

400GbE BER Objective from the Perspective of MTTFPA

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August 2013

www.huawei.com

Motivation

- There are discussions on defining a better BER specification for 400GbE MAC/PLS service interface.
- FEC is likely to be an integral part of 400GbE standard.
- We analyze how BER affects the MTTFPA when RS-FEC is used.
- We analyze if it is difficult to achieve a better BER specification when RS-FEC is used.

Estimate MTTFPA from UCR

- Assume RS-FEC(528,514) is used which can correct up to 7 symbols in a codeword.
- Any uncorrectable codeword must have at least 8 symbol errors.
- Ethernet's CRC32 has the following error detection capability:
 - All 1, 2 or 3 bit random errors;
 - All burst errors of length up to 32 bits;
 - All two burst errors of length up to 8 bits;
 - The above is true for at least 9k-byte frames;
- So, in the worst case (or approximately worst case) , all of 8 symbol errors of an uncorrectable codeword belong to one packet (assuming a 640Byte(~5140bit) packet which exactly occupies one codeword), the CRC32 may fail to detect this false packet.
- This leads to MTTFPA calculation:

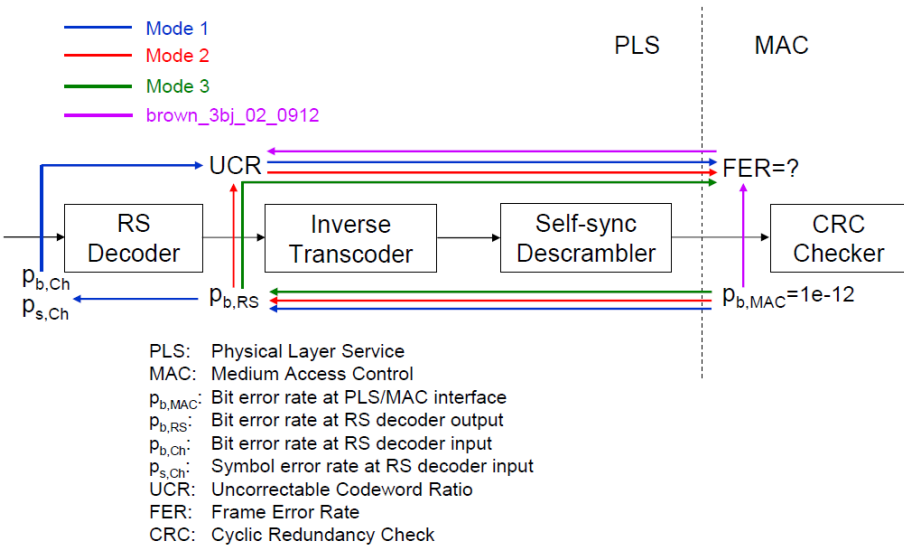
$$MTTFPA > 2^{32} \left(\frac{t_{bit} P}{UCR} \right) \quad (t_{bit} \text{ is bit time } 2.5ps \text{ for } 400GbE, P \text{ is packet size})$$

Estimate MTTFPA from UCR (Cont'd)

- We assume RS-FEC only corrects up to 7 error symbols but does not label codeword with more than 7 detected errors as in 802.3bj.
 - Our analysis would need change if FEC labels codeword with detected errors.
- Is UCR the worst for the 640Byte packet stream?
 - When packet size is greater than 640B, all 8 symbol errors may happen to a single packet and make it a false packet to CRC32; Otherwise when 8 erroneous symbols exists in two adjacent packets, it will cause one or both packets to fail CRC32 error detection.
 - When packet size is less than 640B, let's say 160B, perhaps multiple packets collapse with one FEC codeword error, and thus generate a “worse” worst case. But this is not a significant factor in MTTFPA calculation, even without considering the probability of error distribution.
 - For smallest Ethernet packet(64Byte), it may contain 0 to 8 symbol errors, with respective probability. MTTFPA performance would also be better or close to 640B packet case.
- We suggest to use UCR with 640B packet to calculate the worst MTTFPA for FEC-enabled architecture.

Compute UCR from BER at the MAC/PLS Service Interface

Methodology to Compute FER



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Frame Error Rate

4

Mode 1

NBF: Number of octets per MAC frame

NBC: Number of octets per RS codeword

RS(n,k) code with error correction capability t and symbol size m

100GBASE-KR4 and 100GBASE-CR4 employ RS(528,514), t=7 and m=10 code

100GBASE-KP4 employs RS(544,514), t=15 and m=10 code

$$p_{b,RS} = \frac{p_{b,MAC}}{3}$$

$$p_{b,RS} = \frac{2^{m-1}}{2^m - 1} \sum_{i=t+1}^n \frac{i}{n} \binom{n}{i} p_{s,Ch}^i (1 - p_{s,Ch})^{n-i} \quad \text{Compute } p_{s,Ch} \text{ such that } p_{b,RS} = \frac{1e-12}{3}$$

$$UCR = \sum_{i=t+1}^n \binom{n}{i} p_{s,Ch}^i (1 - p_{s,Ch})^{n-i}$$

$$FER = UCR \left(1 + \frac{NBF}{NBC} \right) \quad \text{Relationship between FER and UCR derived in brown_3bj_02_0912}$$

IBM

Frame Error Rate

5

- There are several existing methods to calculate UCR based on BER at the MAC/PLS service interface.
 - **refer to cideciyan_3bj_01a_0912.pdf**
- Mode1 is dedicated to the architecture with mandatory FEC.

UCR Calculation

- Assume RS-FEC(528,514) in the following formulas:

$$P_{b,RS} = \frac{P_{b,MAC}}{3}$$

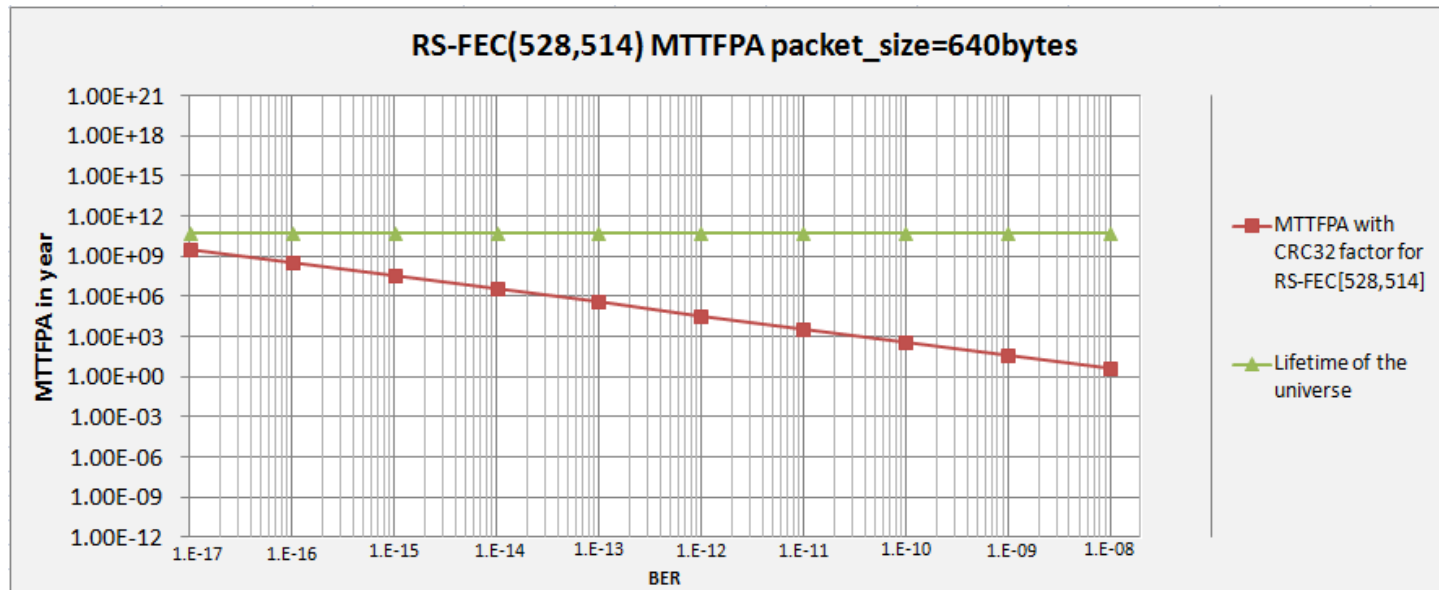
$$P_{b,RS} = \frac{2^{m-1}}{2^m - 1} \sum_{i=8}^{528} \frac{i}{528} C_{528}^i (p_{s,Ch})^i (1 - p_{s,Ch})^{528-i}$$

$$UCR = \sum_{i=8}^{528} C_{528}^i (p_{s,Ch})^i (1 - p_{s,Ch})^{528-i}$$

- We can get the UCR:

$$UCR = \frac{P_{b,RS}}{\left(\frac{2^{m-1}}{2^m - 1} * \frac{i}{528}\right)} = \frac{P_{b,MAC}}{3 * \left(\frac{2^{m-1}}{2^m - 1} * \frac{i}{528}\right)}, (i = 8) \approx 44P_{b,MAC}$$

MTTFPA & BER for 400GbE



- Using RS-FEC(528,514) as an example, we can calculate MTTFPA based on UCR for 640B packet.

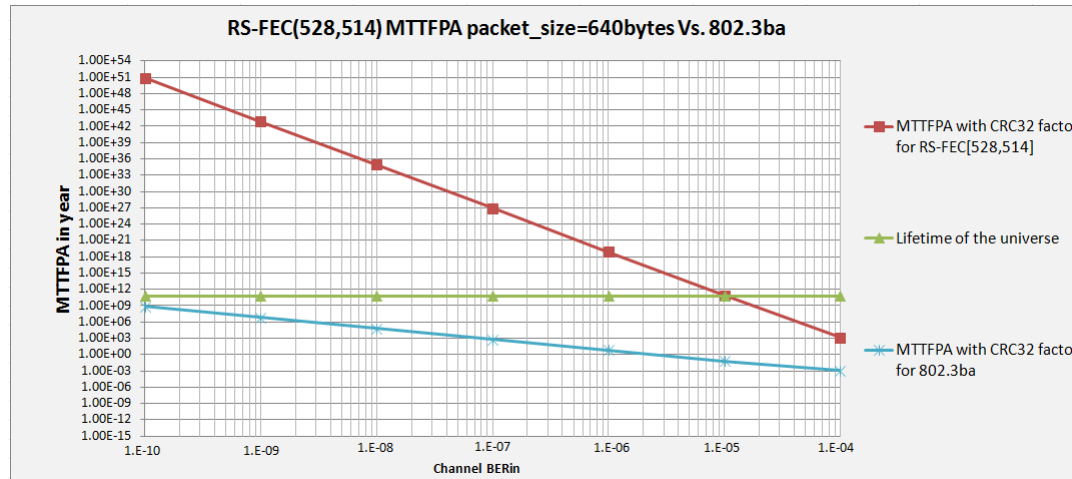
- We can see:

	$P_{b,MAC} 1e-12$	$P_{b,MAC} 1e-15$
MTTFPA	3.96e+4	3.96e+7

- BER($P_{b,MAC}$) 1e-15 can improve the MTTFPA by 1000 times.

Compute MTTFPA from Channel Input BER

- Furthermore, we can compute UCR/MTTFPA from input BER before FEC decoder, for each channel.
- To get a MTTFPA greater than 1e+10 years, the $SER_{in}(P_{s,ch})$ must be lower than 7.68e-5, which implies that the MAC BER should be lower than 3.84e-18.
- The protection mechanism is needed to ensure when the link quality become worse than this, it would still satisfy the MTTFPA.



$P_{b,MAC}$	$P_{s,Ch}$	$P_{b,Ch}$	$MTTFPA$
1e-12	3.75e-4	3.75e-5	3.96e+4
1e-15	1.16e-4	1.16e-5	3.96e+7
3.84e-18	7.68e-5	7.68e-6	1e+10

Is BER 1E-15 A Reasonable Requirement?

Schemes	Output BER / SNR (dB)	Input BER / SNR (dB)	Net Coding Gain(dB)
RS(528,514) for NRZ	1 e-12 / 16.9446	5.2669e-5 / 11.7721	5.1725
	1e-15 / 17.9979	2.1802e-5 / 12.2292	5.7687
RS(544,514) for PAM4	1 e-12 / 23.9343	3.6384e-4 / 17.5653	6.3690
	1 e-15 / 24.9876	2.2614e-4 / 17.8897	7.0979

Refer to [zhai_400_01_0713.pdf](#)

Based on random error model and for optical link only

- From the above analysis, only x2 improvement on the input BER will result in x1000 improvement on the output BER.
- If FEC is used, it is not difficult to modify the MAC/PLS service interface BER requirement to 1e-15.
- It is good for user perception and MTTFPA.

Summary

- We propose a method to estimate MTTFPA based on FEC UCR.
- 400GbE BER objective would be more demanding as calculated in this contribution. We may consider improvement in the following aspects:
 - Higher BERin required;
 - FEC correct and mark errors as FEC mode A described in 802.3bj Draft1.3;
 - Other protection methods;

Thank you