FEC Options for 100G-KR

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Outline

- Introduction
- Coding over Virtual Lane
- Coding over Physical Lane
- Coding across Physical Lane
- Coding with Higher Redundancy Ratio
- Performance Comparisons
- Conclusion

Why Care about FEC

- In 10GBASE-KR, the Fire code (2112, 2080) was adopted. An output BER=1e-15 can be achieved when input BER~=5e-10.
- Can increase MTTFPA to over 2.9e+14 years (10GBase-KR FEC Tutorial)
- No extra redundancy was introduced
- An extra processing latency of about 220 ns was introduced
- If encoding over 25G data stream, we can use RS(528, 520) code over GF(2^10) to achieve 2dB extra coding gain with similar latency. Can obtain output BER=1e-15 when input BER~=2e-6, which can greatly
  - Ease receiver design and implementation
  - Increase stability of the networking systems

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Basics about FEC Codes

- **Fire code**: can correct only 1 burst of errors or 1 sparse bit error
- **BCH code**: best for correcting random errors, but not good at correcting burst errors
- **Reed-Solomon (RS) code**: good at correcting both random errors and burst errors

- An optimal FEC code should
  - Achieve a good balance between correcting random errors and correcting long burst errors
  - The overall processing time involved in encoding and decoding should be sufficiently small

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Different Coding Scenarios

- Encoding over Virtual Lane (VL)
  - 100G Ethernet has 20 VLs, each VL has data rate of 5 Gps
  - Due to the constraint of latency, the code size has to be short at this data rate, which limits the coding gain of possible FEC code to be employed
- Encoding over Physical Lane (PL)
  - A larger coding gain can be achieved with similar or even shorter latency compared to 10GBase-KR case since a larger block size of code is feasible
- Encoding across Physical Lane
  - Even large block sizes of FEC codes can be employed for better coding gain
  - Some implementation issues such as data alignment
- Encoding with Higher Redundancy Ratio
  - Can achieve very high coding gain with short latency
  - Small challenges in system design and implementation

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Encoding Over VL

- Notation:
  - tb: burst error correcting capability per single code
  - tr: random error correcting capability of a single code
  - Tb: burst error correcting capability of the interleaved codes

- The coded data from each VL can be bit or burst (n-bit, 1<n<=tb) interleaved to form the data stream for a PL

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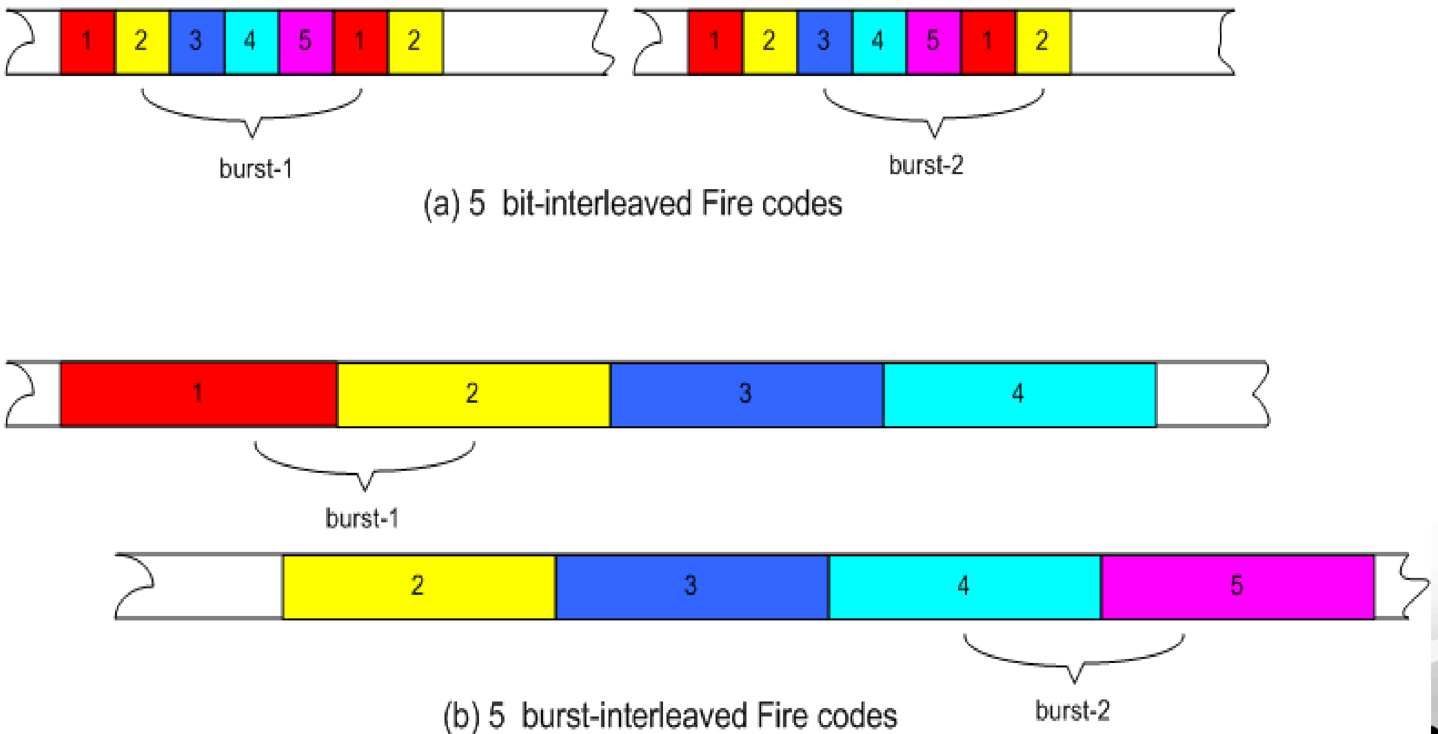
Encoding Over VL (II)

- Burst-interleaving performs better in dealing with multiple short bursts of errors



Encoding Over VL (II)

- Interleaved Fire codes:
  - Fire code (2112, 2080, tb=11), Tb=50bits, processing latency ~ 430 ns
  - *Fire code (858, 845, tb=3): Tb=15 bits, processing latency ~180 ns*
  - Fire code (990, 975, tb=4), Tb=20 bits, processing latency ~ 205 ns
  - All Fire codes have tr=1

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- Interleaved BCH Codes:
  - BCH(2376, 2340, t=3), Tb=15 bits, processing latency ~ 485 ns

- Interleaved (symbol or bit) Reed-Solomon Codes
  - RS(132, 130, t=1) over GF(2^8), Tb=33 bits, processing latency ~220 ns
  - RS(264, 262, t=2) over GF(2^9), Tb=82 bits, processing latency ~485 ns

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Encoding Over PL

- Symbol/Bit Interleaved RS Codes
  - 2X RS(264, 260, t=2), GF(2^m), m=9, 10, 11, etc.
    - Processing latency: 211 + M ns, M <15, when m=10
    - Can correct 2 bursts, each of m+1 bits long
    - Tb=3m+1 bits
    - Using symbol-interleaving instead of bit-interleaving is better for performance
- Single Reed-Solomon Code
  - RS(528, 520, t=4), m=10, 11, etc.
    - Processing latency: 211 + M ns, M~=40, when m=10
    - Can correct 2 bursts, each of m+1 bit long
    - Tb=3m+1 bits

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Coding Across PL

- Encoding can be done over 100G (or 50G) data stream for even shorter latency and better coding gain
- Single RS codes with larger t can be chosen
  - RS(660, 650, t=5), over GF(2^m), m=10, 11, etc.
    - Tb=4m+1
    - Overall latency (100G): 66 + M ns, M = 34 ~44, when m=10
    - Can correct 2 bursts, one with m+1 and the other with 2m+1 bits errors
  - RS(792, 780, t=6), over GF(2^m), m=10, 11, etc.
    - Tb=5m+1
    - Overall latency (100G): 79+ M ns, M = 34 ~ 44, when m=10
    - Can correct 3 bursts, each of m+1 or less bits long
- Implementation issues: need data alignment

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Coding with Higher Redundancy Ratio

- Larger coding gains can be achieved with higher redundancy ratio coding
- RS codes with large t and small code length can be options
  - In general, we can put extra redundancy bits into one (or more) of 66 bit block. E.g., consider RS(270, 260, t=5) over GF(2^m, m=9 or 10). The redundancy ratio is about 4.0% when m=10
  - With similar latency as using RS(264, 260, t=2), we can achieve much higher coding gain now
  - Other FEC options:
    - RS(140, 130, t=5) over GF(2^8), use one 66-bit block, 7.7%
    - RS(138, 130, t=4) over GF(2^10), use one 66-bit block, 8.3%
- Higher line rate will make transmitter and receiver implementation a bit more challenging

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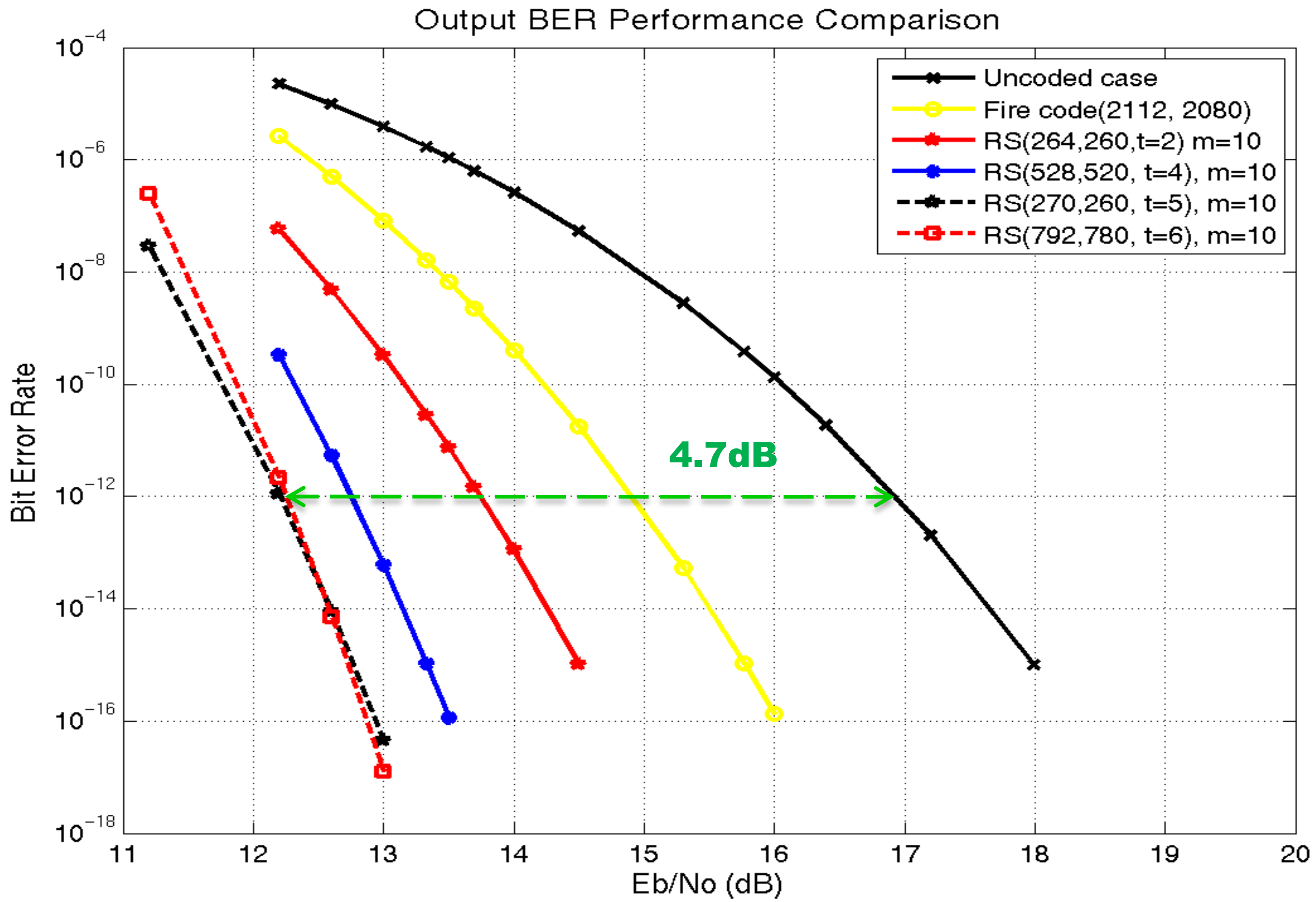
Random Error Correcting Performance (computed)



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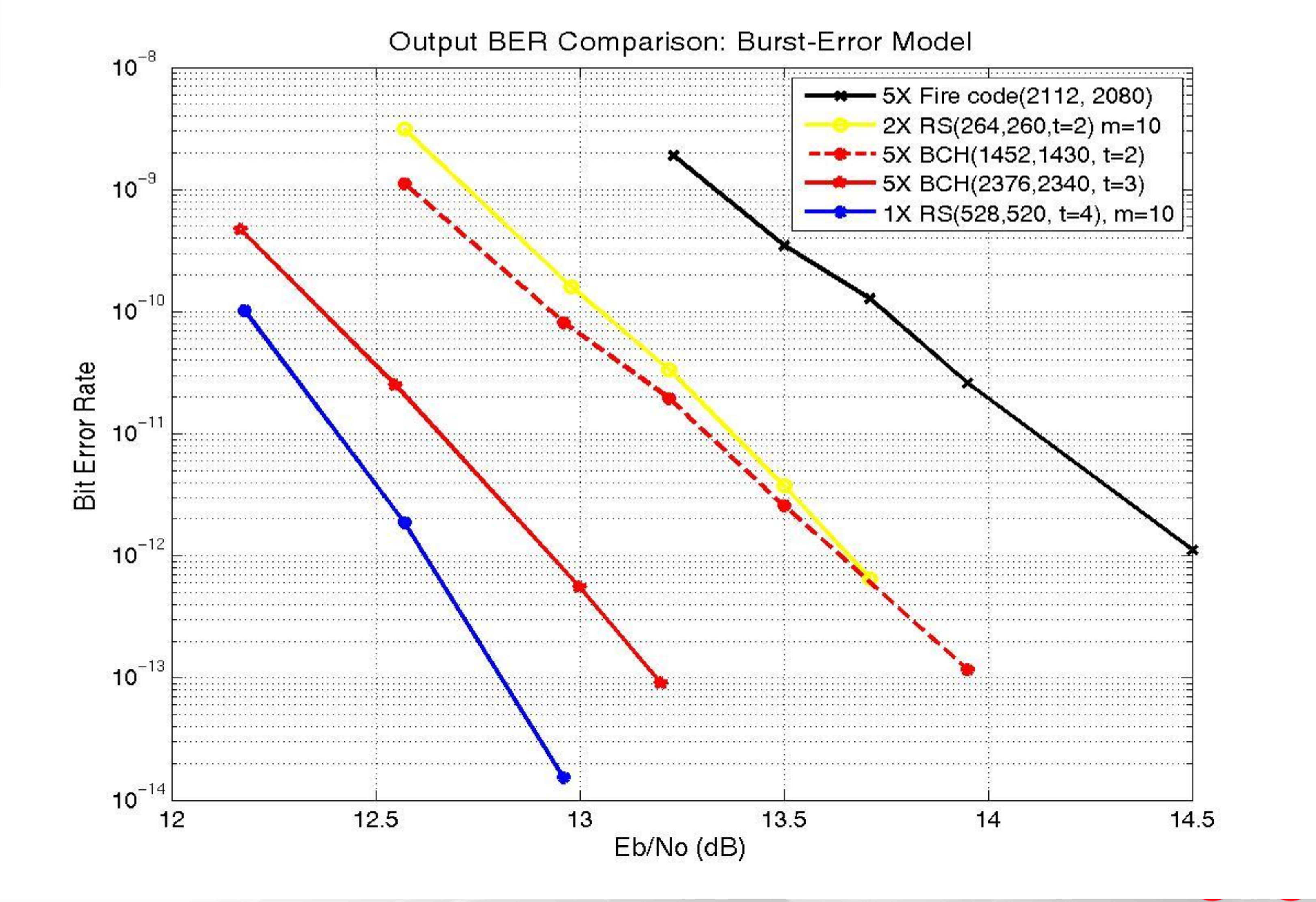
Comparison for Various Codes

FEC Codes	NCG (dB)	Latency (ns)	NCG (dB)	Latency (ns)	NCG (dB)	Latency (ns)
	Coding over virtual lane		Coding over physical lane (25G)		Coding across physical lane (100G)	
Fire code (2112,2080)	2.1	430				
Fire code (858, 845)	2.2	180				
RS(132, 130), m=8	2.2	220				
2X RS(264, 260) , m=10			3.2	225		
RS(528, 520)			4.2	250	4.2	53+40
RS(792, 780)					4.7	80+50
Encoding with 4% redundancy						
RS(270, 260)			4.7	150	4.7	27+27

Simulation Using Analytical Model



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Conclusion

- **Coding over Virtual Lane limits the adoption of a good FEC code due to constraint of latency at low data-rate**
  - Using short Fire code, e.g., (858, 845), may be a good option
- **Coding over Physical Lane leads to promising coding gain with reasonable latency**
  - Using RS(528, 520) over GF(2^m, m>9), may be an optimal option
- **Coding across Physical Lane can potentially achieve highest coding gain with low latency**
  - A bit more implementation complexity such as data alignment
  - Using RS(792, 780) over GF(2^m, m>9) can be considered
- **Coding with Higher Redundancy Ratio can achieve very high coding gain with low latency**
  - Slight more challenging in both transmitter and receiver design
  - Using RS(270, 260) over GF(2^m, m>8) can be an optimal option

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