The impact of DFE on CAUI-4 MTTFPA

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Introduction

If a DFE is assumed to be part of the receiver for CAUI-4 chip-to-chip (C2C), then the probability of burst errors is much greater than for receivers that do not employ DFE. The likely presence of burst errors would call in to question the mean time to false packet acceptance (MTTFPA) performance of a link using CAUI-4.

Because of this, the reference receiver assumed for CAUI-4 C2C in P802.3bm D1.1 employs a CTLE but no DFE.

However, there has been discussion within the P802.3bm Task Force and the CAUI-4 Ad Hoc suggesting that the restriction in performance due to assuming a CTLE only reference receiver severely restricts the broad market potential of the CAUI-4 C2C solution.

This presentation attempts to analyse the impact of a DFE in the CAUI-4 C2C receiver on the MTTFPA performance.

CRC32 and 100GbE 64B/66B PCS

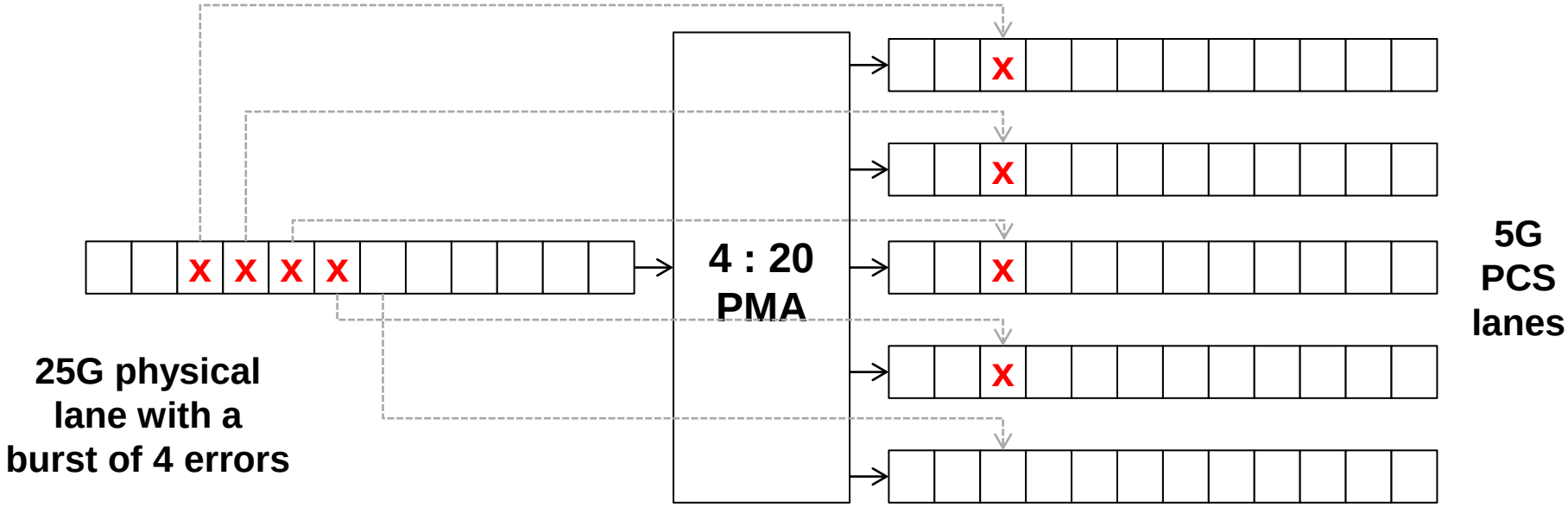
- Ethernet's CRC32 has the following error detection capability
  - All 1, 2 or 3 bit errors are detected
  - All bursts up to 32 bits
  - All double bursts up to 8 bits
  - The above is true for at least up to 9k frames
- For the 100GBASE-R scrambler, single bit errors become 3 bit errors - this was shown to not degrade the error detection capability of the IEEE CRC32 for 10GBASE-R
  - No CRC degradation occurs if the CRC and the scrambler polynomial do not share common factors
  - IEEE CRC32 has no common factors with the X^58 scrambler
  - If the original errors can be detected, then the multiplied errors are also detectable
- For additional background on the CRC32 detection properties and MTTFPA see: gustlin_02_0308, gustlin_04_0509 from IEEE P802.3ba
- But the 100GbE PMA does bit muxing to form physical lanes which impacts the MTTFPA

Burst error model

- For the analysis of MTTFPA for 40GBASE-CR4 and 100GBASE-CR10 performed in gustlin_02_0308 and gustlin_04_0509 an assumption was made that DFE might be used in the receiver. This makes the likelihood of burst errors much greater than that for receivers without DFE.
- The burst error probability was modeled on the assumption that the probability of getting an error in the bit following an initial error (a burst size of 2) is “a”, the probability of a burst of 3 is a^2, the probability of a burst of 4 is a^3, and so on. For the analysis in gustlin_02_0308 and gustlin_04_0509 the value of “a” assumed was approximately 0.1.
- The curves of probability vs burst length on slides 11 to 13 of liu_01_1105 from IEEE P802.3ap confirm that this is a reasonable model to use with the values of “a” varying from about 0.001 at the lowest to about 0.44 at the highest.

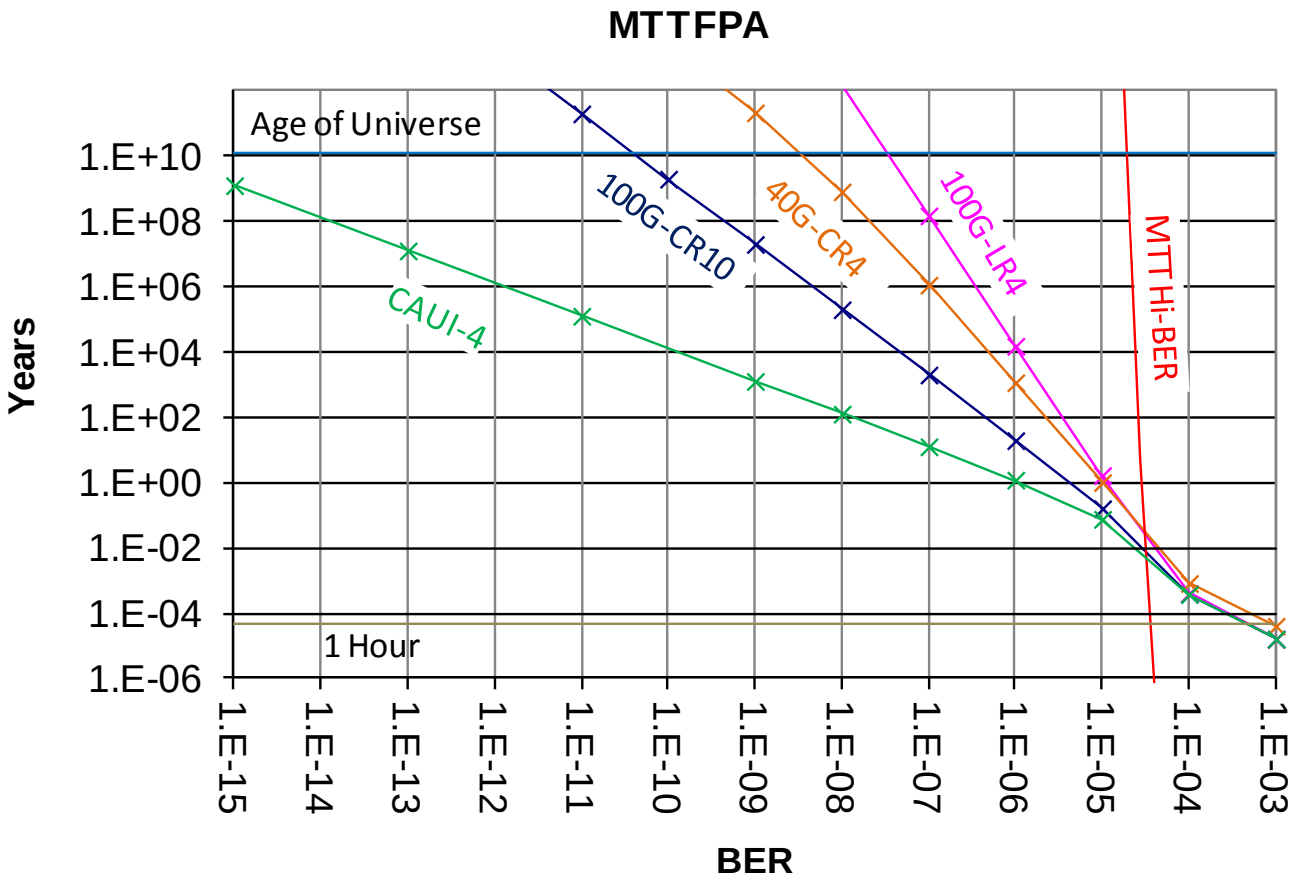
Error patterns not 100% detectable

- If the CAUI-4 25G lanes are carrying RS-FEC encoded data then the MTTFPA calculations have already been done in the P802.3bj project and measures are in place to ensure adequate performance.
- If the CAUI-4 25G lanes are carrying 64B/66B encoded data then each CAUI-4 physical lane is composed of five bit-interleaved PCS lanes. This means that a burst of four errors on a physical lane turns in to four separate error events in the PCS.



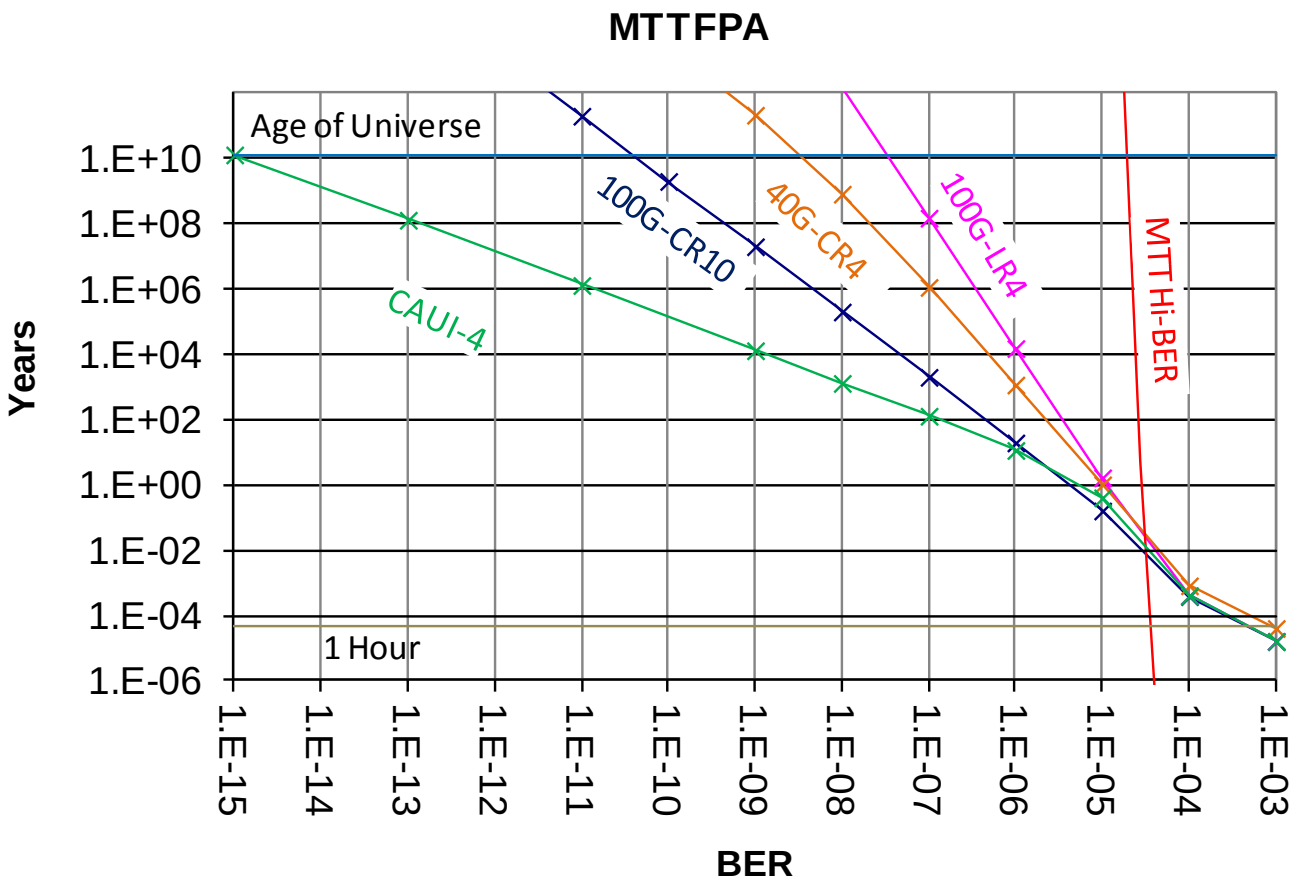
MTTFPA for a = 0.1

- For double and triple bursts, the same limiting cases as for 100GBASE-CR10 apply: 2 x burst of 2, 1 x burst of 2 and 2 separate errors respectively. If we assume a = 0.1 as per the 100GBASE-CR10 analysis we get:



MTTFPA for a = 0.046

- If we set the value of “a” such that the MTTFPA is the age of the universe for a BER of 1E-15, then we need a probability of a burst of 4 of 0.0001 which is equivalent to a = 0.046. This changes the curve to:



How do we constrain the value of “a”

- The worst value of “a” among the curves in liu_01_1105 from IEEE P802.3ap is about 0.44 which would result in a MTTFPA that is a factor of 1000 below the age of the universe.

- If we assume the use of a DFE for CAUI-4 C2C to improve its performance and want to preserve a MTTFPA of the age of the universe, then it would be useful to establish a method of constraining the DFE such that the probability of an initial error becoming a burst of 4 or more errors is less than 0.0001 ($a < 0.046$).

- The next slide starts to look at the relationship between the tap weight of a single tap DFE and the probability of a successive error.

Relationship between DFE tap weight and “a”

- For a 1-tap DFE the probability of a successive error can be modeled as [1]:

$$P_{se} = \frac{1}{4}\left[\operatorname{erfc}\left(\frac{\left(1+\frac{2b_1}{b_0}\right)Q}{\sqrt{2}}\right) + \operatorname{erfc}\left(\frac{\left(1-\frac{2b_1}{b_0}\right)Q}{\sqrt{2}}\right)\right] \quad \text{and} \quad Q = \sqrt{2}\times \operatorname{erfc}^{-1}(2\times BER)$$

Where:

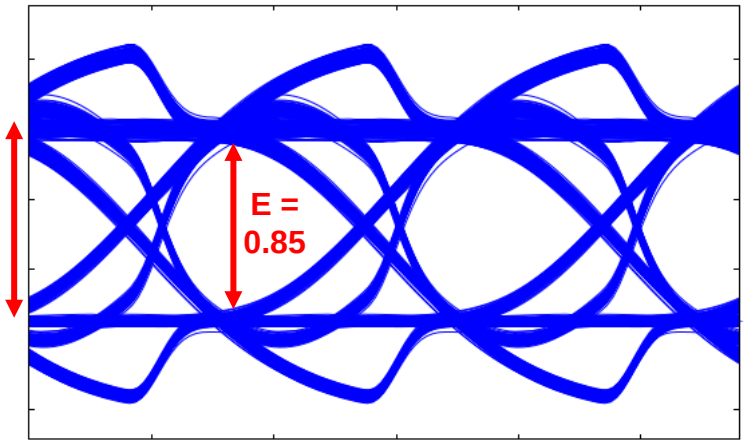
P_{se}	is the probability of error in the bit following an initial errored bit
b_1/b_0	is the ratio of the DFE tap to the main tap
BER	is the overall bit error ratio

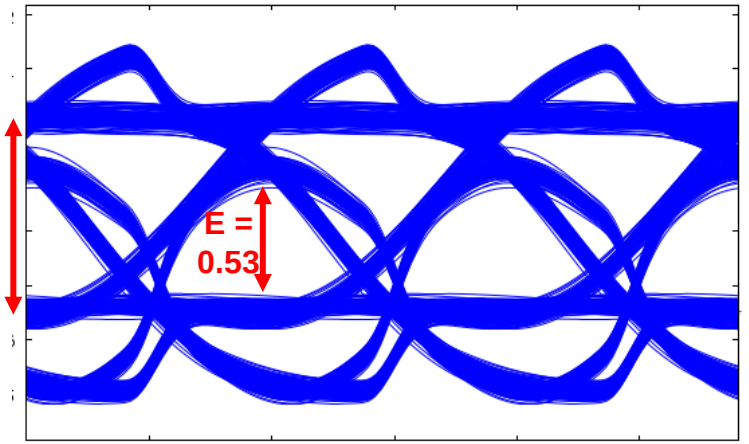
This function gives $b_1/b_0 = 0.4164$ for $P_{se} = 0.046$

[1] C. Liu, P. Aziz, A. Healey, “Enhanced Equalization and Forward Correction Coding Technologies for 25+Gb/s Serial Link System”, DesignCon 2012, February 2012

Equalized eye closure

However, this function assumes that the equalised eye is fully open (except for noise) as per the eye on the left. If the equalised eye is not fully open, as on the right, then the effective offset in the decision point will have a larger effect on the probability of a subsequent error than the formula predicts.





To account for this we can modify the formula to include an eye closure term (E) as below:

$$P_{se} \approx \frac{1}{8}\left[\operatorname{erfc}\left(\frac{\left(1+\frac{2b_1}{b_0}\times\frac{1}{E}\right)Q'}{\sqrt{2}}\right)+\operatorname{erfc}\left(\frac{\left(1-\frac{2b_1}{b_0}\times\frac{1}{E}\right)Q'}{\sqrt{2}}\right)\right] \quad \text{and} \quad Q' = \sqrt{2}\times\operatorname{erfc}^{-1}(4\times BER)$$

Conclusions

In order for the CAUI-4 C2C MTTFPA to be greater than the age of the universe, the probability of an initial error becoming a burst of 4 or more errors must be less than 0.0001.

Even for a single tap DFE the burst error probability is dependent not only on the relative tap weights, but also on the degree of closure of the equalized eye, which in turn depends on the characteristics of the channel.

Thanks!