CEI-P FEC and 802.3ap

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Agenda

- **Overview of OIF CEI-P and its Firecode FEC**
  - Frame Format overview
  - FEC performance
  - Implementation cost
    - Gates
    - Latency/Sync Time
- **Relevance to 802.3ap**
  - Fit with 802.3 layers
  - Potential Benefits of FEC
  - Options

OIF CEI-P Frame Format [1]

T_0	64 Bit Payload Word 0	T_1	64 Bit Payload Word 1	T_3	64 Bit Payload Word 2	S_0
T_3	64 Bit Payload Word 3	T_4	64 Bit Payload Word 4	T_5	64 Bit Payload Word 5	
T_6	64 Bit Payload Word 6	T_7	64 Bit Payload Word 7	T_8	64 Bit Payload Word 8	S_1
T_9	64 Bit Payload Word 9	T_{10}	64 Bit Payload Word 10	T_{11}	64 Bit Payload Word 11	
T_{12}	64 Bit Payload Word 12	T_{13}	64 Bit Payload Word 13	T_{14}	64 Bit Payload Word 14	S_2
T_{15}	64 Bit Payload Word 15	T_{16}	64 Bit Payload Word 16	T_{16}	64 Bit Payload Word 17	
T_{18}	64 Bit Payload Word 18	T_{19}	64 Bit Payload Word 19	T_{20}	64 Bit Payload Word 20	S_3
T_{21}	64 Bit Payload Word 21	T_{22}	64 Bit Payload Word 22	T_{23}	64 Bit Payload Word 23	
20 Overhead Bits : Oh[19:0]						

Frame length = 1584 bits

- T_n= Transcode bit for 64bit payload word n – Allows 65b64 or 10GBASE-R transcoding
- S_{0-3} = Supervisory channel – Allows a telecom-style serial management channel
- Oh[19:0] = Firecode[19:0] xor State[2:0] – Provides optional FEC
- All of packet is scrambled with a free-running ($X^{17} + X^{14} + 1$) Scrambler
- Firecode generator polynomial $g(x) = (X^{13} + 1)(X^7 + X + 1)$
- Firecode is calculated over scrambled packet, then is itself scrambled
- CEI-P frame has exactly the same overhead as 64b66 encoding

CEI-P Firecode performance calculation

- **The CEI-P firecode provides correction for a single 1 to 7bit burst error in each 1584 bit frame [2].**
  - A Firecode was specifically chosen by CEI-P to address DFE error multiplication
- **The corrected BER can be found by considering the probability of frames with 2 or more burst errors**
  - The probability of n errors in a 1584 bit frame = $(BER^n)*1584!/((1584-n)! * n!)$
  - .. Ignoring n>2, probability of an uncorrectable frame = $(BER^2)\ (1584*1583)/2$
- **If a frame contains 2 or more separate bursts, then the errors are uncorrectable, and there is a 1 in 10 probability that 1-7 valid bits may be modified in error.**
  - The unwanted correction is a 7 bit mask but only bits that are a 1 are altered, so on average 4 additional bits are corrupted per frame
  - Therefore, on average an uncorrectable frame contains 2+4/10 = 2.4 errors
- **The corrected BER = (probability of uncorrectable frame)*(# of errors in frame)/1584**
  - = (probability of Uncorrectable frame)*2.4/1584
  - = $(2.4/1584)*(BER^2)*(1584*1583)/2$
  - = $2.4*1583/2*(BER^2)$
- **Corrected_BER ~= $1900*(BER^2)$**

CEI-P Firecode FEC BER performance

- **BER Corrected_BER**

BER	Corrected_BER
10-6	0.19*10-8
10-7	0.19*10-10
10-8	0.19*10-12
10-9	0.19*10-14
10-10	0.19*10-16
10-11	0.19*10-18
10-12	0.19*10-20
10-13	0.19*10-22

- **For a thorough BER analysis that includes DFE/Firecode interactions, refer to Jim Hamstra's OIF contributions on the subject [3] & [4].**
  - Results are at least an order of magnitude better than above.

CEI-P Firecode FEC costs

- **Firecode protected frames can be corrected using simple error trapping [2].**
  - Parallel implementations are practical and efficient at 10G data rates.

- **Area for a 33bit wide datapath**
  Transmit framer/coder : 3K gates @312.5Mhz
  Rx Sync : 4K gates @ 312.5Mhz
  Rx Error correction : 6K gates + 48x33 dual port RAM @ 312.5Mhz
  Rx deframer : 1K gates

  Total Rx/Tx = 14K gates + 48x33 dual port RAM @ 312.5Mhz

- **Latency**
  1584+ bits latency

- **Sync time**
  ~500us worst case (without parallel sync engines)
  - Two 1584 frames to parse at all 1584 possible frame starts ($= 2*1584^2 * 1E^{-10}$)
  - Presumes no errors

Relevance to 802.3ap

- **The CEI-P FEC could be applied to 802.3ap**
  - Re-use/reference CEI-P protocol
  - Create our own using similar techniques

Fit with 802.3 layering

- **CEI-P or a similar frame could form a FEC sub-layer below the 10GBASE-R PCS (clause 49) in a similar manner to the WAN Interface Sublayer (Clause 50)**
  - 10GBASE-R Sync bits would be collapsed into a single T bit
  - Provides full 10G data-rate, So no data-rate throttling would be needed, unlike WIS
  - May be possible to spoof existing BER monitor by corrupting Sync bits
- **10GBASE-R Latency : clause 49.2.15 states**
  - "The sum of transmit delay contributed by a 10GBASE-R PCS shall be no more than 3584 BT."
  - This compares well with the frame delay required for error correction of 1584 BT.
  - It should be practical to meet this requirement with a combined 10GBASE-R PCS & FEC sub-layer.

Benefits to 802.3ap

- **Ethernet BER objective of 10^{-12} could be achieved with a 10^{-8} channel**
- **Channels meeting the Ethernet BER objective of 10^{-12} could provide an effective BER of 10^{-20}**
- **Is this a way to reconcile the contradictory channel expectations within the TF ?**
  - Ethernet system vendors with legacy backplanes happy with Ethernet BERs
  - Datacomm backplane users with 10^{-18} BER expectations
- **CEI-P supervisory channel (S-bits) could be used as a back channel for adaptive Tx equalization**
  - OIF have already discussed a scheme for this

Options

- **Select FEC support by AN**
  - Advertise sublayer support as an AN option
- **Engage/disengage FEC error correction based on channel BER**
  - Allows good channels to remove correction latency

References

[1] Optical Internetworking Forum, oif2004.229.06, *Common Electrical I/O – Protocol (CEI-P) Implementation Agreement*, January 2005

[2] S. Lin and D. Costello, *Error Control Coding : Fundamentals and Applications,* Prentice Hall, Englewood Cliffs, New Jersey 1983

[3] Jim Hamstra, *Effect of DFE Error propogation on FEC,* oif2003.267.02

[4] Jim Hamstra, *Firecode Performance,* oif2003.383.00

Summary

- A lightweight Firecode FEC can be implemented at low cost for 10G rates
- For BER's above 10^{-8} a Firecode FEC can provide substantial gains in payload BER
- A CEI-P like frame could be used as a WIS-like sublayer below 10GBASE-R

Backup foils

Firecode Entropy Calculations

- **The entropy of the error location is approx 10.63 bits + 6 more bits to extend burst to 7 bits = 16.63 bits - 2 $^{-(20 - 16.63)}$ = 10.34^{-1} which is probability of mis-correction in presence of arbitrary random error pattern.**
  - log2 of 1584 = 10.63 bits to locate first errored bit, plus 6 additional error mask bits = 16.63 bits = total correction entropy
  - Total length of Fire Code polynomial = 20 bits - 16.63 bits entropy = 3.37 bits = guard band against mis-correction
    - This is the combination of low probability of pointing beyond end of block for first error plus higher probability of more than 7 bit span in correction mask - both of the above indicate uncorrectable errors