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Title	**Soft Iterative Decoding for Mobile Wireless Communications**
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Re:	Mobility Enabling Technologies and Capabilities
Abstract	This submission discusses the soft iterative decoding of certain types of error-control codes, and their applications to mobile wireless
Purpose	For informational use only.
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Soft Iterative Decoding for Mobile Wireless Communications

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Contents

- Error-Control Codes
- Understanding Soft Iterative Decoding
- Application to Mobile Wireless

Error-Control Codes (ECC)

- ECCs introduce redundancy into a data sequence
- Allows for correction of errors resulting from the noisy, imperfect channel

- In past decade, new paradigm: ECCs with structure that allows soft iterative decoding
- Soft = probabilistic messages
- Iterative = repeated passing of messages
- Significant coding gain

Examples of ECCs

“Traditional ECCs”

- Repetition
- Single-parity check
- Hamming codes
- Convolutional codes
- BCH codes
- Reed-Solomon codes

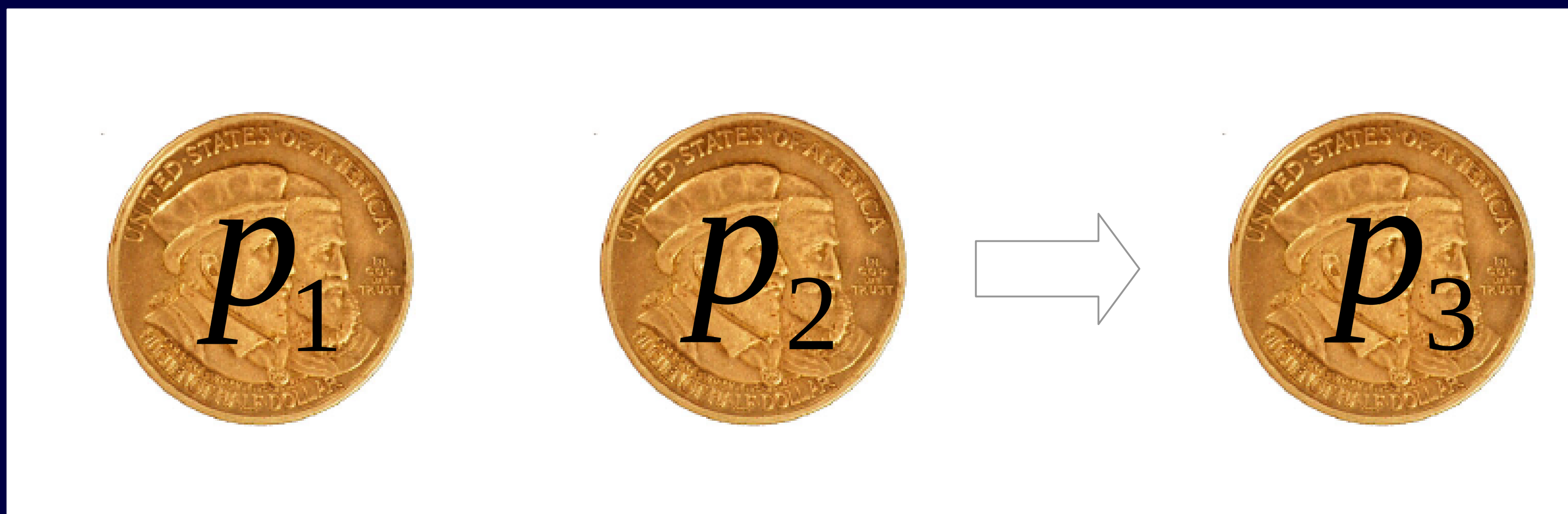
“ECCs that allow soft iterative decoding”

- Turbo decoding of concatenated convolutional codes
- Turbo decoding of product codes
- Low-density parity-check (LDPC) codes

Comparison

Traditional ECCs	Soft iterative ECCs
• Algebraic decoding methods	• Probabilistic decoding methods
• Less complexity	• High complexity
• Less coding gain	• High coding gain
• Good for short codewords	• Good for long codewords

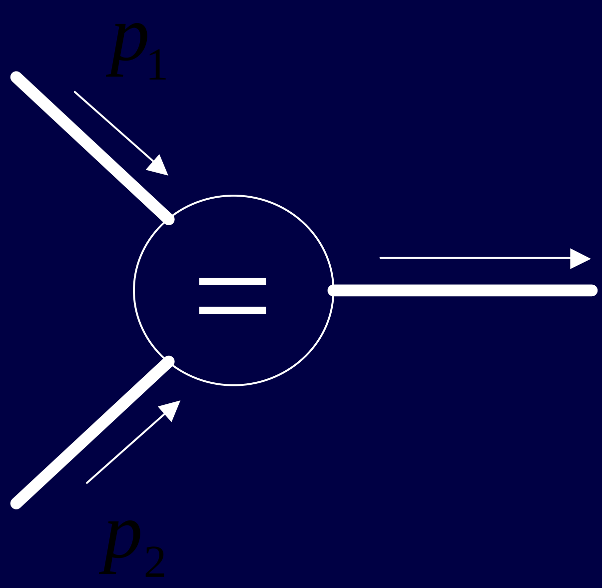
Coin Puzzle: Equality



Suppose the probability that the first coin is a head is p_1=2/3
and the probability that the first coin is a head is p_2=2/3.
If all three coins are all heads or all tails,
what is the probability p_3 that the third coin is a head?

$$x_1 = x_2 = x_3$$

Equality node

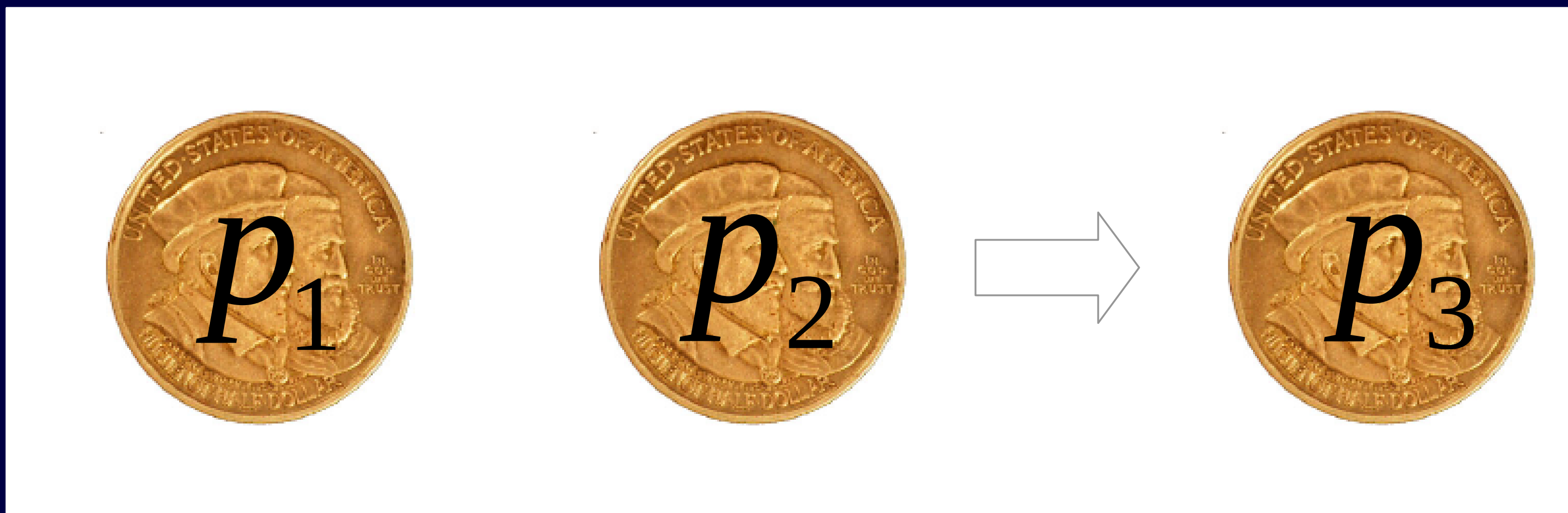


Coin 1	Coin 2	Coin 3	Probability
Head	Head	Head	p_1p_2
Head	Head	Tail	
Head	Tail	Head	
Head	Tail	Tail	
Tail	Head	Head	
Tail	Head	Tail	
Tail	Tail	Head	
Tail	Tail	Tail	$(1-p_1)(1-p_2)$

Answer:

$$p_3 = \frac{p_1 p_2}{p_1 p_2 + (1 - p_1)(1 - p_2)}$$

Coin Puzzle: Parity-check

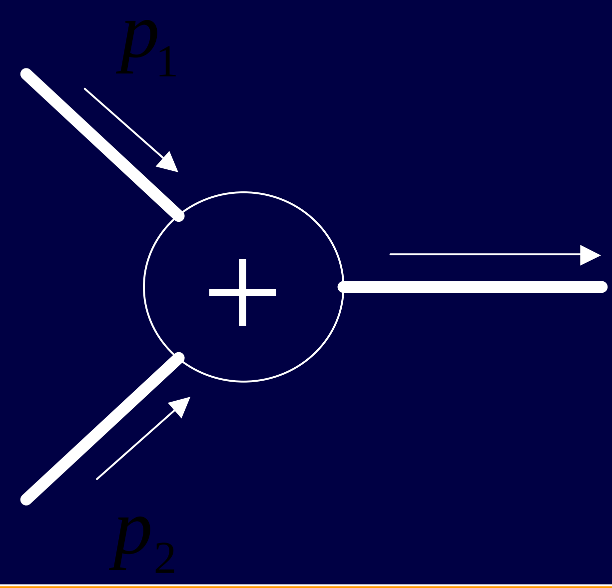


Suppose the probability that the first coin is a head is p_1=2/3
and the probability that the first coin is a head is p_2=2/3.
If exactly two of the coins are heads, or all are tails,
what is the probability p_3 that the third coin is a head?

$$x_1 \oplus x_2 \oplus x_3 = 0$$

Parity-check node

Coin 1	Coin 2	Coin 3	Probability
Head	Head	Head	
Head	Head	Tail	$p_1 p_2$
Head	Tail	Head	$p_1(1-p_2)$
Head	Tail	Tail	
Tail	Head	Head	$(1-p_1)p_2$
Tail	Head	Tail	
Tail	Tail	Head	
Tail	Tail	Tail	$(1-p_1)(1-p_2)$



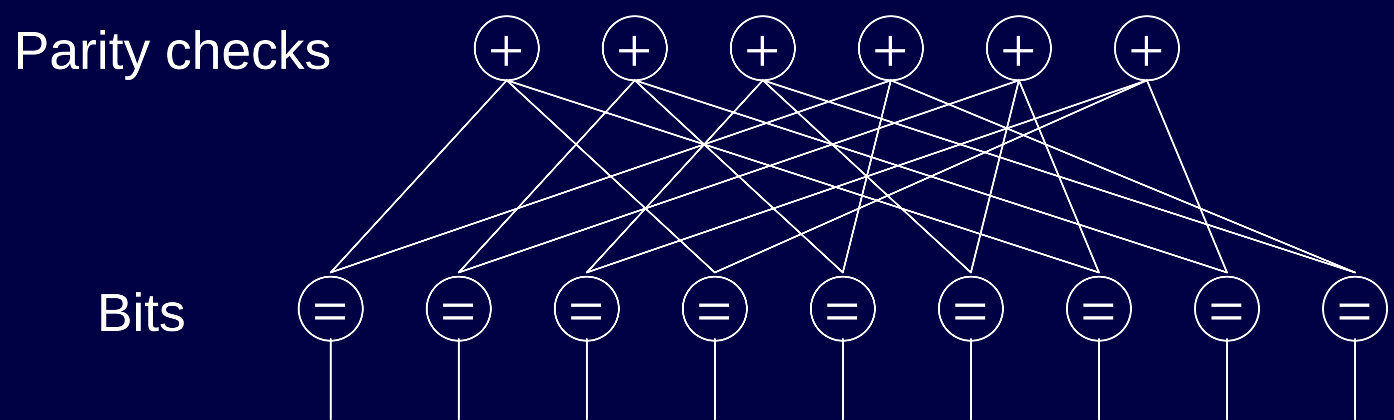
Answer:

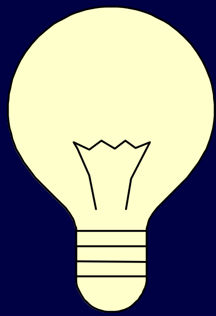
$$p_3 = p_1(1-p_2) + (1-p_1)p_2$$

$$1 - 2p_3 = (1-2p_1)(1-2p_2)$$

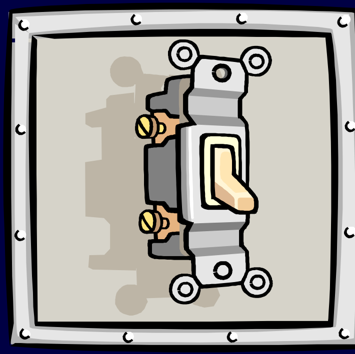
Parity-check matrix as a graph

$$\begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ \vdots \\ v_9 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$



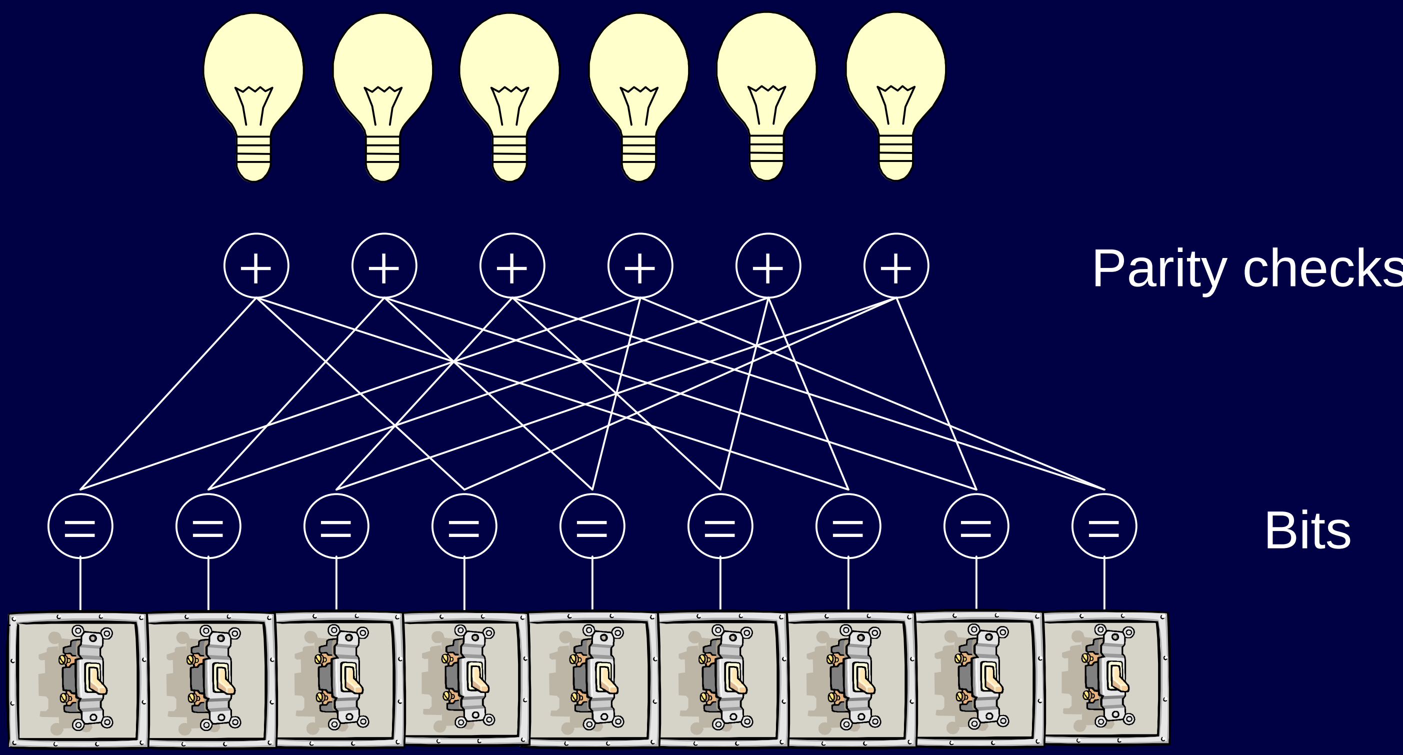


The Case of the Mysterious Light Bulbs

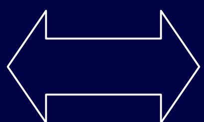


- Someone has broken into the Lightbulb Factory at night and turned on some of the light bulbs. Your job is to flip the light switches so as to turn off all the lights in order to conserve energy.
- The problem is that each light switch affects many light bulbs, and each light bulb is connected to many light switches. Light bulbs go between two states (“on” and “off”) whenever a connected switch is flipped.
- Your mission is to turn off all the lights while flipping the fewest number of switches possible.

An analogy for LDPC codes

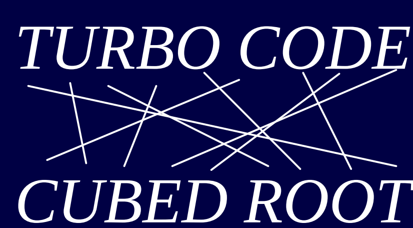


Flipping the minimum set of switches to turn off all the lights.

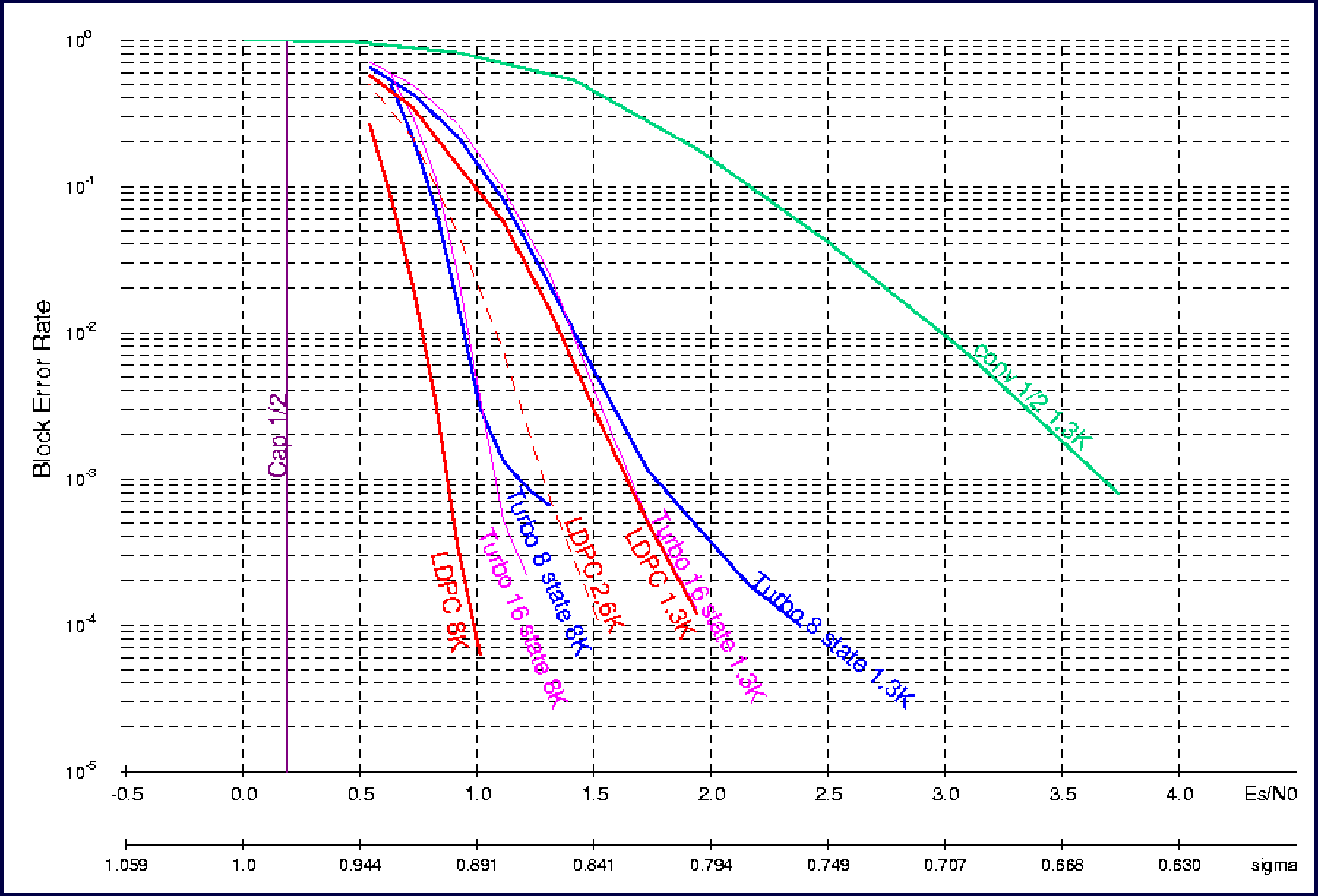


Correcting bit errors in the received word so that all the parity checks are satisfied

More analogies

Error-Control Code	Analogy
"Turbo" Product Codes (TPC)	Crossword puzzle *A T E* *G E L* *O A K*
Turbo Convolutional Codes (TCC)	Anagram 

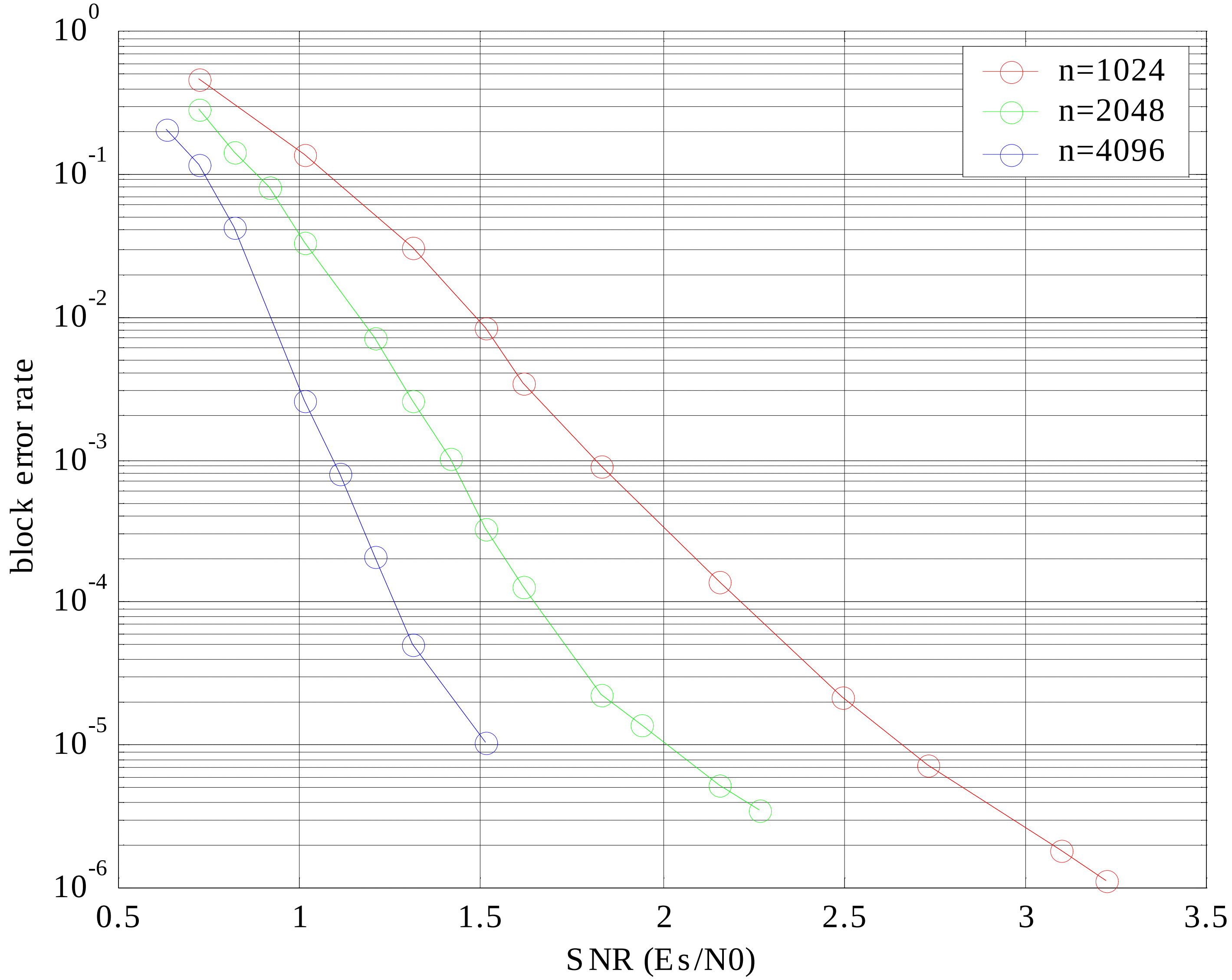
Comparison of various ECCs



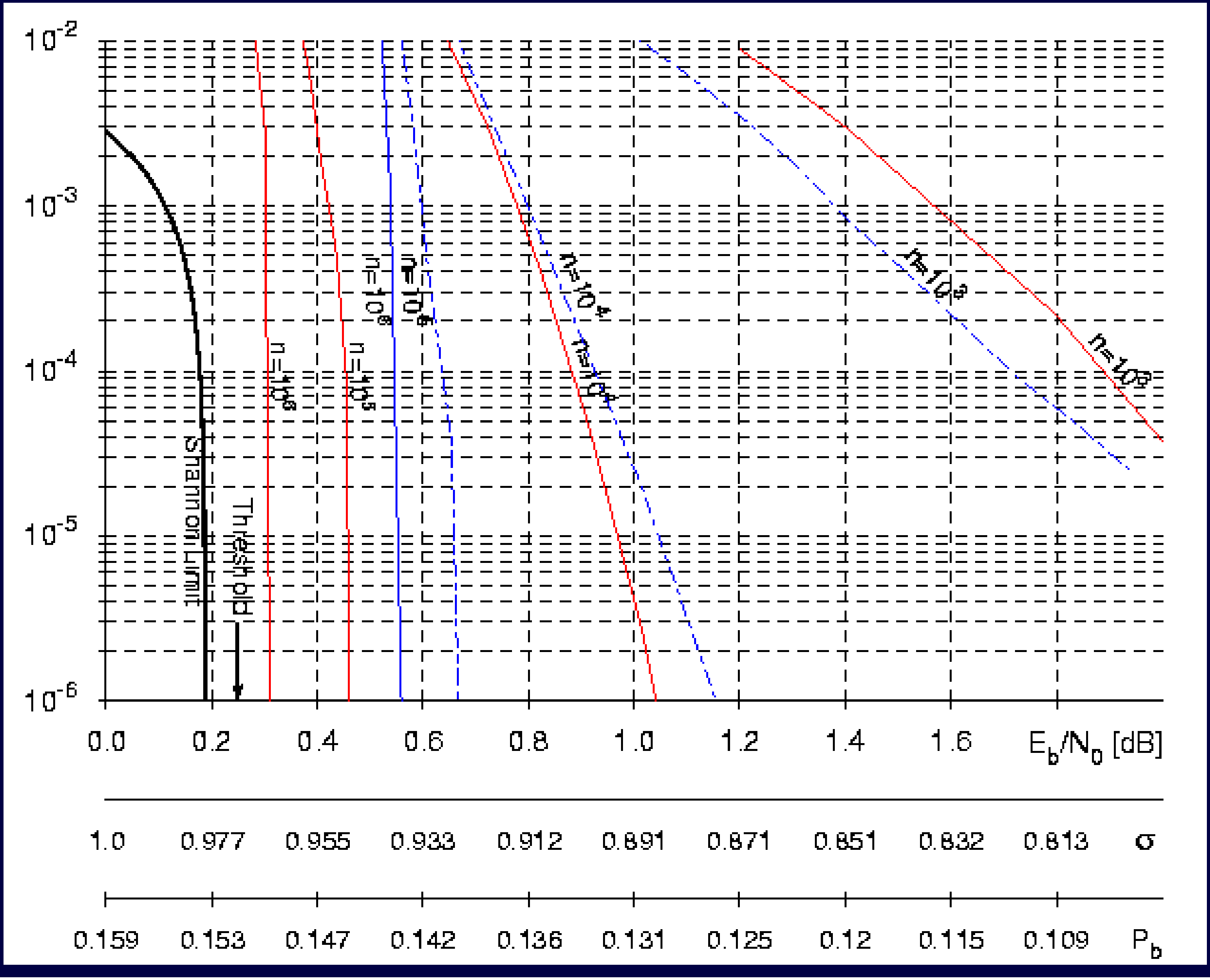
Mobile Wireless Considerations

- A packet-based mobile wireless system needs:
  - Short blocks for frequent control messages
  - Long blocks for data traffic
  - A variety of code rates for link adaptation
- Retransmission / ARQ
  - Maximize coding gain at $\sim 10^{-3}$ packet error rate
  - Error floor not a serious problem
- Multipath fading channels
  - With OFDM, multipath becomes frequency selectivity
  - ECC sees variations in channel gain across codeword

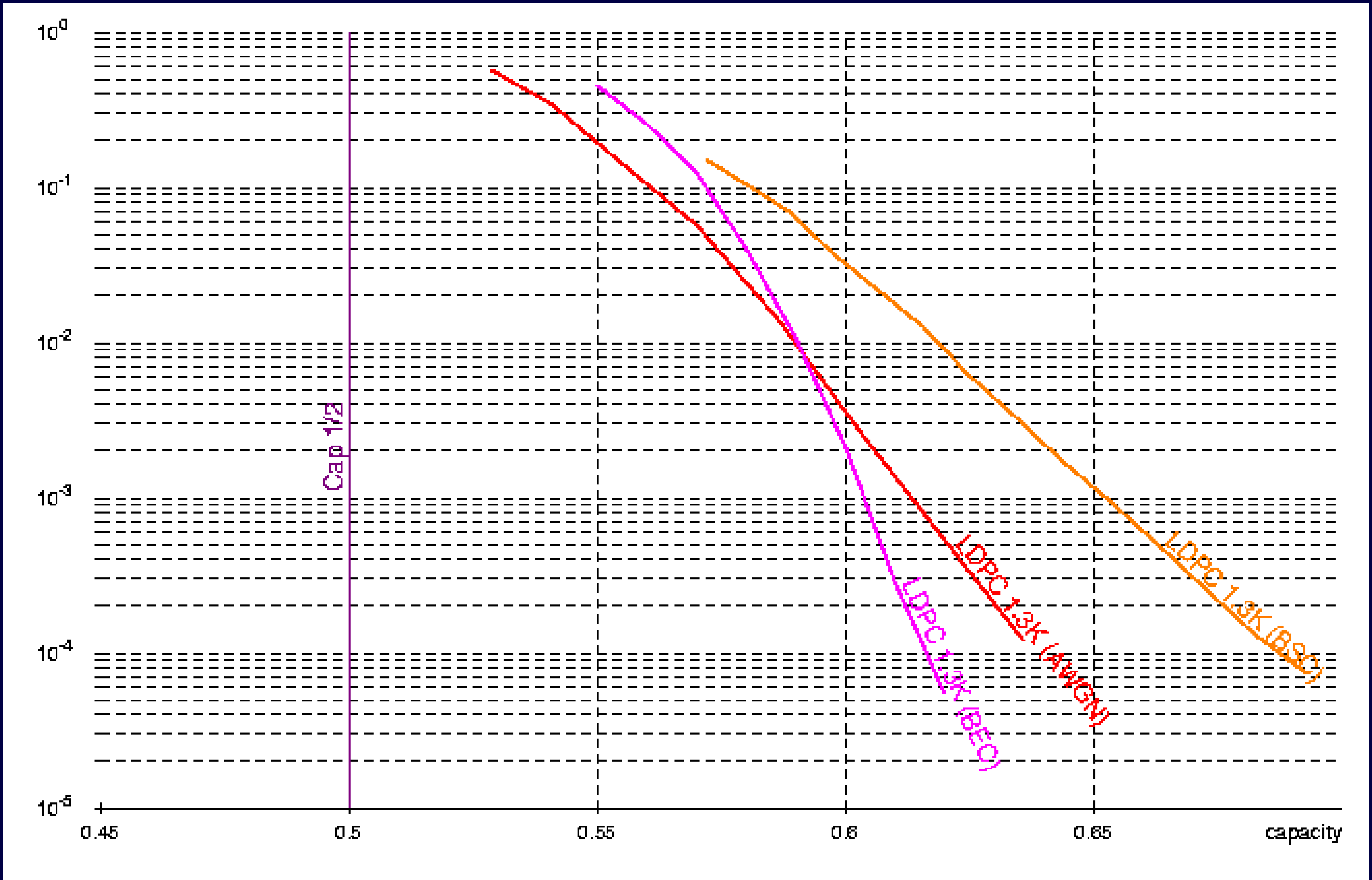
Comparison of block lengths



Comparison of block lengths



Robustness on different channels



Summary

- Turbo and LDPC codes can provide practical methods for achieving high coding gain in communication systems
- Key elements are soft decoding and iterative message-passing.
- These codes meet the needs of wireless communications, e.g., in terms of block lengths, code rates, and robustness in multipath channels.