Update on FEC Proposal for 10GbE Backplane Ethernet

Andrey Belegolovy
Andrey Ovchinnikov
Ilango Ganga
Fulvio Spagna
Luke Chang

DEG Digital Enterprise Group

Contributors & Supporters

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- Andre Szczepanek - Texas Instruments

Supporters

- Harmeet Bhugra - IDT
- Magesh Valliappan - Broadcom
- Cathy Liu - LSI Logic
- David Koenen - HP

Key Messages

- FEC Proposal made to the 802.3ap TF - Sep ‘05 Interim along with draft text (Reference: ganga_01_0905 & ganga_02_0905)
  - Task Force expressed interest in continuing the FEC work (vide Strawpoll
  - TF requested to perform simulations with additional impairments
  - TF members requested to make FEC optional
- This is an update on FEC to the task force

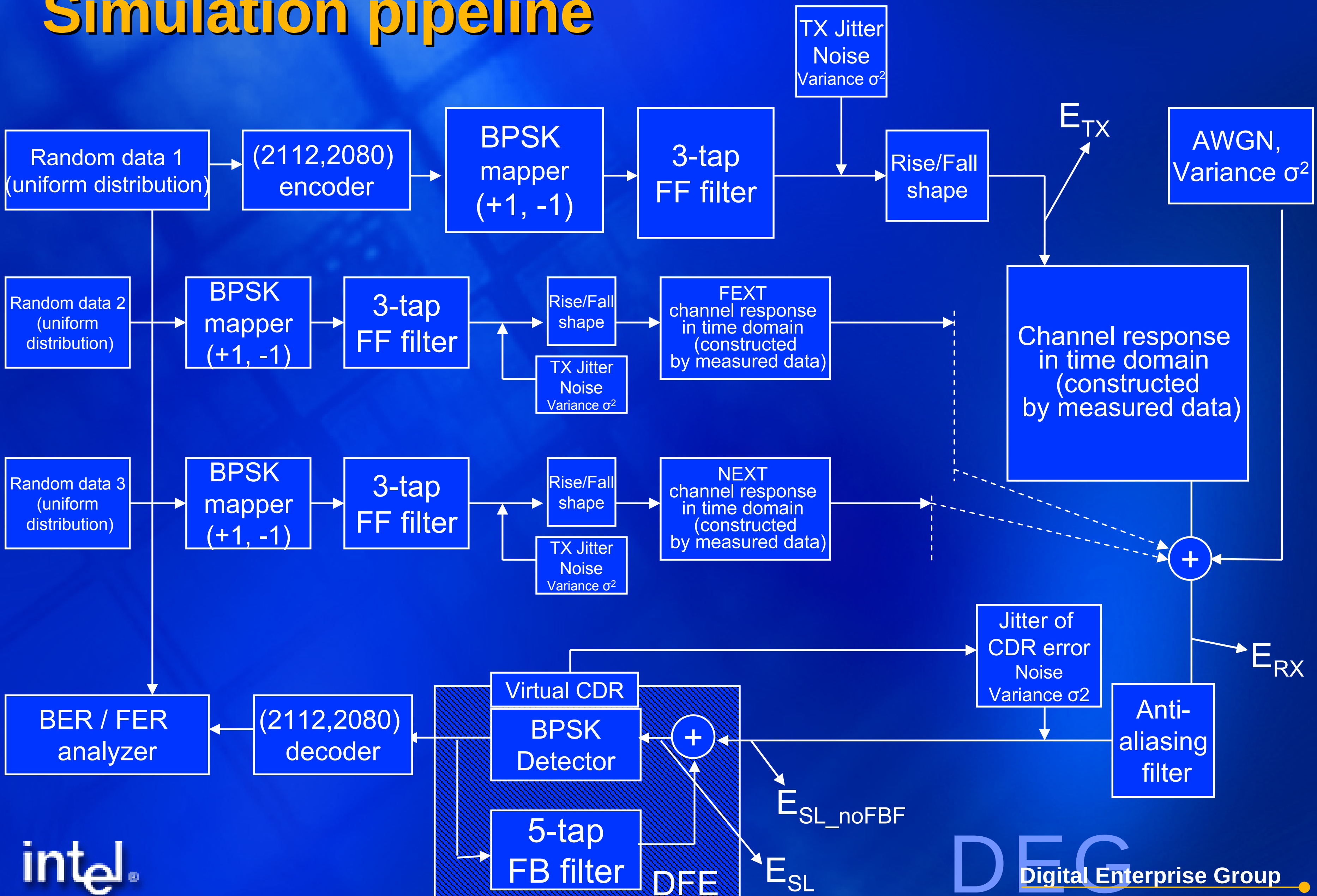
Recap on FEC Objectives

- FEC to provide additional margin and increase link budget
- BER objective of 10^{-12} or better on broader set of channels (green/gray)
- Minimum changes to existing sublayers
  - Locate between PCS & PMA and be compatible with existing PCS (clause 49) & PMA (clause 51)
- Negotiate FEC capability through Auto-Negotiation
- No increase in baud rate or decrease in payload rate
- Low overhead (latency/area/power)
- Leverage previous work presented to the task force (Reference: szczepanek_01_0305, szczepanek_05_0505)

FEC Enhanced Simulation model overview

- Simulation to closely model real backplane systems, include additional impairments - As per feedback from 802.3ap Sep'05 interim/TF Members
- Parameters to consider
  - Include TX FIR filter
  - Include TX Jitter and rise/fall time shaper
  - Include Cross talk (NEXT, FEXT)
  - Include the effect of CDR
  - Plot BER curve with SNR at slicer
  - Include additional test channels from channel library: Intel, Tyco, Molex
    - Improved channel data from peters_m1_0605.zip, peters_01_0605.pdf
    - Include Channels from Tyco and Molex
- Error distribution with new simulation setup
  - P(m,n)-characteristics, burst error length

Simulation pipeline



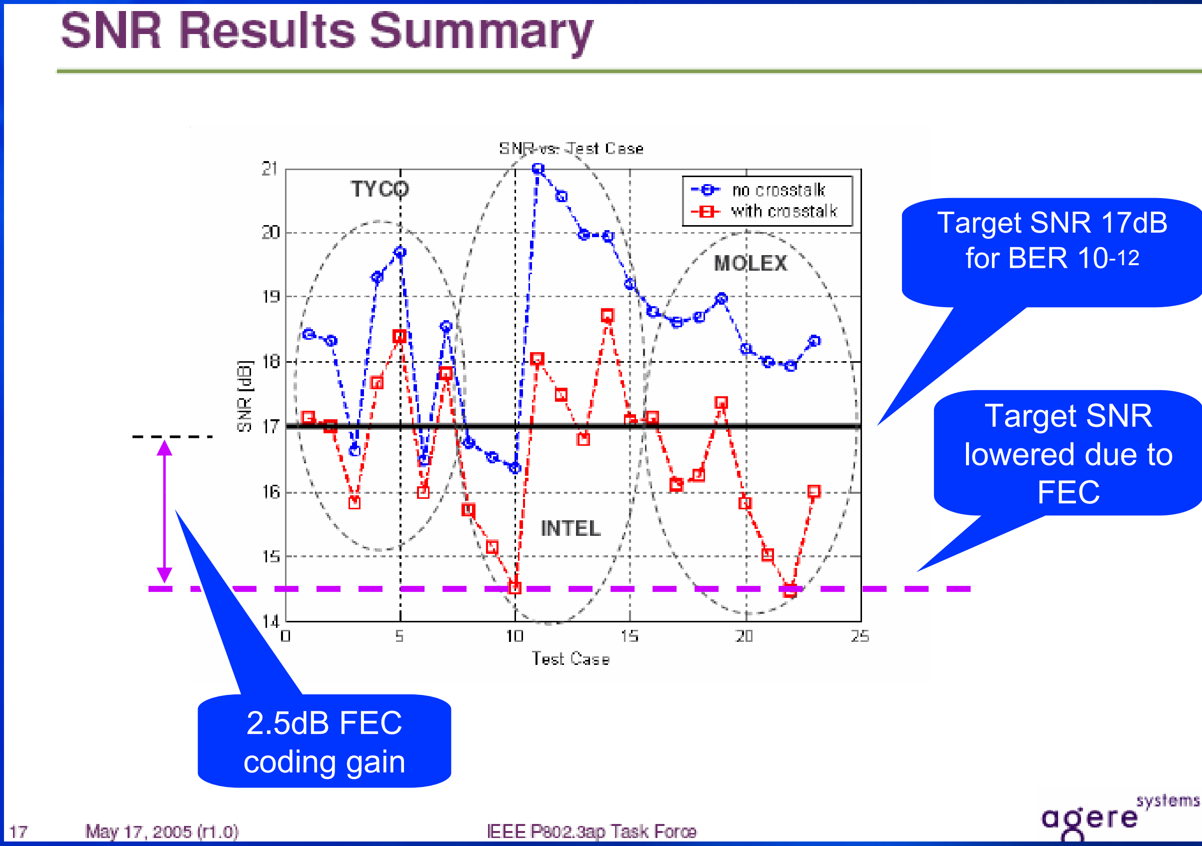
Simulation conditions

- Time Domain simulation
- Simulation model includes
  - 3 tap FIR filter: Optimal for the given channel
  - Rise/Fall time shaper: 24ps
  - Tx Jitter: 0.05UI(random, variance), 0.05UI(sine, amplitude)
  - Channels: Time domain response constructed from frequency domain parameters from 802.3ap channel model library
  - Cross talk: 1 NEXT and 1 FEXT aggressor (Intel, Molex, Tyco)
  - DFE: Optimal for the given channel
  - CDR effect: By equivalent noise with variance 0.01-0.04
  - AA filter: 2-pole filter p1 = 0.7/T, p2 = 1.0/T

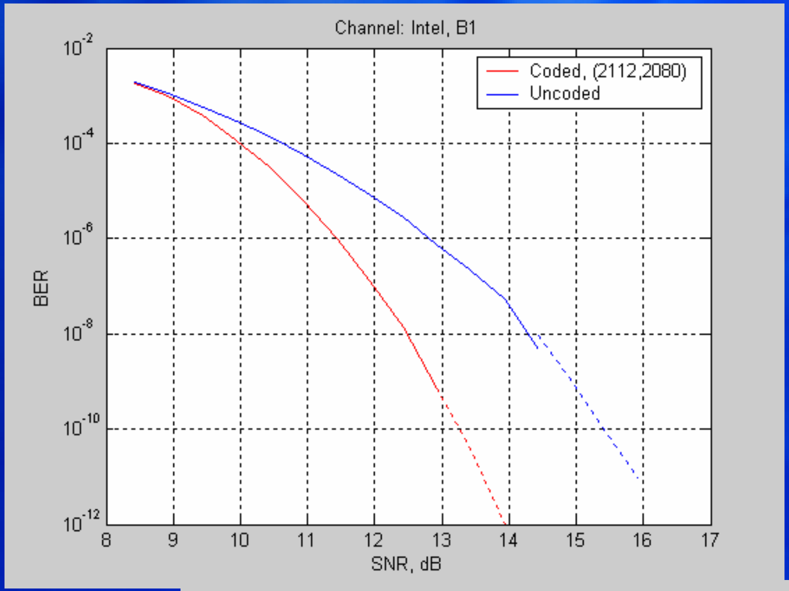
FEC Gain Vs SNR for test channels

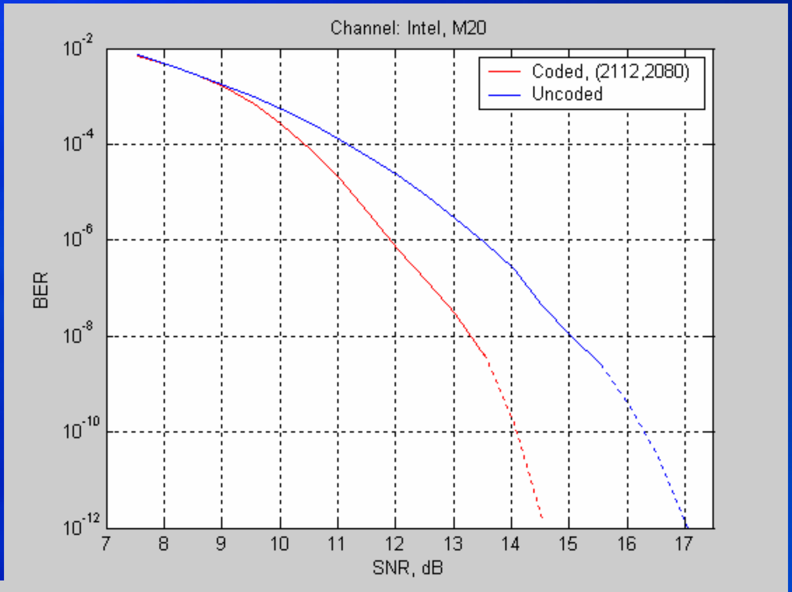
- Gain of 2.5dB allows channels listed in the graph to meet the target SNR of 17dB
- SNR difference between best and worst case channels is ~5dB
- In relative terms 2.5dB gain provides ~50% improvement for worst case channels
- Picked 7 channels below target SNR for FEC sims
  - Intel: T12, M20, B1
  - Tyco: Case3, Case6
  - Molex: in J4K4G4H4
    out J3K3G3H3

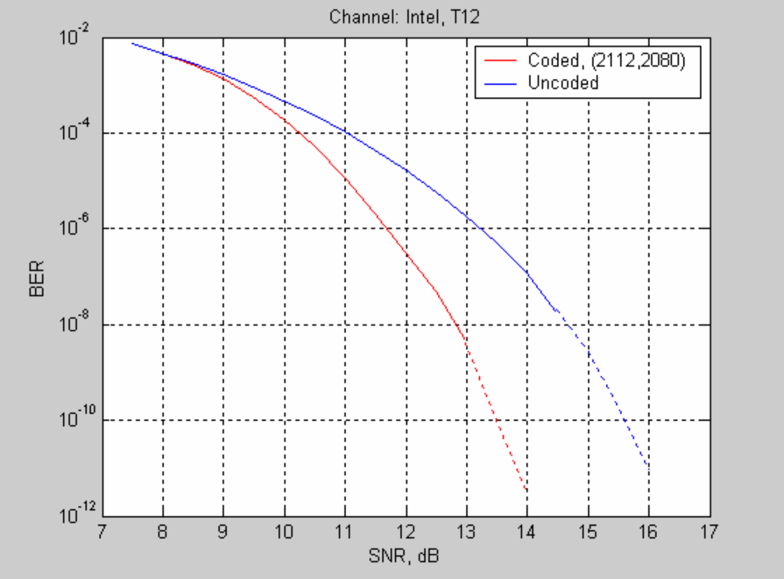
Reference: slide from healey_01_0505.pdf



Simulation results - Intel channels





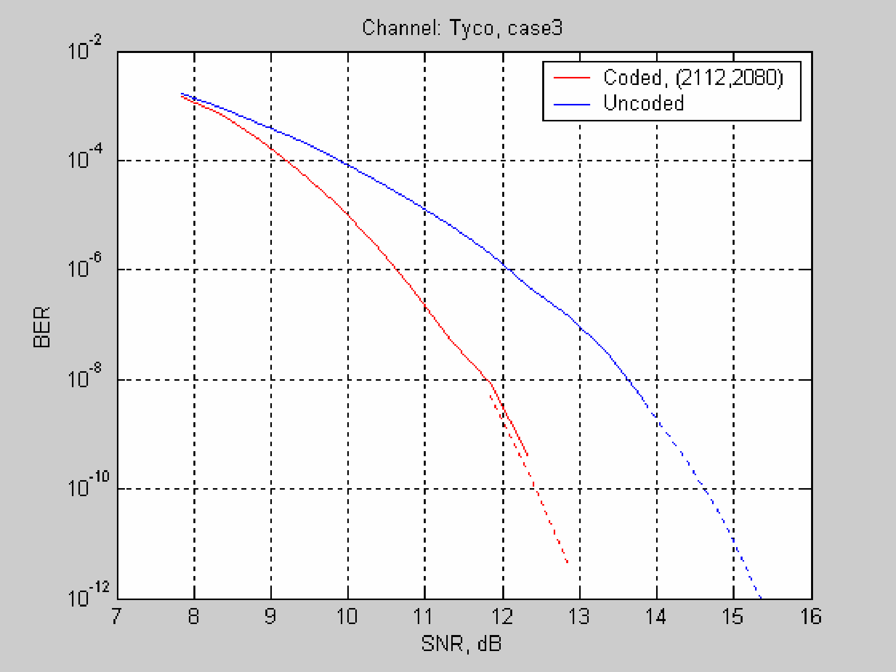


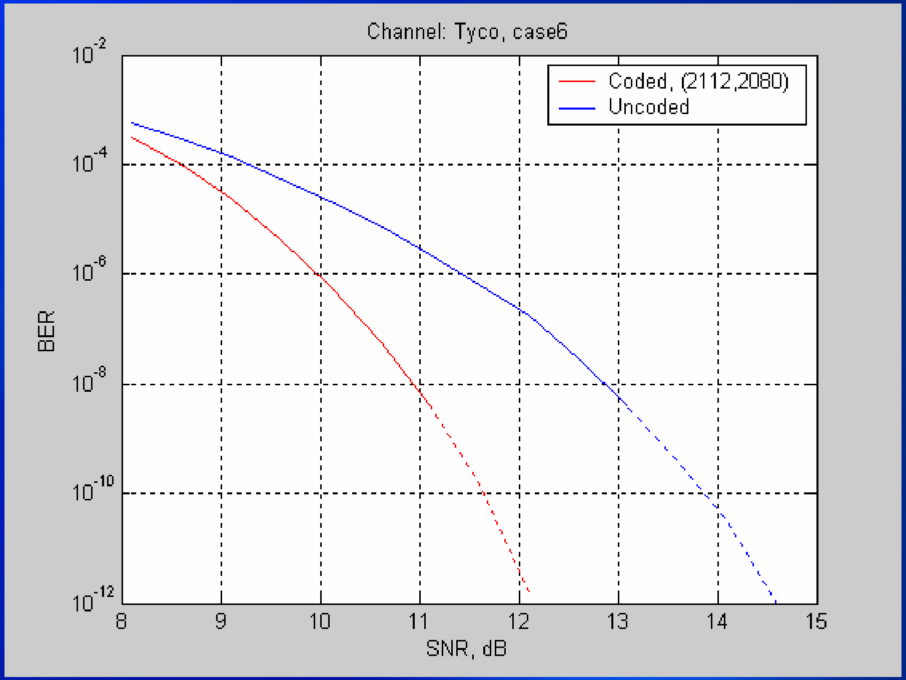
Intel Test channels (Peters_01_0605)
T12, M20, B1

SNR = SNR at slicer
Simulations to BER of 10^{-8}/10^{-9} and extrapolated to 10^{-12}

Sims show ~2dB coding gain at BER 10^{-9}

Simulation results - Tyco channels



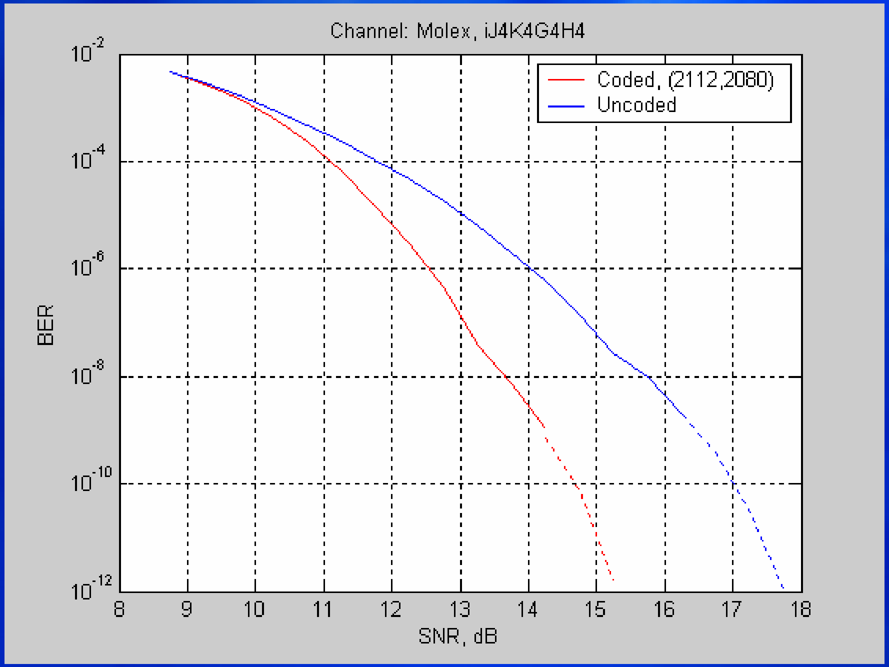


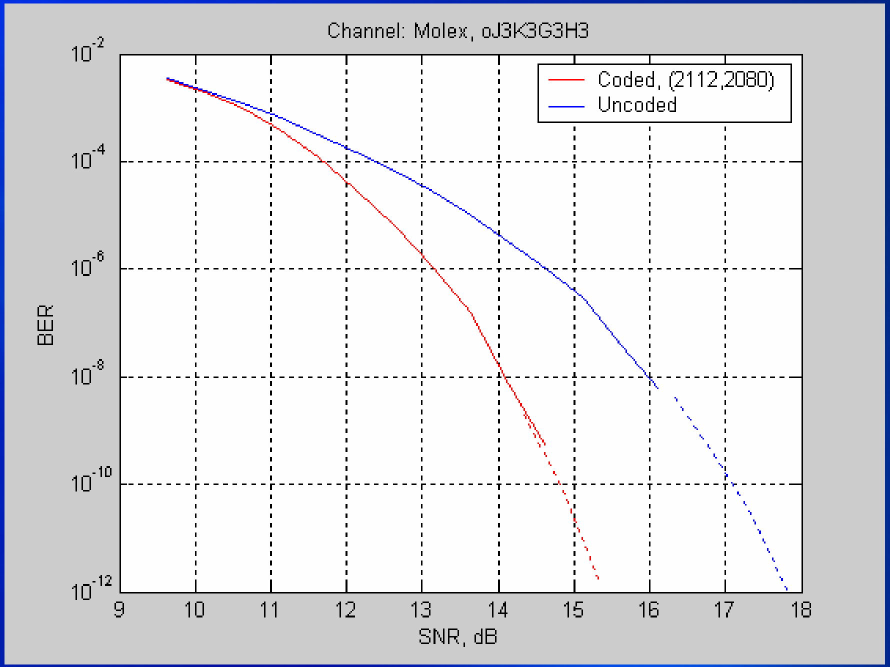
Tyco Test channels
Case 3, Case 6

SNR = SNR at slicer
Simulations to BER of $10^{-8}/10^{-9}$ and extrapolated to 10^{-12}

Sims show ~2dB coding gain at BER 10^{-9}

Simulation results - Molex channels





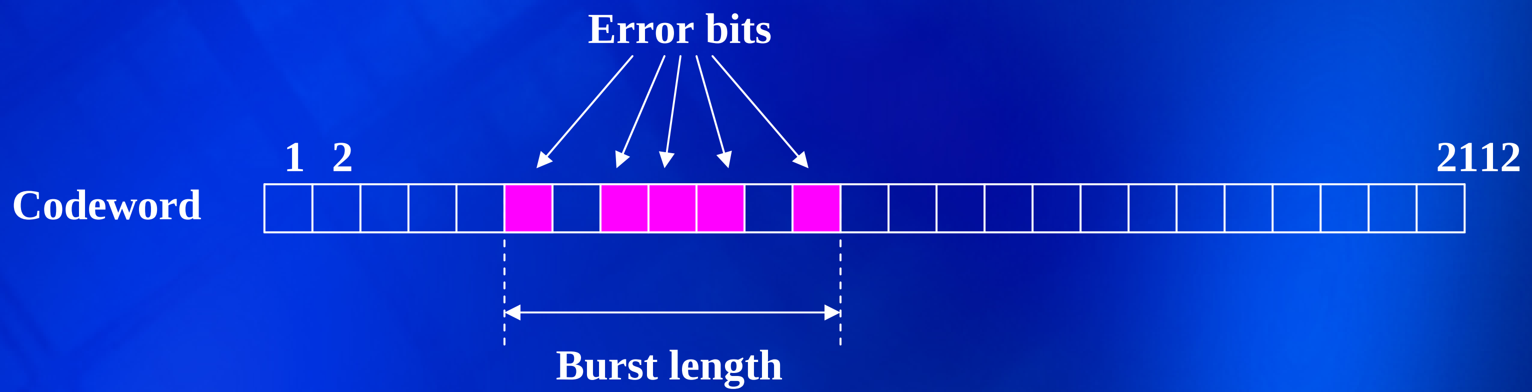
Molex test channels
Inbound J4K4G4H4
Outbound J3K3G3H3

Sims show ~2dB coding gain at BER 10^{-9}

SNR = SNR at slicer
Simulations to BER of $10^{-8}/10^{-9}$ and extrapolated to 10^{-12}

Error distribution

- P(m,n) characteristics (for 7 channels)
  - Normalized number of frames that have m errors
- Burst lengths (for 7 channels)
  - Error burst length is the distance between first and last error inside 1 codeword



Error distribution, Intel channels

B1

m	Pr(m,2112)
0	0,983481
1	0,015378
2	0,001123
3	1,7E-05
4	1E-06
5	0
6	0
7	0
8	0
9	0
10	0
11	0

m	Pr(burst of length m)
1	0,930928022
2	0,061020643
3	0,000605364
4	0
5	0
6	0
7	0
8	6,05364E-05
9	6,05364E-05
10	0
11	0
>11	0,007324899

- Data in all tables:
- P(m,n)-characteristics for frames of length 2112
- Burst length distribution
  - Normalized probability of error burst event of given length for error frames
- $2*10^9$ bits simulated for each channel at SNR that gives coded BER about $\mathbf{10^{-8}}$

Error distribution, Intel channels (2)

T12

m	Pr(m,2112)
0	0,993339
1	0,001518
2	0,004781
3	0,00028
4	7,5E-05
5	6E-06
6	1E-06
7	0
8	0
9	0
10	0
11	0

m	Pr(burst of length m)
1	0,22789371
2	0,710253716
3	0,039333433
4	0,013511485
5	0,004954211
6	0,00060051
7	0,000150128
8	0
9	0
10	0,000150128
11	0
>11	0,00315268

M20

m	Pr(m,2112)
0	0,996229
1	0,001594
2	0,002039
3	0,000108
4	2,6E-05
5	4E-06
6	0
7	0
8	0
9	0
10	0
11	0

m	Pr(burst of length m)
1	0,422699549
2	0,538053567
3	0,029965526
4	0,007159905
5	0,001325908
6	0
7	0
8	0
9	0
10	0
11	0
>11	0,000795545

Error distribution, Tyco channels

Case3

m	Pr(m,2112)
0	0,99088
1	0,005896
2	0,002988
3	0,000203
4	3,1E-05
5	2E-06
6	0
7	0
8	0
9	0
10	0
11	0

m	Pr(burst of length m)
1	0,646491228
2	0,325
3	0,021162281
4	0,002850877
5	0,000219298
6	0
7	0
8	0
9	0
10	0,000109649
11	0
>11	0,004166667

Case6

m	Pr(m,2112)
0	0,990547
1	0,004483
2	0,004148
3	0,000604
4	0,000163
5	4E-05
6	1,4E-05
7	1E-06
8	0
9	0
10	0
11	0

m	Pr(burst of length m)
1	0,474240982
2	0,436898339
3	0,062308262
4	0,015867978
5	0,004125674
6	0,001586798
7	0,000105787
8	0
9	0
10	0,000105787
11	0
>11	0,004760394

Error distribution, Molex channels

Inbound J4K4G4H4

m	Pr(m,2112)
0	0,991277
1	0,004644
2	0,003764
3	0,000242
4	6,7E-05
5	6E-06
6	0
7	0
8	0
9	0
10	0
11	0

m	Pr(burst of length m)
1	0,532385647
2	0,428866216
3	0,026940273
4	0,006534449
5	0,000573197
6	0,000114639
7	0
8	0
9	0
10	0,000114639
11	0
>11	0,004470939

Outbound J3K3G3H3

m	Pr(m,2112)
0	0,985625
1	0,008644
2	0,005329
3	0,000328
4	6,7E-05
5	6E-06
6	1E-06
7	0
8	0
9	0
10	0
11	0

m	Pr(burst of length m)
1	0,601321739
2	0,367095652
3	0,02066087
4	0,003756522
5	0,000347826
6	0,00013913
7	0
8	0
9	0
10	0,00013913
11	0
>11	0,00653913

Error distribution analysis

- Errors are not independent
  - Probability of two errors in a frame is significantly larger than squared probability of single error
- Errors are grouped into error bursts
  - Larger part of the frame is free of errors
- Error bursts of length 10 to 11 were found
  - FEC code (2112,2080) should correct error burst of 11
- DFE error propagation is an important consideration for 802.3ap channels
- Burst error correcting FEC code (2112,2080) provides 2-2.5 dB coding gain

FEC code description

- The (2112, 2080) burst error correction code is a shortened cyclic code with 32 redundant bits
  - Guaranteed errors burst length that can be corrected is t = 11 bits
  - It is a systematic code well suited for correction of the burst errors, typical in a backplane channel (Clause 69.3) resulting from DFE error propagation
  - The (2112, 2080) code was constructed by shortening of cyclic code (42987, 42955)
- Generator polynomial
  - $g(x)=x^{32}+x^{23}+x^{21}+x^{11}+x^{2}+1$
- For (2112, 2080) code
  - encoder: systematic, represented by LFSR of length 32
  - decoder: Meggitt decoder for shortened cyclic codes
  - detector: syndrome calculation
- PN-2112 bit sequence
  - Generated by scrambler polynomial from Clause 49 $r(x)= x^{58}+x^{39}+1$ with initial state of $x^{57}=1$ and $x^{i-1}=x^{i}$(XOR)1 or binary 101010….
  - For every codeword PN-2112 sequence is returned to its initial state
  - Scrambling with PN-2112 sequence is necessary to maintain DC balance and to ensure FEC block sync (ensures any shift in code word is not equal to another)

Conclusions

- The FEC code (2112, 2080) allows
  - to have ~2.0-2.5 dB TX energy gain
  - the BER to go from ~10^{-8} to 10^{-12} or better with same SNR
- 802.3ap test channels have error burst length of up to 11 bits
  - (2112, 2080) with minimum t = 11 bits is optimum code for 802.3ap channels
- Low latency
  - Encoder latency is 32 bits
  - Decoder latency is 2112+ bits (approx 200ns at 10G)
  - FEC function can be disabled to bypass decoder latency
- FEC block synchronization
  - 2112 bit block shifts will find lost sync, continuous sync monitoring during normal operation mode (uses conventional n/m serial locking techniques)
  - Required only at link start or in case of loss of connection

Summary / Proposal

- FEC allows to achieve BER objective of 10^{-12} or better on broader set of channels
- FEC provides additional margin to address manufacturing variations, PVT/environmental variations, interoperability with multi-vendor devices

Proposal

- Include Forward Error Correction (FEC) to 10GBASE-KR PHY
  - FEC sublayer between PCS & PMA (compatible to clause 49 & 51)
  - FEC is optional to implement and optional to turn it on
- Use shortened cyclic code (2112,2080) for FEC
- Auto-negotiation to advertise FEC capabilities in PHY