

BER and FER for 100GBASE-SR4

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Introduction

There is a growing consensus that the specification for 100GBASE-SR4 (proposed to fulfil the IEEE P802.3bm objective to “Define a 100 Gb/s PHY for operation up to at least 100 m of MMF”) should include mandatory FEC.

The FEC scheme that has been widely proposed for this is the RS(528,514) scheme defined in Clause 91 of IEEE P802.3bj D 1.2 for 100GBASE-CR4/KR4 which has a symbol size m of 10 bits and a symbol correction ability t of 7 symbols.

This contribution is aimed at defining what bit error ratio (BER) would be required at the FEC decoder input to meet the objective of “Support a BER better than or equal to 10^{-12} at the MAC/PLS service interface”

100GBASE-CR4/KR4/KP4 BER

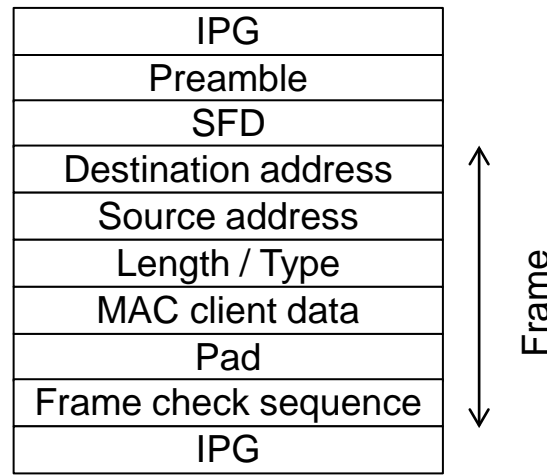
The performance targets for 100GBASE-CR4 in Clause 92, 100GBASE-KR4 in Clause 93 and 100GBASE-KP4 in Clause 94 of IEEE P802.3bj D 1.2 are:

- BER at the PMA service interface should be less than 10^{-5}
- “For a complete Physical Layer, this specification is considered to be satisfied by a frame error ratio less than 1.7×10^{-10} for 64 octet frames with minimum inter-packet gap.”

However, the PMDs mentioned above are expected to operate with a significant occurrence of burst errors due to the equalisation employed in their receivers, which is not expected to be the case for 100GBASE-SR4.

Size of MAC frames and FEC codewords

A MAC frame starts with the Destination Address and ends with the frame check sequence. These bits are preceded by the interpacket gap (IPG), 7 octets of preamble and 1 octet of start-of-frame delimiter (SFD).



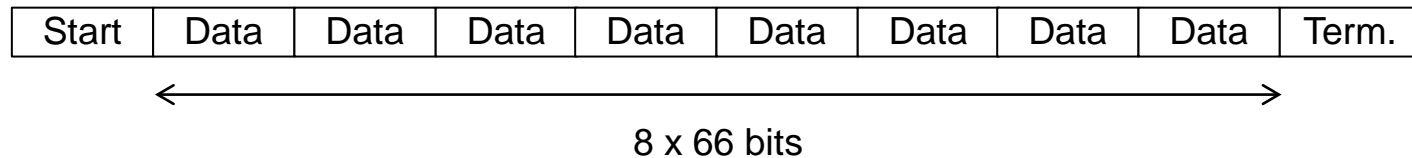
The first octet of the preamble is mapped to a start control character by the RS and is always aligned to the start of a 64-bit block.

Consequently, a 64 octet frame will be encoded as a Start 64-bit block (which contains the Preamble and SFD), followed by eight 64-bit blocks containing the MAC frame, followed by a Terminate 64-bit block containing 7 Idle control characters – 10 64-bit blocks in all with minimum interpacket gap.

The Clause 91 FEC codeword contains eighty 64-bit blocks.

Errors causing a frame to be dropped

As described on the previous slide, a 64 octet MAC frame with minimum interpacket gap after 64B/66B coding is a Start block, 8 data blocks and a terminate block.



According to the definition of “R_TYPE” in 82.2.18.2.3, Start is recognised as “a sync header of 10 and a block type field of 0x78” and Terminate is recognised as “a sync header of 10, a block type field of 0x87, 0x99, 0xAA, 0xB4, 0xCC, 0xD2, 0xE1 or 0xFF and all control characters are valid”

Therefore, with 64B/66B coding a frame will be dropped if there is an error in 8 x 66 bits for the data blocks + 10 bits in the Start block + 66 bits for the terminate block = 604 bits. Because of the error multiplication in the descrambler, it will also be dropped if there were errors in any of the preceding 58 bits, making a total of 662 bits that must be correct at the descrambler input per frame.

Bad Mac frames per bad FEC codeword

If a FEC codeword is uncorrectable and marked as bad, this will affect all of the 64 octet frames that are wholly or partially contained in the FEC codeword.

There are two cases to consider:

If the first 64-bit block of the FEC codeword is a Start block. Here the FEC codeword contains exactly 8 MAC frames with minimum IPG. But, there may be errors in the last 64-bit block of the codeword and the error multiplication of the de-scrambler will sometimes cause errors in the first 64-bit block from the next codeword, resulting in 9 affected MAC frames.

If the first 64-bit block is not a Start block, then the FEC codeword will overlap with parts of 9 MAC frames. In this case there will be at least one 64-bit block with no uncorrected errors at the end of the last affected MAC frame, so the error multiplication of the de-scrambler will not affect the next frame, resulting in 9 affected MAC frames.

The result of this is that:

$$\text{FER} = \text{CER} * (1 + 1/8) = \text{CER} * 1.125 \quad (1)$$

Where FER is the MAC frame error ratio and CER is the FEC codeword error ratio. This equation is in accordance with the relationship between FER and CER derived in slide 7 of [brown_3bj_02_0912](#)

FEC equations

RS(528,514), $m = 10$, $t = 7$ FEC corrects 7 or less symbol errors in a FEC codeword, so when uncorrected errors appear, there are 8 or more uncorrected symbols in the output FEC codeword.

If the input BER is BER_{in} , then the input symbol error ratio (or the probability that an input symbol contains errors) SER_{in} is given by:

$$SER_{in} = 1 - (1 - BER_{in})^{10} \approx 10 \times BER_{in} \text{ (for small } BER_{in}) \quad (2)$$

The codeword error ratio (the probability of an uncorrectable FEC codeword) is:

$$CER = \sum_{i=8}^{528} \binom{528}{i} SER_{in}^i (1 - SER_{in})^{528-i} \quad (3)$$

The output SER (probability that a symbol is not corrected) and BER are:

$$SER_{out} = \sum_{i=8}^{528} \frac{i}{528} \binom{528}{i} SER_{in}^i (1 - SER_{in})^{528-i} \quad (4)$$

$$BER_{out} = SER_{out} \times \frac{BER_{in}}{SER_{in}} \approx \frac{SER_{out}}{10} \text{ (for small } BER_{in}) \quad (5)$$

Calculation options 1

- A) Base the calculation on a BER in to BER out through the processing. Using equations 2, 4 and 5, and accounting for the 3 x error multiplication in the de-scrambler a BER_{out} of 10^{-12} is a BER after FEC correction of 3.33×10^{-13} which requires a BER_{in} = **4.57E-5** which is a Q of 3.91 and $10\text{Log}(Q_o/Q_i) = \text{2.55 dB}$
But this ignores uncorrectable FEC codewords being marked as bad.
- B) Base the frame error ratio (FER) calculation on the probability a MAC frame is dropped for standard 64B/66B coding. If the errors are distributed randomly, then the FER is given by:

$$\text{FER} = 10^{-12} \times \text{size_of_bits_must_be_correct} \quad (6)$$

So, for the slide 5 frame (662 bits), $\text{FER} = 10^{-12} \times 662 = 6.62 \times 10^{-10}$

Using equations 2, 3 and 1 for $\text{FER} = 6.62 \times 10^{-10}$ requires a BER_{in} = **5.19E-5** which is a Q of 3.88 and $10\text{Log}(Q_o/Q_i) = \text{2.58 dB}$

Calculation options 2

- C) Base the frame error ratio (FER) calculation on the probability a MAC frame alone contains errors for standard 64B/66B coding. If the errors are distributed randomly, then the FER is given by:

$$\text{FER} = 10^{-12} \times \text{size_of_frame} \quad (7)$$

So, for a 64 octet frame (512 bits), $\text{FER} = 10^{-12} \times 512 = 5.12 \times 10^{-10}$

Using equations 2, 3 and 1 for $\text{FER} = 5.12 \times 10^{-10}$ requires a $\text{BER}_{\text{in}} = 5.02\text{E-}5$ which is a Q of 3.89 and $10\text{Log}(Q_0/Q_i) = 2.57 \text{ dB}$

- D) Equation 1 takes “with minimum inter-packet gap” to mean after any idle characters that can be deleted have been. If, alternatively, it is taken to mean that the 96 bit interpacket gap from Table 4-2 is preserved on average, then equation 1 changes to:

$$\text{FER} = \text{CER} * (1 + 84/640) = \text{CER} * 1.13125$$

However, this is a small change and none of the results for options B or C changes.

800 octet frames

Basing the calculation on 800 octet frames as per 10GBASE-T, equation 7 gives an FER of 6.4×10^{-9} . Equation 1 becomes:

$$\text{FER} = \text{CER} * (1 + 816/640) = \text{CER} * 2.275$$

Equations 2 and 3 for FER = 6.4×10^{-9} requires a $\text{BER}_{\text{in}} = 6.36\text{E-}5$ which is a Q of 3.83 and $10\text{Log}(Q_0/Q_i) = 2.64 \text{ dB}$

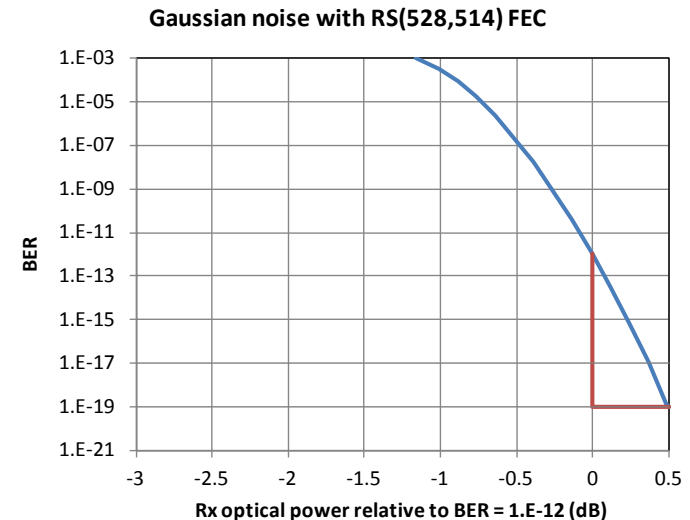
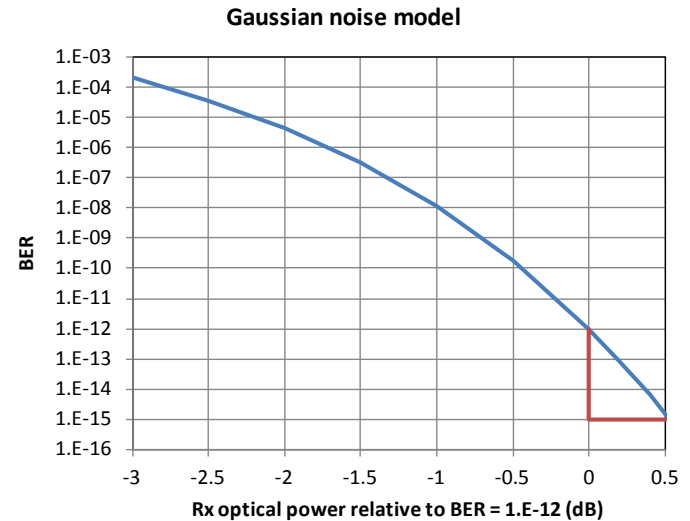
This is an improvement of 0.07 dB over the result of option C, but is much less defensible as minimum size frames will give a worse result.

It seems better to stay with 64 octet frames (the smallest allowed) and accept the 0.07 dB reduction in performance.

The effect of FEC on margin

For a receiver limited by Gaussian receiver noise, a margin of ≈ 0.5 dB is required to give a BER of $1E-15$ rather than the spec limit of $1E-12$.

With the addition of RS(528,514) FEC, the same 0.5 dB margin takes the BER from $1E-12$ to $\approx 1E-19$



Conclusion

All three calculation options A, B and C give similar results with only 0.03 dB between them.

Option A ignores uncorrectable FEC codewords being marked as bad.

Between options B and C, B seems more correct as even with 64B/66B coded data, frames containing errors are dropped rather than being passed through with errors.

Between options B and C, C is very slightly more conservative so it is proposed to base the 100GBASE-SR4 requirements (if the RS(528,514) scheme defined in Clause 91 of IEEE P802.3bj is adopted) on:

- BER at the PMA service interface should be less than 5×10^{-5}
- “For a complete Physical Layer, this specification is considered to be satisfied by a frame error ratio less than 5.12×10^{-10} for 64 octet frames with minimum inter-packet gap.”

Thanks!