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Error Control Coding and Ethernet

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Agenda

- Background on error control coding
- History of error control coding in Ethernet
- Cyclic, Reed Solomon, BCH codes
- FEC in other systems, speed, cost
- FEC in EFM?

Error control coding

- **Detect/correct errors that occur during transmission**
  - CRCs for detection (e.g. CRC-32 in Ethernet)
  - Forward Error Correction (FEC) (e.g. G.975, 10Gbps)
  - Sometimes called Error Correction Coding (ECC)
- **Error control coding requires redundant bits**
  - Bits are a function of the data, often viewed as overhead
- **Information Theory**
  - Best systems require error control, Shannon 1948
  - "You give me allowed overhead, I'll give you a better system"
- **Line coding (8B10B)**
  - Not used for error control explicitly, but greatly assists in system reliability

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Error control in Ethernet

- **10/100 Mbps Ethernet: 32 bit Frame Check Sequence (CRC-32)**
  - Cyclic redundancy check
  - Detects 99.999999977% of all errors
  - Detects all bursts of length 31 bits or less
- **Gigabit Ethernet:**
  - Copper: 4D5PAM (FEC implicit in trellis code)
  - Fiber: 8B10B used for timing/DC control (no FEC)
- **10 Gigabit Ethernet:**
  - No FEC specified
  - ITU G.975, 7% overhead Reed Solomon code

FEC in EFM?

- **What does CRC-32 in frame structure succeed in doing?**
  - Detects virtually all errors with low complexity
- **What does CRC-32 in frame structure fail to do?**
  - Real time applications
    - Cannot tolerate retransmissions
  - Dramatically reduce the number of retransmissions
    - Reduce congestion in network
  - Increase link budget
    - Coding gain
- **Can redundancy pay for itself?**

Reed Solomon Codes

- **Gold standard for forward error control (FEC) in optical networks, magnetic, optical storage**
- **Maximum error correcting for code parameters and byte-oriented systems.**
- **Most widely used for burst error correction (CD, DVD, hard drives)**
- **Optical networks: random error correction, leverage parallelism**
- **Implementation**
  - Use Galois Field Arithmetic
  - Lookup tables via primitive polynomials
  - Encoded and decoded in polynomial form
- **In DSPs now**

Reed Solomon Codes

- **ADSL: variable overhead Reed Solomon code**
  - Variable packet size = variable overhead
- **Hard drives: 1.4 Gbps**
  - Fixed packet size = fixed overhead
- **CD/DVD**
- **Very mature low cost technology**

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Some technical details

- **Encoding**

Info to be sent: 11001011 11010110 00010101

Encoder

Data actually sent: 11001011 11010110 00010101 01001001

Parity bits

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A deeper look

Info to be sent: 11001011 11010110 00010101

Galois Field (256) → Polynomial mult → Galois Field (256)

11001011 11010110 00010101

↓

α(203) α(198) α(21)

↓

[α(203) α(198) α(21)] [β(1) β(2)]

↓

[α(203) α(198) α(21) α(73)]

↓

11001011 11010110 00010101 01001001

↓

Data actually sent: 11001011 11010110 00010101 01001001

Parity bits

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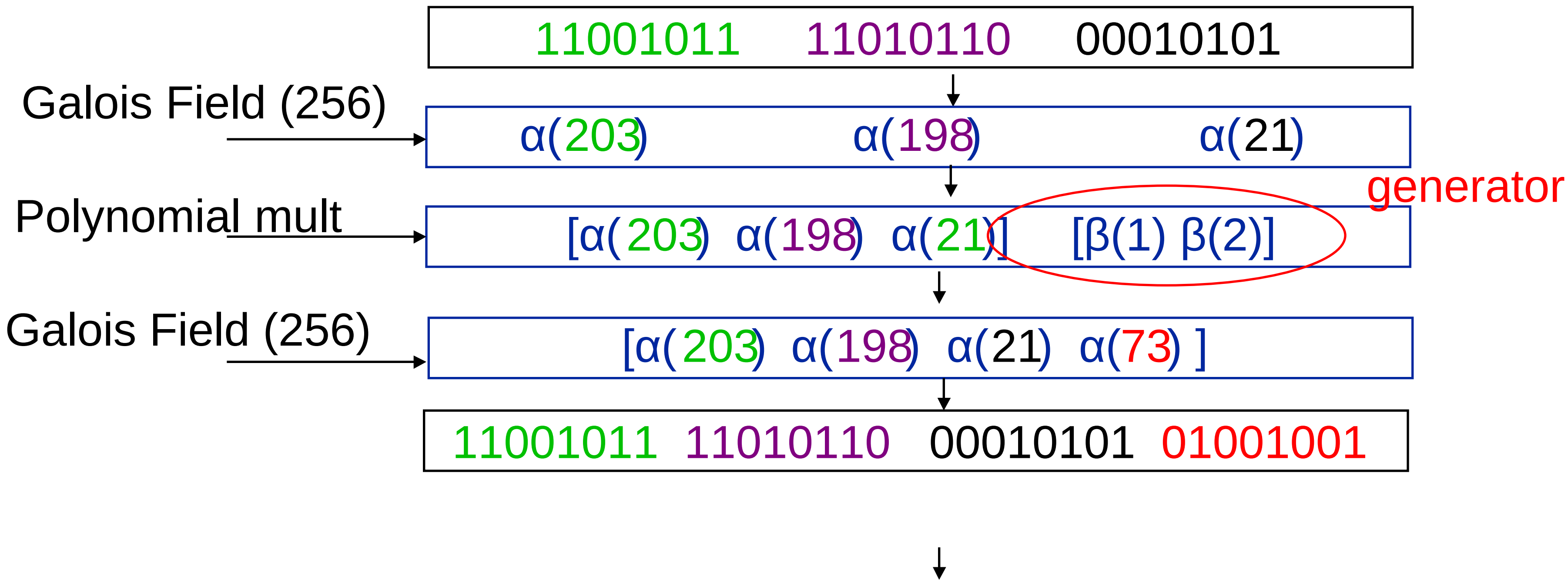
A deeper look

Info to be sent: 11001011 11010110 00010101

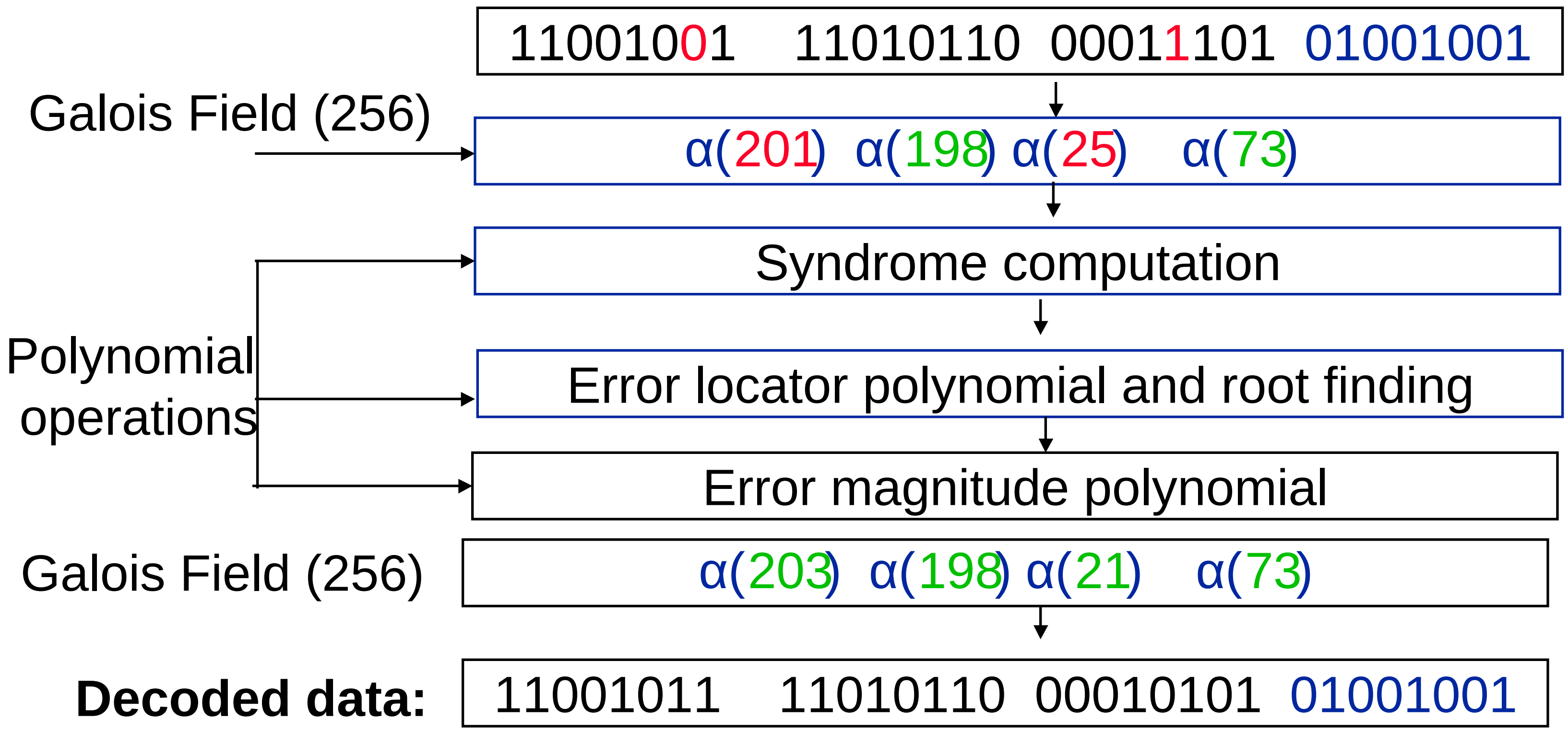


Data actually sent: 11001011 11010110 00010101 01001001

Parity bits

Decoding

Data received : 11001001   11010110 00011101 01001001



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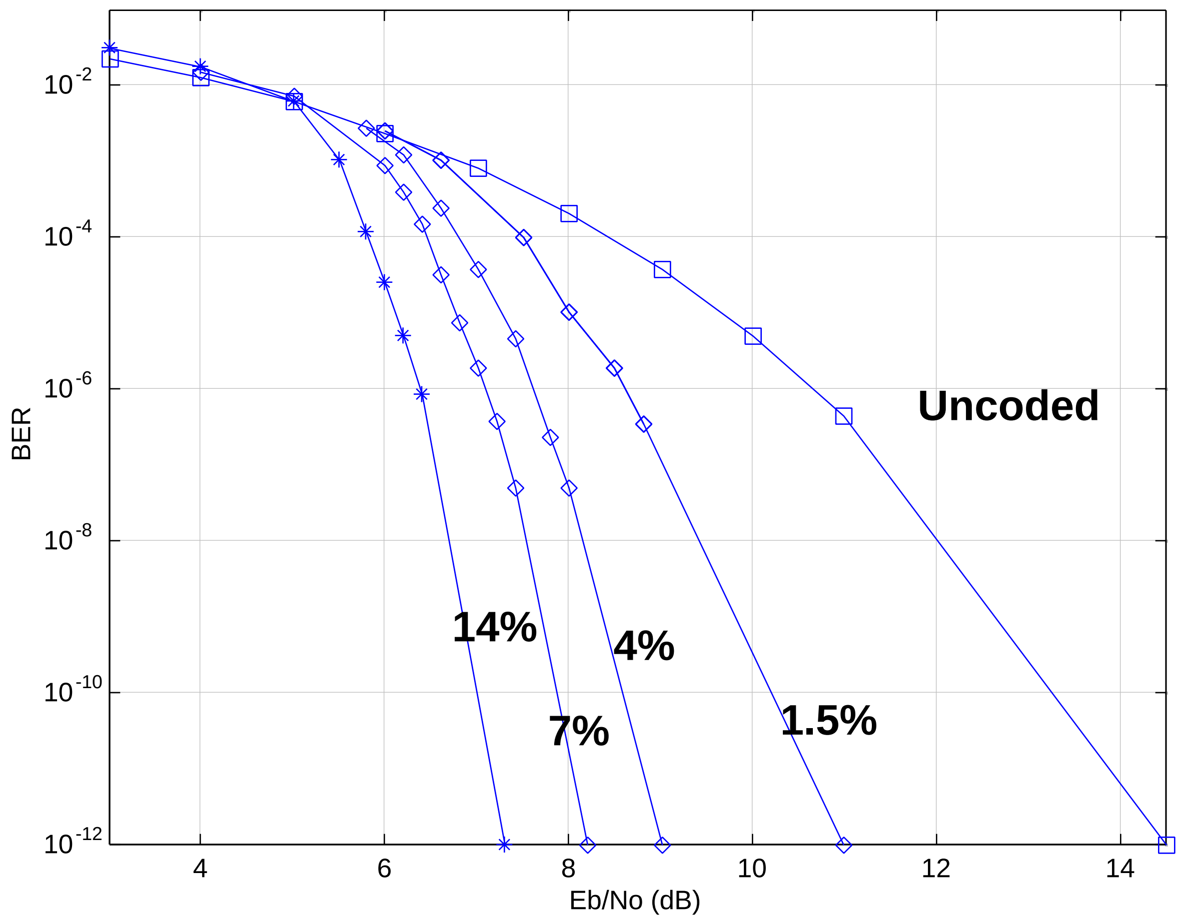
Design points

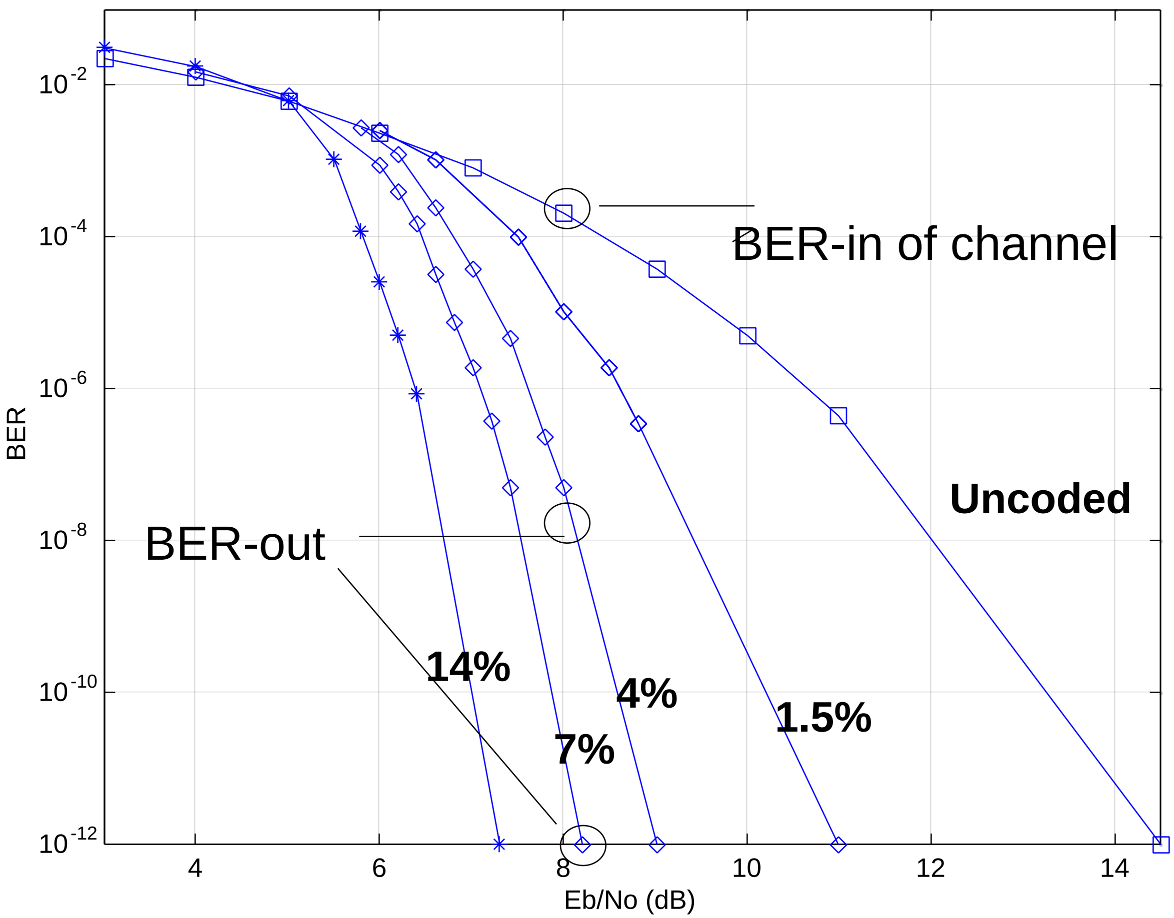
- **Let n be the length of codeword (in bytes)**
- **Let k be length of message (in bytes)**
- **Byte oriented RS code has length n=255 bytes**
- **Reed Solomon code can correct (n-k)/2 byte errors**
  - Maximum error correcting capability of any byte-oriented code
  - Direct relationship between overhead and error correction

- **Processing is on byte level (~1/8 the bit rate)**
- **Interleaving very common (G.975)**
  - Multiplex 16 encoders/decoders

Performance vs overhead



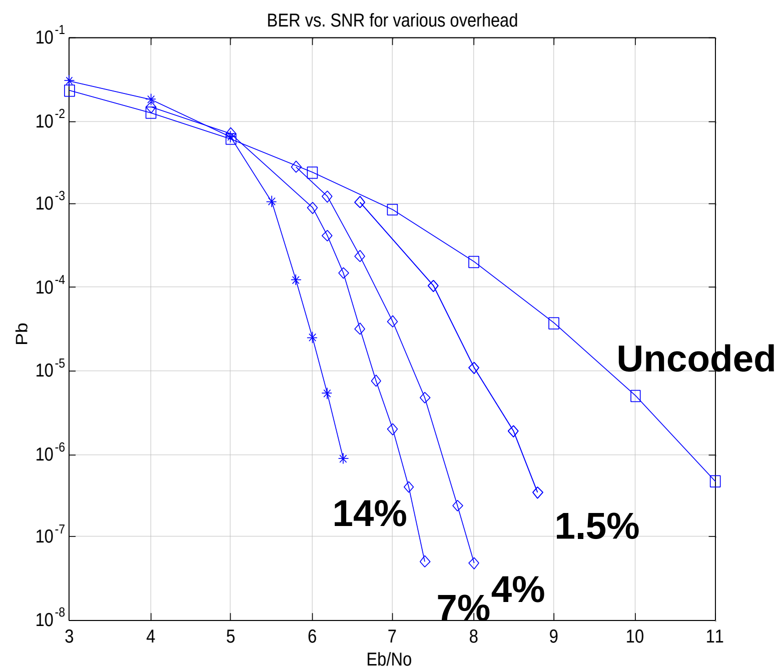
BER-in vs. BER-out



Why FEC in EFM?

- **Does redundancy pay for itself?**

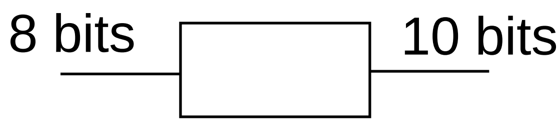
- **BER plots show there is much left on the table w/o FEC**
  - at BER-out of 1e-10 to 1e-15
  - Great gains are possible



- **Unified approach?**
  - Point-to-point optical?
  - Point-to-multipoint optical?
  - Copper

Case Study: FEC in P2MP EPON?

- **8B10B coding**



  - 20% overhead
  - Advants: Good DC control, good 1's density, improved timing recovery

- **Possible approach: 16B/18B plus 7% FEC**
  - 18% overhead
  - Minimize retransmission
  - Extended reach from coding gain
  - Increase number of nodes supported in point-to-multipoint config
  - Minor changes in DC control

5 Criteria and Conclusion

- **Broad Market Potential**
- **Compatibility**
- **Distinct Identity**
- **Technical feasibility**
- **Economic Feasibility**

- **Unified proposal**
  - Companies interested in unified FEC approach for EoVDSL, PTP, PTMP please contact us

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