Achieving BER/FLR targets with clause 74 FEC

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Frame Loss Ratio

- 802.3by objective: **Support a BER of better than or equal to 10^{-12} at the MAC/PLS service interface (or the frame loss ratio equivalent)** (P802_3by_Objectives)
- What is the frame loss ratio equivalent?
- 802.3bj and 802.3bm specified frame loss assuming 64-octet MAC frame with minimum inter-packet gap. After 64B/66B coding, this consists of a start block, 8 data blocks and a terminate block. The total PCS data size is 10 blocks.

Start	Data	Data	Data	Data	Data	Data	Data	Data	Term

- With 64B/66B coding, a frame will be dropped if there is an error in 8 × 66 bits for the data blocks + 10 bits in the Start block + 66 bits for the terminate block = 604 bits. Because of error multiplication effect of the descrambler, a total of 620 bits must be correct at the descrambler input per frame. (anslow_01a_1112_mmf)

Frame Loss Ratio

- A frame containing any errors on the 620 “bits that must be correct” is dropped, so for BER=10^{-12}, the frame loss ratio is:

$$FLR = 620 \times 10^{-12} = 6.2 \times 10^{-10}.$$

- With FEC, assuming any uncorrectable codeword is marked as bad, all packets contained in this codeword are dropped. In addition, the packet after this codeword may also be corrupted due to scrambler error multiplication. Therefore codeword error ratio is (brown_3bj_02_0912):

$$CER = FLR/(1+MAC\_Frame\_Size/Codeword\_Size)$$

- Clause 91 RS-FEC contains 80 64-bit blocks. Therefore, the requirement is $CER=FLR/(1+10/80)=0.89 \times FLR=5.52 \times 10^{-10}$.

- Clause 74 FEC contains 32 64-bit blocks. Therefore, the requirement is $CER=FLR/(1+10/32)=0.76 \times FLR=4.71 \times 10^{-10}$.

DFE Error Propagation

- DFE error propagation can cause a single random error to become a long burst, which can severely impact FEC error correction capability.
- A simple assumption is the Gilbert model ([1], cideciyan_02a_1111) with parameter *a*. Under this model, the probability of having a burst longer than L is

$$P(\text{burst longer than L}) = \text{BER} \times a^{L}$$

This model is representative of a DFE with a single tap or one dominant tap. For PAM-2, $0 \leq a \leq 0.5$ is the BER assuming a previous decision was wrong.

- For a longer DFE, a more complex analysis is required. For example, 5-tap DFE error propagation effect for different channels has been studied in liu_01_1105.
- The COM tool (originally developed for 802.3bj) performs calculation of burst probabilities according to assumed DFE taps and noise distributions. (developed for CAUI-4 in 802.3bm)

[1] E. N. Gilbert (1960), "Capacity of a burst-noise channel", Bell System Technical Journal 39: 1253–1265.

DER target for Clause 74 FEC

- Clause 74 FEC is binary burst error correction code (2112,2080). It corrects a single burst up to 11 bits.
- Uncorrectable codewords are mainly caused by either two uncorrelated errors anywhere (almost) in the codeword (denoted 2E), or a burst longer than 11 bits (denoted 1E/11P). Assuming the Gilbert model with parameter *a*, for a codeword of length 2112, CER can be determined from the detector error ratio (DER):

$$CER = \binom{2112}{2} DER^2 + 2112 \cdot a^{11} \cdot DER \approx \frac{(2112 \cdot DER)^2}{2} + 2112 \cdot a^{11} \cdot DER$$

- For a given FLR target and the calculated CER, the DER requirement can be extracted:
  - When $DER \ll \frac{2}{2112} a^{11}$, 1E/11P is more probable than 2E, $CER \approx 2112 \cdot a^{11} \cdot DER$, and the requirement becomes: $DER < \frac{CER}{2112 \cdot a^{11}}$.
  - When $DER \gg \frac{2}{2112} a^{11}$, 2E is more probable than 1E/11P, $CER \approx \frac{(2112 \cdot DER)^2}{2}$, and the requirement becomes: $DER < \frac{\sqrt{2 \cdot CER}}{2112}$.
  - An equivalent expression for the tipping point is $0.5 \cdot CER \gtrless 2a^{2 \cdot 11}$ (when 50% of the codeword errors are caused by error propagation).
- The effect of *a* and DER on CER is shown on the next slide.

DER Target for Clause 74 FEC

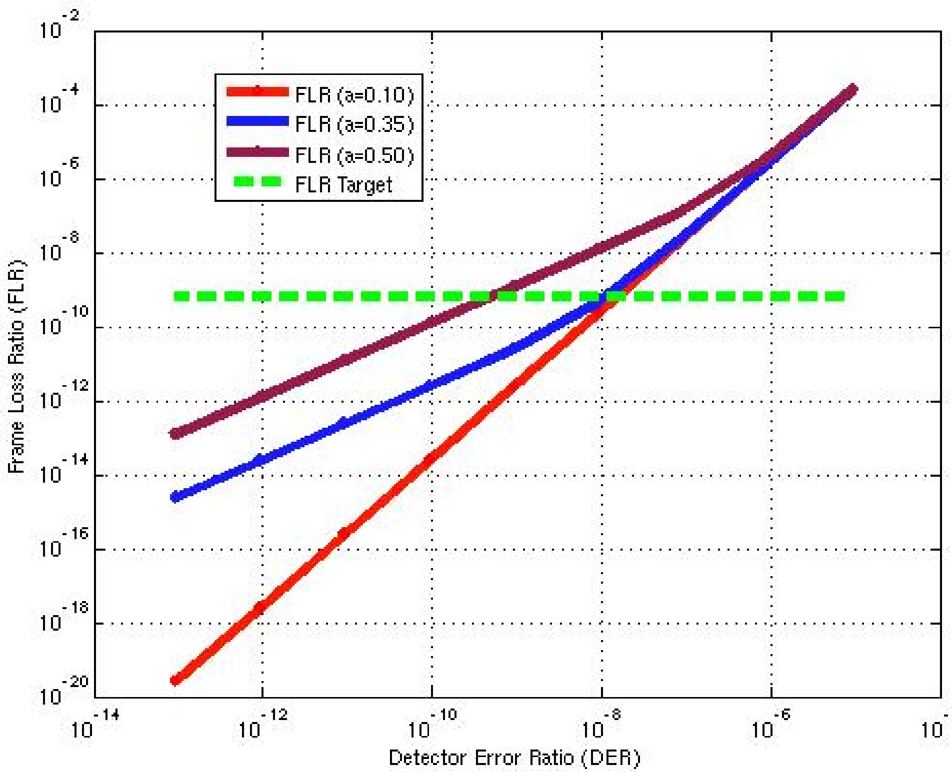
- To make error propagation insignificant, since the CER limit for clause 74 FEC is 4.71×10^{-10}, we should have

$$4.71 \times 10^{-10} > 4a^{2 \cdot 11}$$

or

$$a < \left(\frac{4.71 \times 10^{-10}}{4}\right)^{\frac{1}{22}} = 0.354$$

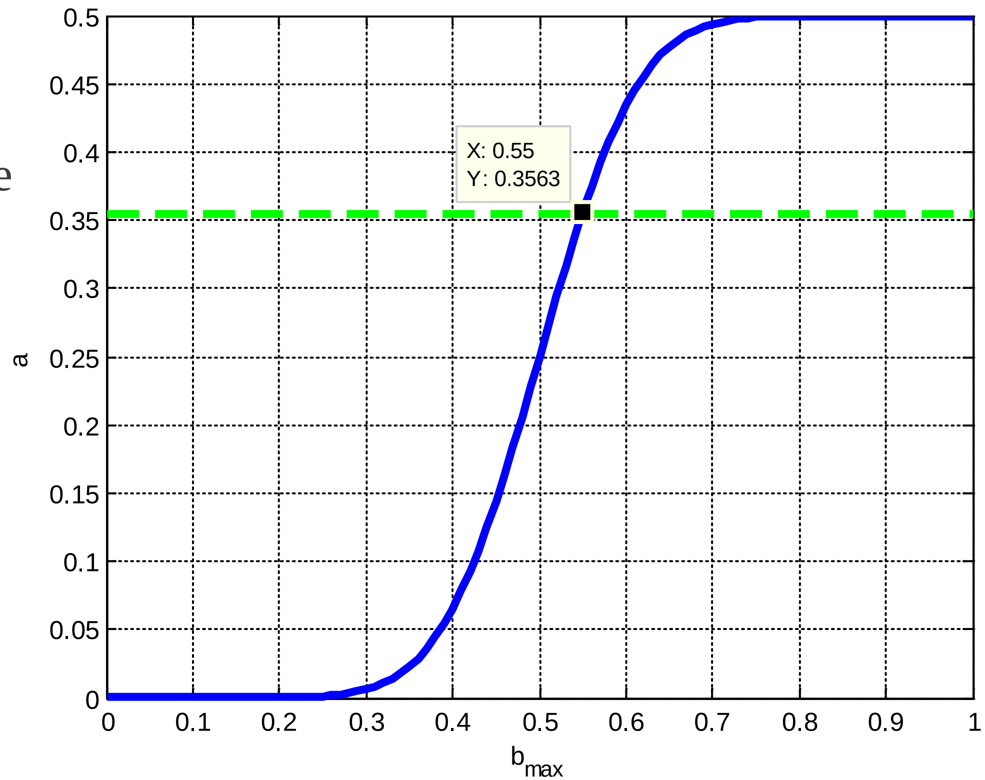
- If this is satisfied, the requirement for satisfying the FLR objective becomes DER < ~10^{-8}.



DFE EP Parameter (*a*)	0.10	0.35	0.50
DER Requirement	1.45×10^{-8}	1.05×10^{-8}	4.57×10^{-10}

COM DFE limit for Clause 74 FEC

- What is required to get a<0.354?
- For a single-tap DFE with Gaussian noise that yields DER=10^{-8}, we have
$$SNR = Q^{-1}(10^{-8})$$
- With tap value b, a wrong decision causes (with probability ½) a lower SNR:
$$SNR_{EP} = (1 - 2b) \cdot Q^{-1}(10^{-8})$$
$$\Rightarrow \quad a = 0.5 \cdot Q(SNR_{EP})$$
- We can solve for b that yields
$$SNR_{EP} = Q^{-1}(2 \cdot 0.354)$$



- As the graph shows, the limit is b ≈ 0.55 .
- To account for multi-tap DFE, we suggest using b_{max}=0.5 which provides a healthy margin (the assumption of one dominant tap seems justifiable from many past presentations).

Receiver tolerance test limits

- When RS-FEC is used, receiver tolerance test requirements are specified in terms of symbol error ratio (symbol error counters are available).
- With clause 74 FEC, we need another metric and counters.
- Clause 74 includes codeword error counters (FEC_corrected_blocks_counter and FEC_uncorrected_blocks_counter – see 74.8.4)
- Since we established the CER requirements for this FEC, we can state the test requirements as:

$$\text{Measured codeword error rate} < 4.71 \times 10^{-10}$$

DER Target for RS-FEC

- 802.3by adopted the RS-FEC code of clause 91, RS(528,514) over GF(210), correcting up to 7 10-bit symbols.
- If only random errors are considered, raw RS symbol error rate before FEC is $SER=1-(1-DER)^{10}$. Uncorrectable codewords are caused by more than 7 symbol errors, so the uncorrectable FEC codeword error rate is:

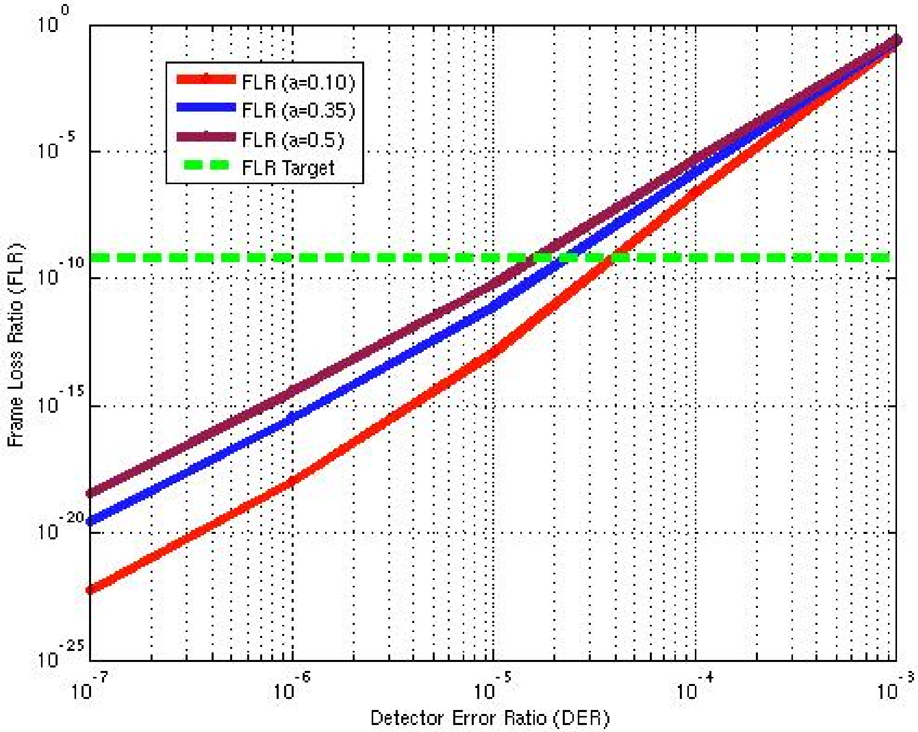
$$CER = \sum_{i=8}^{528} \binom{528}{i} SER^i \cdot (1 - SER)^{528-i}$$

- When burst errors are considered, 7 or fewer random errors can corrupt more than 7 10-bit symbols and cause uncorrectable codewords. CER can be modeled as:

CER=P(1 symbol error)·P(1 burst error corrupts more than 7 symbols)
+ P(2 symbol error)·P(2 burst errors corrupt more than 7 symbols)
+ ⋯
+ P(7 symbol error)·P(7 burst errors corrupt more than 7 symbols)
+ P(more than 7 symbol errors)

- Analysis results are shown in the next slide. They support the requirement $DER<10^{-5}$ used in 802.3bj even for *a*=0.5 (the maximum value in the Gilbert model).

DER Target for RS-FEC



DFE EP Parameter (*a*)	0.10	0.35	0.50
DER Requirement	3.89×10^{-5}	2.24×10^{-5}	1.55×10^{-5}

Proposal

- Use the following values for COM whenever BASE-R FEC (Clause 74) is used:
  - $DER=10^{-8}$
  - $b_{max}(1\ldots14)=0.5$
- Require codeword error ratio $< 4.7 \times 10^{-10}$ in receiver tolerance tests whenever BASE-R FEC is used (using the sum of FEC_corrected_blocks_counter and FEC_uncorrected_blocks_counter).
- For RS-FEC mode, retain the COM parameters $DER=10^{-5}$ and $b_{max}(1..14)=1$ and the requirement $SER<10^{-4}$ in receiver tests.

Thank you! Questions?

Slides in backup section:

- DER Targets for Lower FLR

DER Targets for Lower FLR

- FLR=6.2 × 10^{-10} yields mean time between frame loss events of 40 seconds.
- Some applications may demand much longer MTTBFL (such as “over the weekend”…)
- MTTBFL is about 4.6 days if FLR=6.20 × 10^{-14}, or BER=10^{-16} for uncorrelated errors (factor of 10^{-4} better than 802.3by objective!)
- What does that translate to?

DFE EP Parameter (*a*)	DER		
	No FEC	BASE-R	RS-FEC
0.10	$1x10^{-16}$	$1.45x10^{-10}$	$8.71x10^{-6}$
0.35	$1x10^{-16}$	$1.45x10^{-12}$	$3.24x10^{-6}$
0.50	$1x10^{-16}$	$4.57x10^{-14}$	$1.91x10^{-6}$