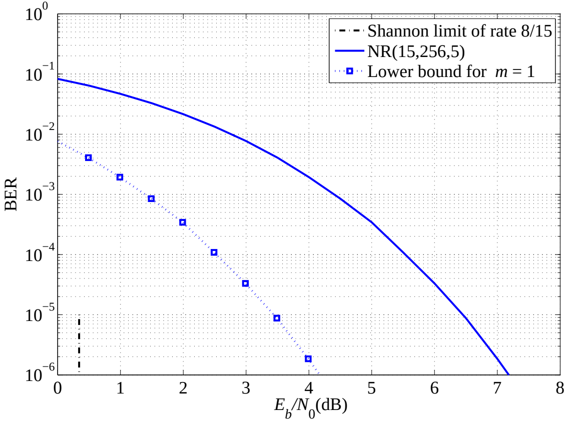

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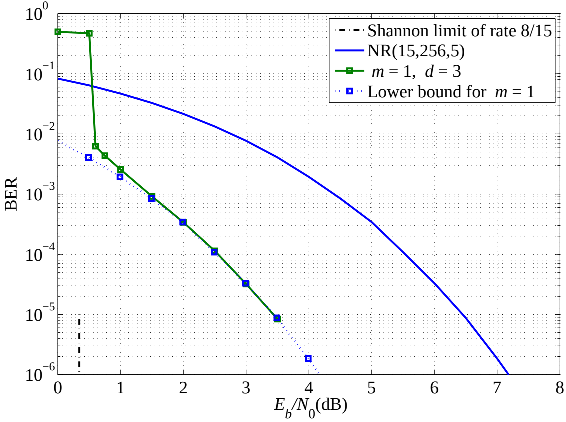

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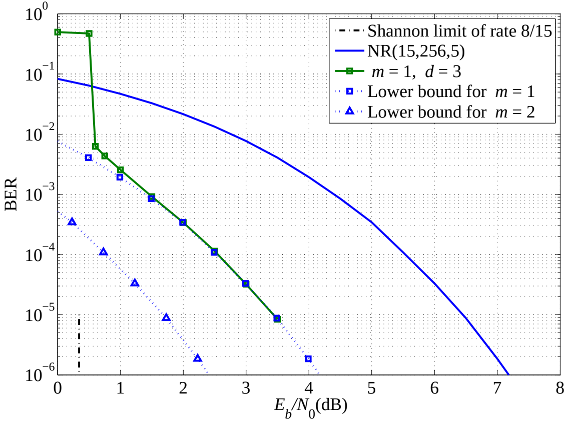

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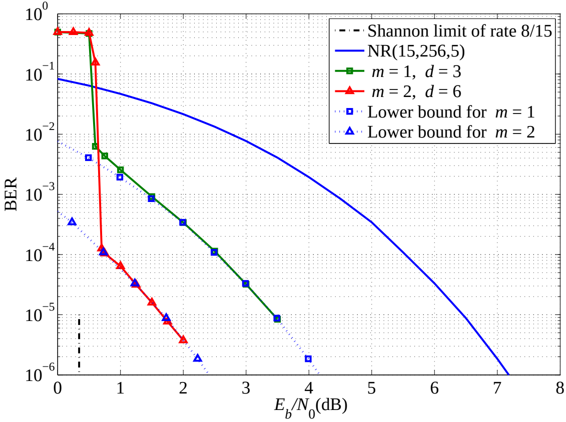

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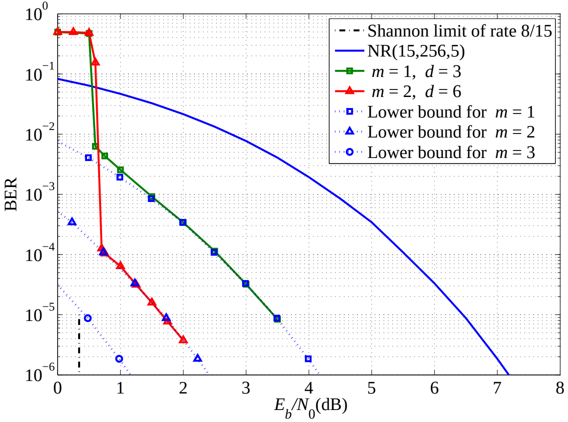

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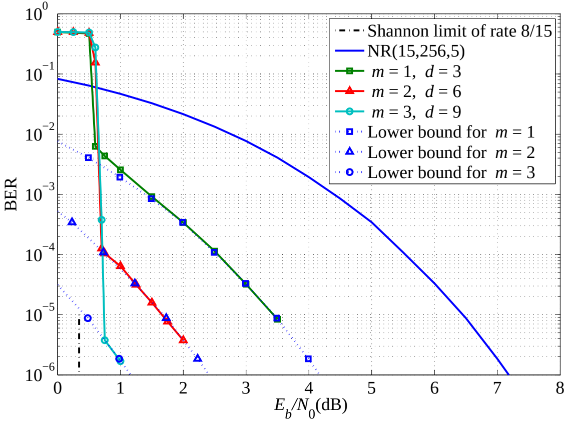

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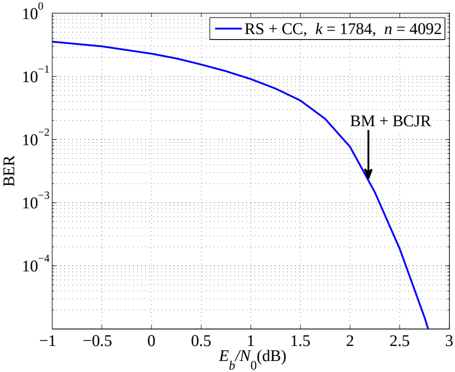

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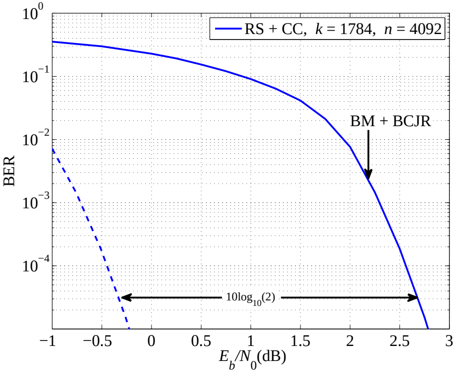

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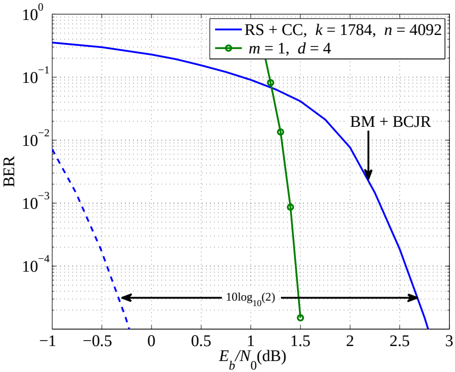

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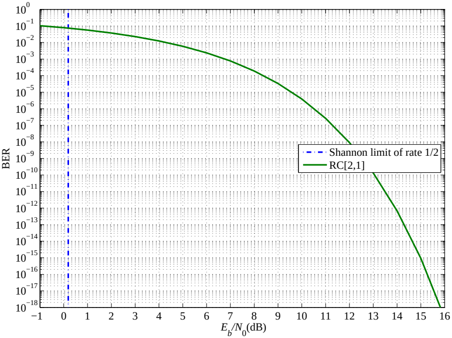
A Construction Example

- For a target code rate $R_{\mathrm{target}} = 0.5$ and different target BERs p_{target}, the repetition code $[2,1](k=1, n=2)$ with $0 \to 00$ and $1 \to 11$ is chosen.
- The encoding memories required to approach the Shannon limit using the BMST of RC $[2,1]^B$ is listed in the table.

p_{target}	3×10^{-3}	10^{-5}	10^{-15}
γ_{target} (dB)	5.78	9.59	14.99
γ_{lim} (dB)	0.19	0.19	0.19
Gap (dB)	6.59	9.40	14.80
m	3	8	30



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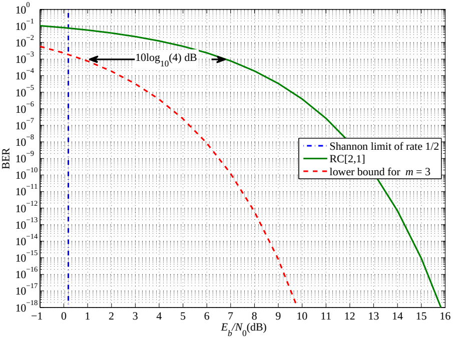

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p_{target}	3×10^{-3}	10^{-5}	10^{-15}
γ_{target} (dB)	5.78	9.59	14.99
$\gamma_{\lim}$ (dB)	0.19	0.19	0.19
Gap (dB)	6.59	9.40	14.80
m	3	8	30

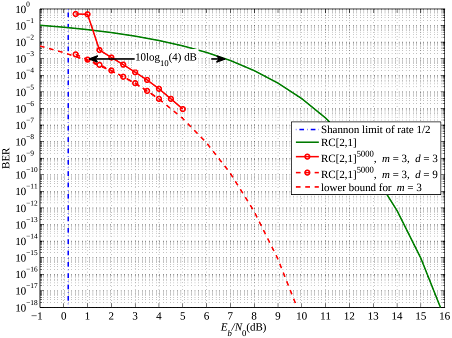

Figure: The basic code is the 5000-fold Cartesian product of the repetition code $[2,1]^{5000}$. The system encodes $L = 100000$ sub-blocks of data and the iterative sliding-window decoding algorithm with $I_{\max} = 18$.

A Construction Example

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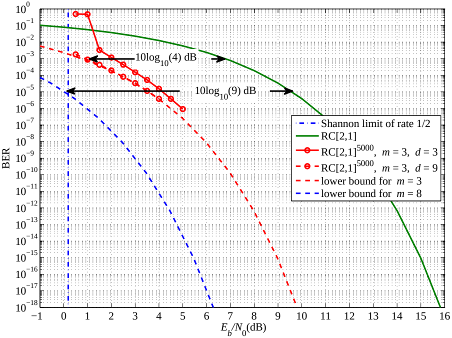

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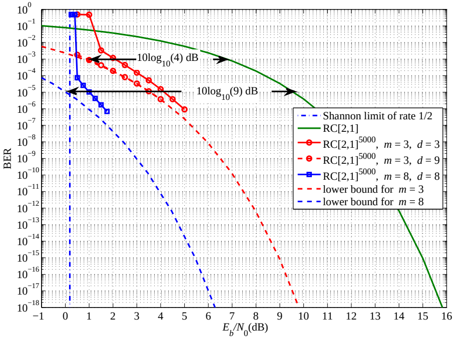

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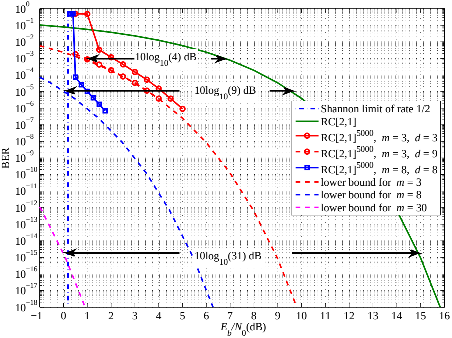

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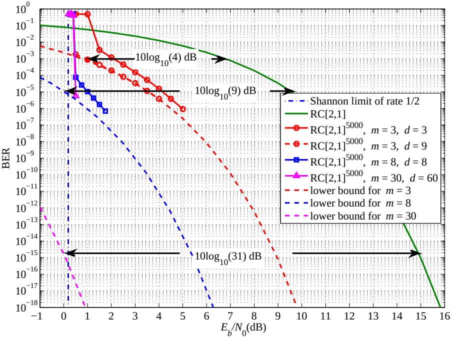

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Outline

BMST Can also Combine with High-order Modulations

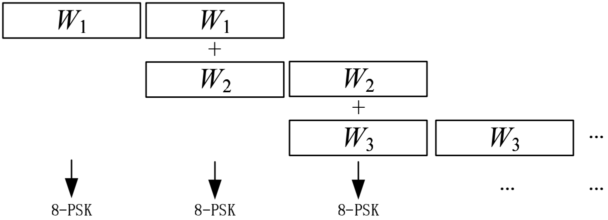


Figure: The BMST system with 8-PSK.

BMST with 8-PSK over AWGN channels

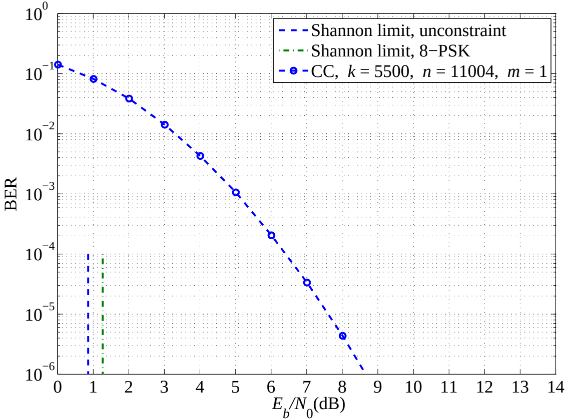
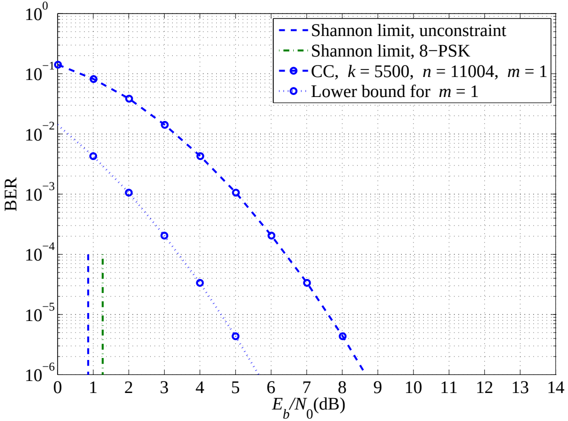


Figure: The basic code is a terminated 4-state $(2, 1, 2)$ convolutional code defined by the polynomial generator matrix $G(D) = [1 + D^2, 1 + D + D^2]$ with $k = 5500$ and $n = 11004$. Signals are transmitted using 8-PSK modulation with Gray mapping over AWGN channels. The system encodes $L = 1000$ sub-blocks of data and the iterative sliding-window decoding algorithm is performed, where the encoding memories and the decoding delays are specified in the legends.

BMST with 8-PSK over AWGN channels



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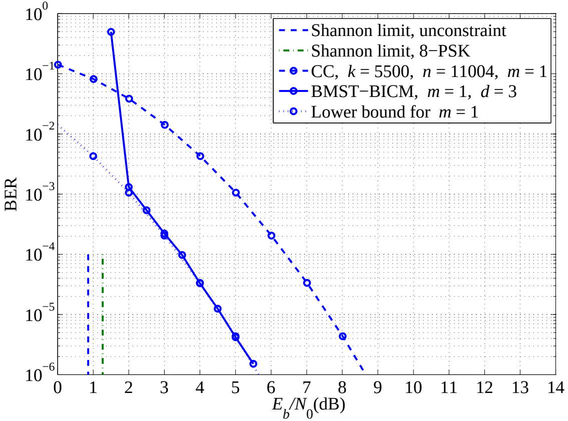

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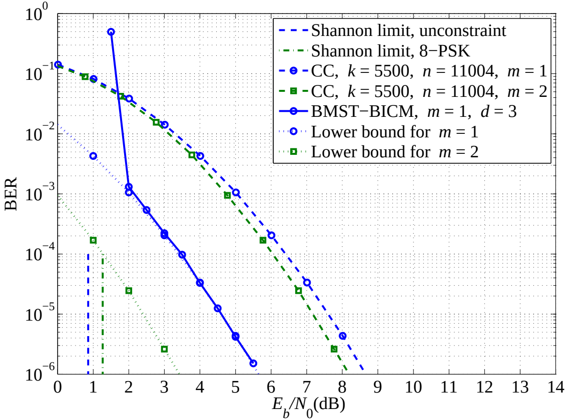

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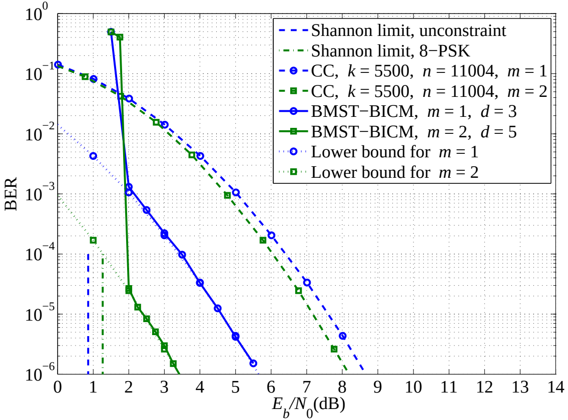

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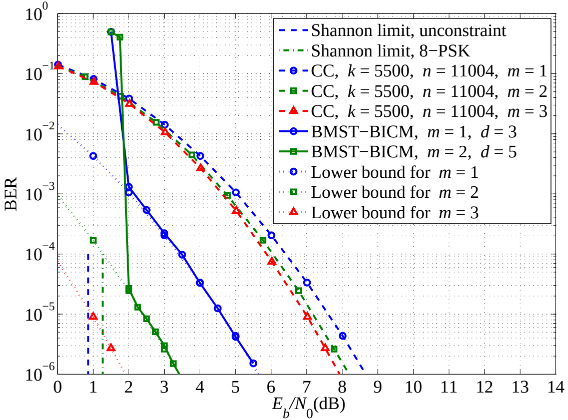

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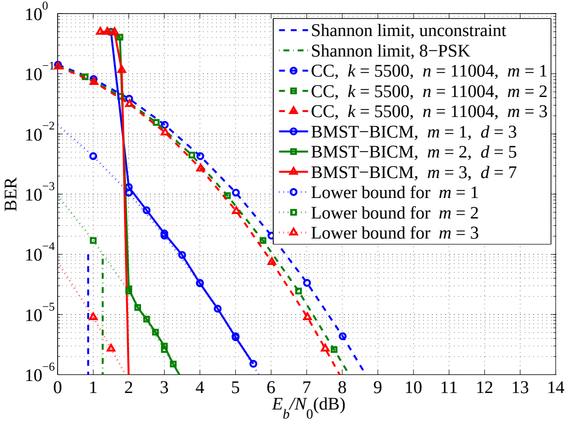

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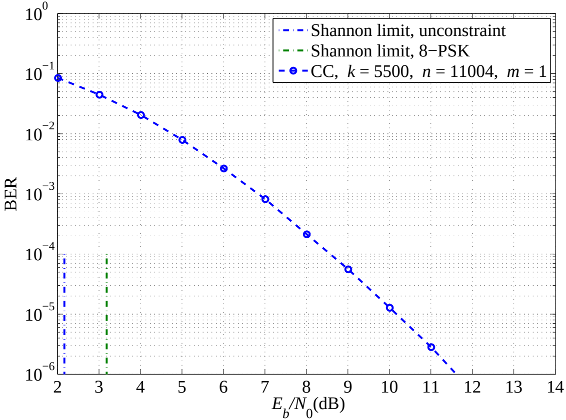
BMST with 8-PSK over Rayleigh fading channels



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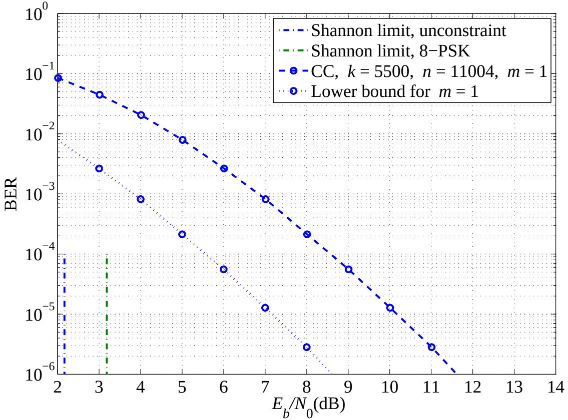

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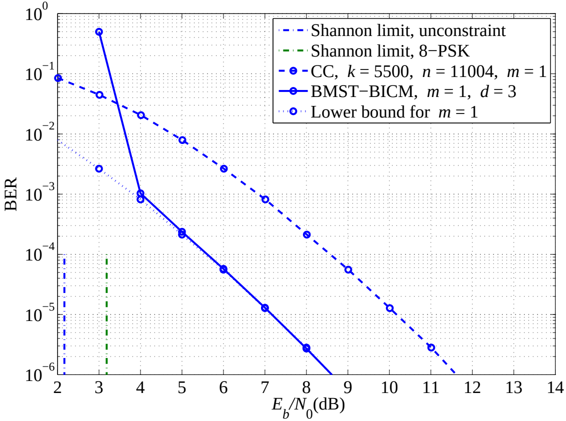

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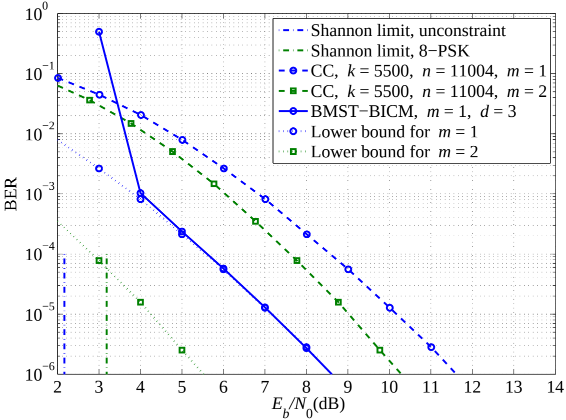

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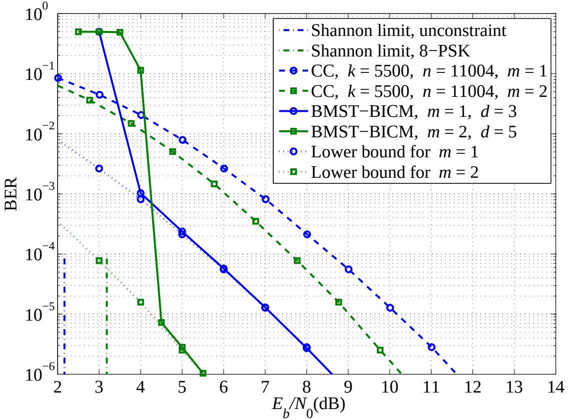

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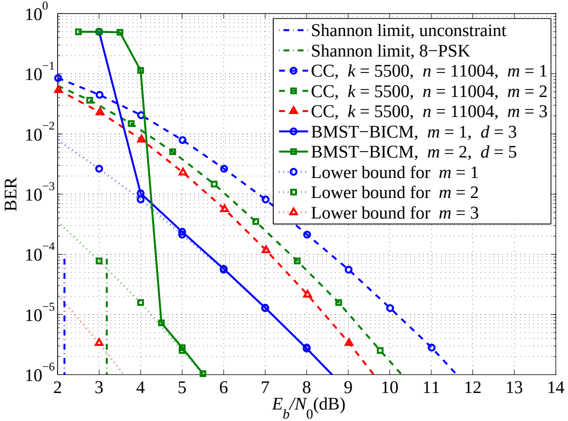
BMST with 8-PSK over Rayleigh fading channels



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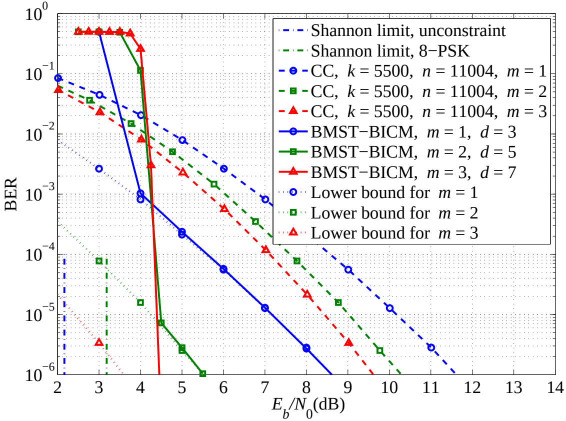
BMST with 8-PSK over Rayleigh fading channels



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Outline

BMST with Continuous phase modulation (CPM)

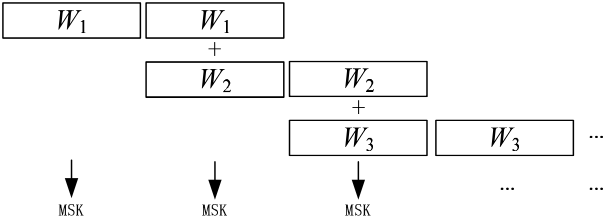


Figure: The BMST system with MSK.

BMST with MSK

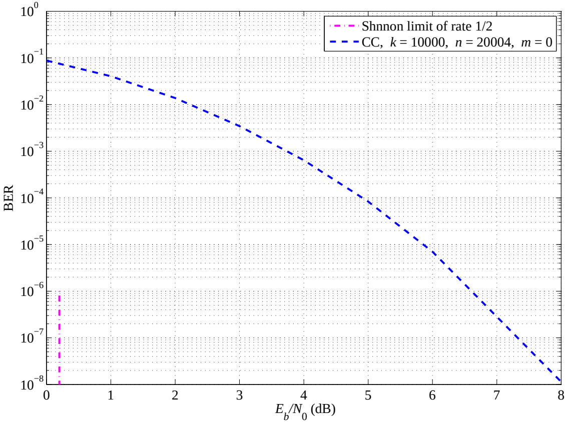
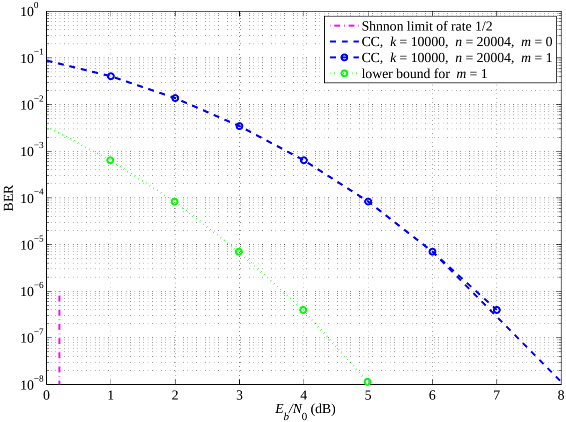


Figure: The basic code is a terminated 4-state $(2, 1, 2)$ convolutional code defined by the polynomial generator matrix $G(D) = [1 + D^2, 1 + D + D^2]$ with $k = 10000$ and $n = 20004$. Signals are transmitted using non-recursive MSK modulation over AWGN channels. The system encodes $L = 1000$ sub-blocks of data and the iterative sliding-window decoding algorithm with $d = 7$ and $I_{\max} = 18$ is performed, where the encoding memories are specified in the legends.



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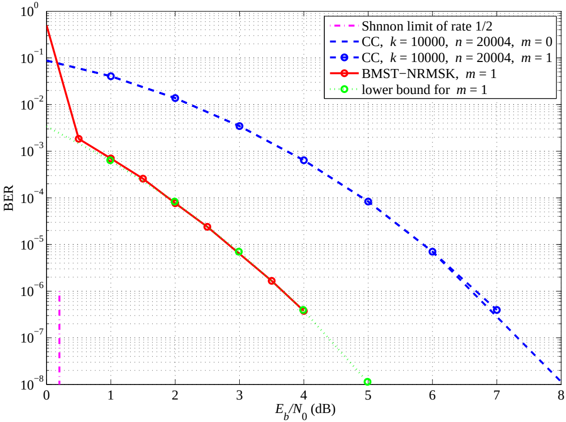

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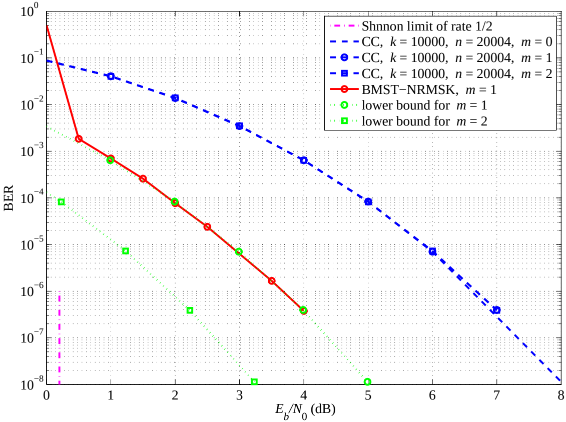

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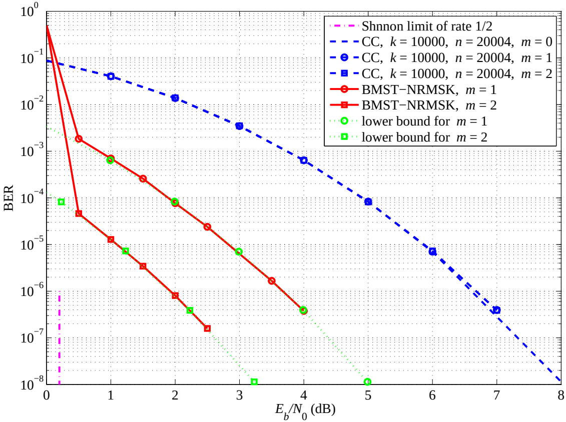

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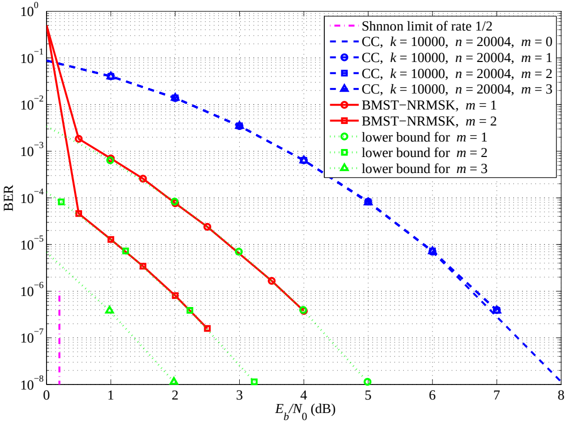

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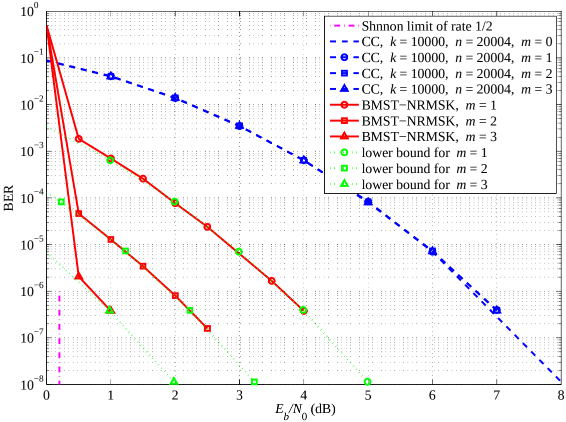
BMST with MSK



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Outline

BMST with Spacial Modulation (SM)

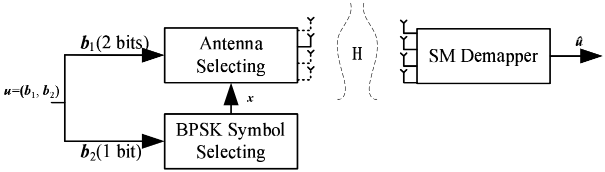
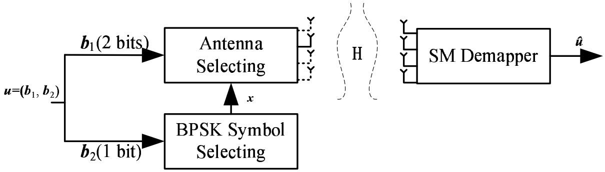


Figure: The spacial modulation with 4 transmitter antennas and 4 receiver antennas using BPSK modulation. Only one antenna is active for each transmission.

BMST with Spacial Modulation (SM)



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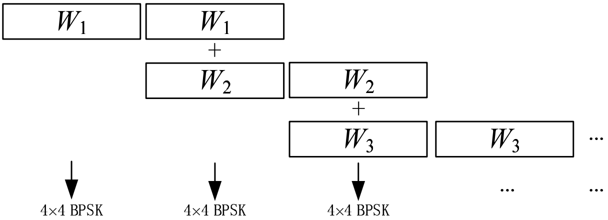
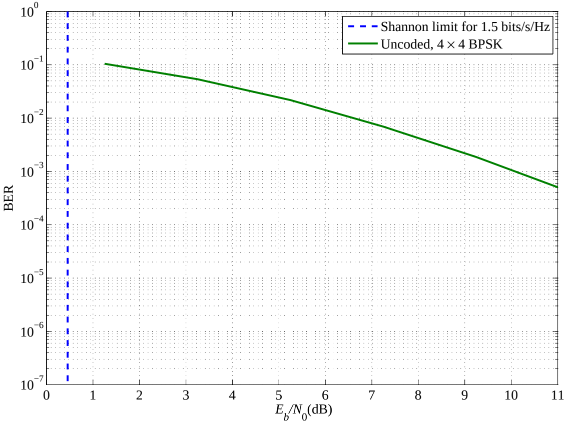


Figure: The BMST system with a 4×4 BPSK spacial modulation with only one antenna being active for each transimission.

BMST with Spacial Modulation over Rayleigh fading channel



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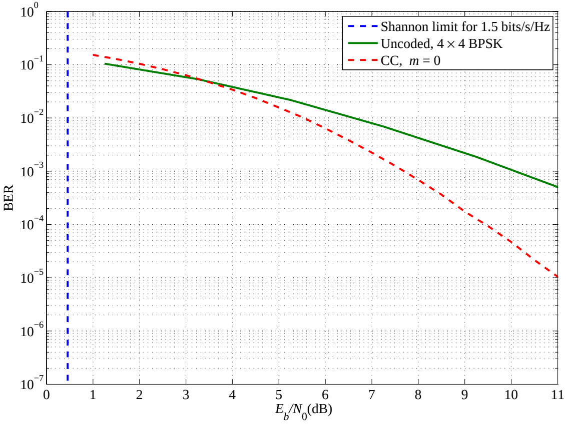
BMST with Spacial Modulation over Rayleigh fading channel



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BMST with Spacial Modulation over Rayleigh fading channel

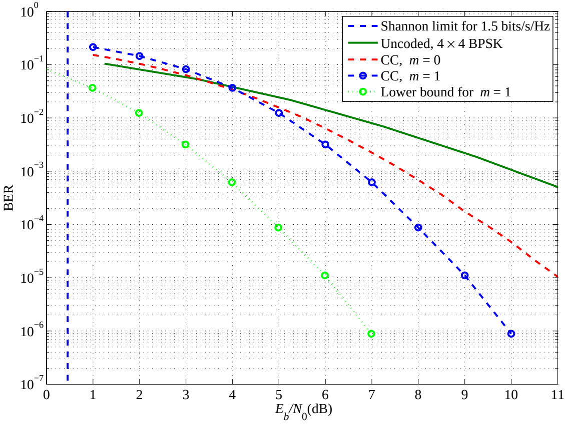

Figure: The basic code is a terminated 4-state $(2, 1, 2)$ convolutional code defined by the polynomial generator matrix $G(D) = [1 + D^2, 1 + D + D^2]$ with $k = 7000$ and $n = 14004$. Signals are transmitted using BPSK with 4 transmitter antennas and 4 receiver antennas over Rayleigh fading channels. Only one antenna is active for each BPSK symbol. The system encodes $L = 1000$ sub-blocks of data and the iterative sliding-window decoding algorithm with $I_{\max} = 18$ is performed.

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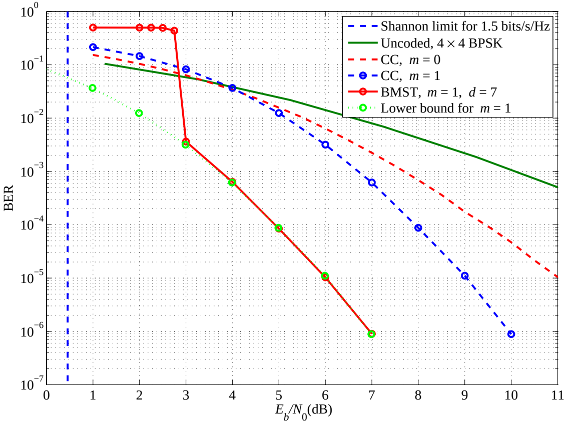

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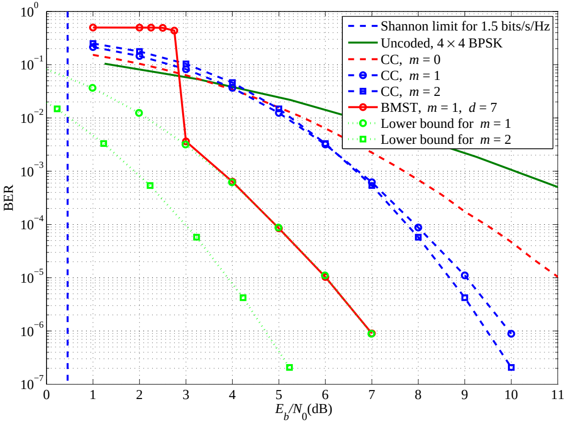

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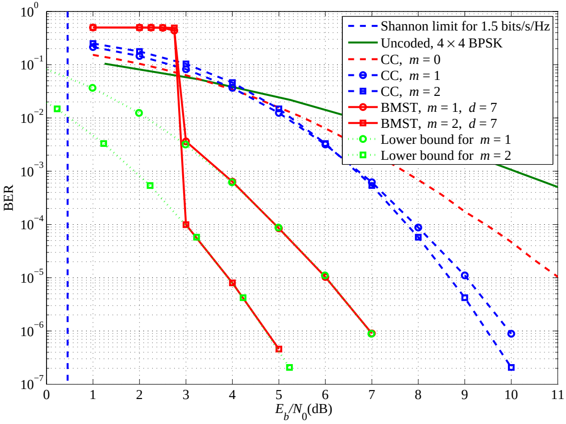

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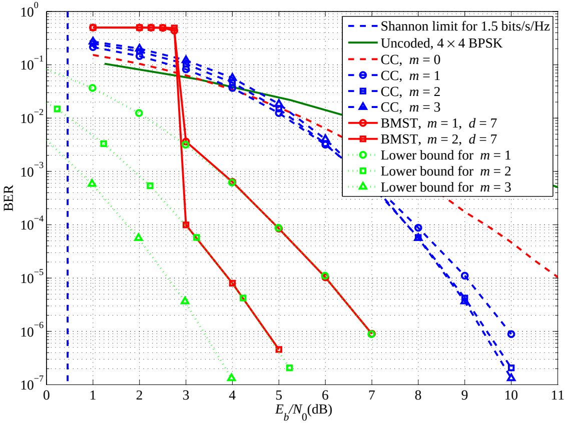

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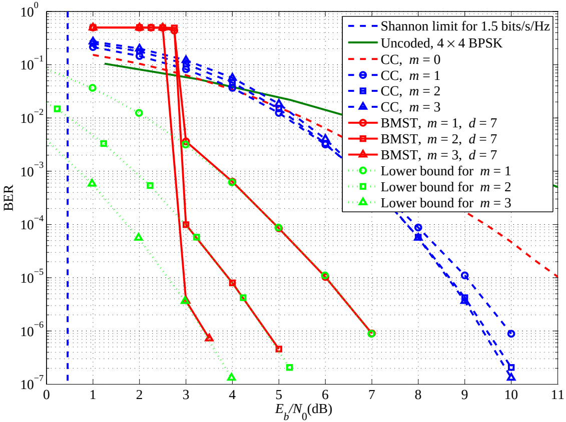

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Outline

Conclusions

Conclusions

- We presented a new method for constructing long codes from short codes;
- The encoding process can be as fast as the short code, while the decoding has a fixed but tunable delay.
- With an iterative sliding-window decoding algorithm, the performance of BMST can approach the derived lower bound in low error rate region;
- This scheme can be generalized, for example, to non-binary codes, lattice codes, and so on.
- In principle, any code can be the basic code as long as
  1. it is defined over a group (but not necessarily group code; (This is required by the *superposition* before transmission).
  2. it has an efficient encoding algorithm;
  3. it has an exact (or approximated) soft-in-soft-out (SISO) decoding algorithm.
- The BMST scheme is easy to combine with high-order modulation, continuous phase modulation (CPM), and even spacial modulation (SM) etc. and has a good performance.

Related Works

X. Ma, C. Liang, K. Huang, and Q. Zhuang,
Obtaining Extra Coding Gain for Short Codes by Block Markov Superposition Transmission.
in Proc. IEEE Int. Symp. Information Theory 2013, Istanbul, Turkey, Jul. 2013.

X. Ma, C. Liang, K. Huang, and Q. Zhuang,
Block Markov Superposition Transmission Construction of Big Convolutional Codes from Short Codes.
submitted to *IEEE Trans. Inf. Theory* .

C. Liang, K. Huang, X. Ma, and B. Bai,
Block Markov Superposition Transmission with Bit-Interleaved Coded Modulation.
accepted by *IEEE Commum. Lett.*.

X. Liu, C. Liang, and, X. Ma,
Block Markov Superposition Transmission of Convolutional Codes with MSK Signaling.
submitted to *IET Commun.*.

C. Liang, X. Ma, Q. Zhuang, and B. Bai,
Approaching the Channel Capacity within One dB at a BER of 10^{15}.
submitted to *Proc. IEEE Int. Symp. Information Theory 2014*.

J. Hu, C. Liang, X. Ma, and B. Bai,
Block Markov Superposition Transmission of Short Polar Codes: A New Class of Multiple-rate Codes.
submitted to *Proc. IEEE Int. Symp. Information Theory 2014*.

Thank You for Your Attention!

Acknowledgements

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- This work is joint with:
  - Prof. Baoming Bai from Xidian University.
  - Students: Chulong Liang, Jingnan Hu, Kechao Huang, Qiutao Zhuang, Xiaopei Xu, Xiying Liu, and Zhihua Yang.