# EPoC Frame Loss Ratio (FLR) objectives

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# Frame Error Ratio (FER) objectives

- The latest version of P802.3bn Task Force objectives are available at the following URL: http://www.ieee802.org/3/bn/EPoC_objectives_update_1115.pdf
- One of the PHY performance metrics is listed as:
  - A downstream Frame Error Ratio better than $10^{-6}$ at the MAC/PLS service interface
  - An upstream Frame Error Ratio better than $5\times10^{-5}$ at the MAC/PLS service interface
- However, this metric can be met by a system dropping lots of packets within PCS due to detected but uncorrected bit errors out of FEC decoder

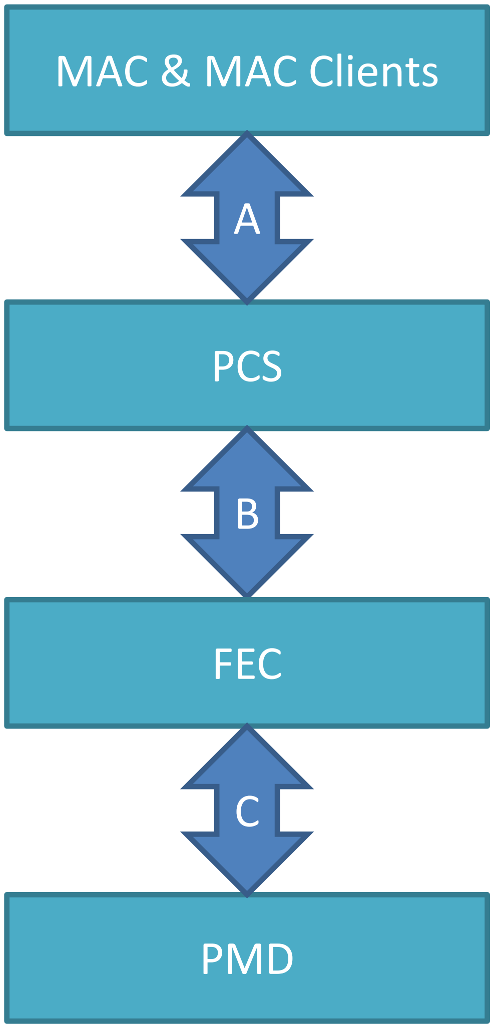
# What is FER?

- As defined in P802.3bn objectives, a FER represents the ratio between the number of frames that have errors and the total number of frames observed at the MAC/PLS service interface
- There are two issues with this definition:
  - CRC32 bit error detection capabilities are limited and some errored frames may pass undetected
  - The FER does not reflect correctly the operation of FEC-enabled system, especially in terms of loss of frames at the PCS level due to uncorrectable bit errors

# Ethernet CRC32

- Ethernet CRC32 has considerable error detection capability thanks to the Hamming distance of 4 (for large frames), allowing the guaranteed detection of up to 3 errored bits located anywhere in a frame.
- Ethernet CRC32 can also detect any 32-bit burst or any two 8-bit bursts in a packet.
- This provides an effective MTTFPA (mean time to false packet acceptance) in the billions of years in PHYs with no FEC
- When FEC is added to the PHY, uncorrected errors occur in groups, so CRC32 is not enough to protect against uncorrectable errors passed through by FEC decoder.
  - Frames with undetected errors where CRC32 happens to match are accepted by MAC as if they were actually correct.

# In a picture …




- NOTE: FEC is shown separate from PCS just for explanation of the problem
- FER at i/f A sees only frames reconstructed completely by FEC decoder (with potentially undetected bit errors)
- FEC decoder can invalidate many codewords due to excessive / uncorrected bit errors. The PCS may then turn (many) MAC frames into /E/ characters (ignored by MAC). FER at i/f A never knows about such lost MAC frames (they never reach MAC)

# Numeric example

- Assume that FEC fails to decode correctly every fourth MAC frame (on average), E2E frame loss is as bad as 0.25, i.e., one in four MAC frames never reaches destination MAC.
- Within the 25% of MAC frames that the FEC does not succeed in decoding correctly, there will be a small probability that the errors are not detected. For the RS(528, 514) code in the P802.3bj draft, this probability is ~$10^{-6}$. These frames are not marked as bad and pass through to MAC/PLS service interface.
- Under these assumptions, FER at MAC/PLS service interface is then: $(10^{-6} \times 0.25)/(0.75 + 10^{-6} \times 0.25) = 3.3 \times 10^{-7}$. This is better than $10^{-6}$ and $5\times10^{-5}$, so the EPoC objective would be still met.
- **What about 25% of MAC frames that were lost at the FEC decoder due to uncorrected bit errors ? These affect the FLR**

# So what's the problem with FER? (1)

- When received data is badly errored, FEC decoder may fail to correct all errors in the received bit stream.
- At the output of FEC decoder, multiple data vectors are marked as invalid and then replaced with /E/ characters by the PCS on XGMII. The resulting MAC frame is then invalid.
- Even though we may have lots of frames being lost due to uncorrectable errors at FEC decoder, these are not accounted for in FER at the MAC/PLS service interface.
- This also means that a PHY with poor bit error performance can still meet the established FER target, even though it is effectively dropping lots of frames (has a poor FLR).

# So what's the problem with FER? (2)

- Ethernet CRC32 has certain bit error detection capability (see slide 4)
- When there are 4 or more errored bits in a MAC frame, or the bit error burst is longer than 32 bits, or there are more than two bit error bursts, each with 9 errored bits or more, a frame is occasionally accepted as correct, causing a false packet acceptance event.
- Time between false packet acceptance events (MTTFPA – see next slide) defines the average time when both the FEC decoder and CRC32 fail to detect bit errors in the frame and MAC accepts such invalid frame, causing potentially end-station crash.

# What's MTTFPA?

- Mean Time To False Packet Acceptance (MTTFPA) is a key parameter, indicating the rate at which "damaged" packets are accepted by MAC as valid.
- Acceptance of damaged packets can hard-crash a telecommunication system.
- For 1GE (operating with BER of $10^{-12}$), the Mean Time to False Packet Acceptance (MTTFPA) was calculated to be approximately 60 billion years (~4 × the age of the Universe).
- For 10GE (operating with BER of $10^{-12}$), the MTTFPA was calculated at $\sim 10^{39}$ years, many orders of magnitude larger than for 1GE.

# FER & MTTFPA relationship

- Knowing FER at MAC/PLS service interface, it is simple to estimate MTTFPA, assuming the following:
  - packet_size: worst case packet size is a 64 octets with preamble and average IFG = (64 + 8 + 12) x 8 = 672 bits
  - data_rate: 10 Gbit/s (assuming that is MAC we use)
  - frame_rate can be calculated as data_rate/packet_size and it is equal 14880952.38 frames / second
  - This means there is an upstream errored frame every $(\text{frame\_rate} \times \text{FER})^{-1}$ = 1.34 ms !!! Because the errors are in groups, the probability of the CRC32 not detecting is 1/(2^32), so MTTFPA is equal to approximately ~67 days.
- Source for further reading: szczepanek_01_1105.pdf

# MTTFPA in EPoC

- Actual MTTFPA in EPoC is estimated at ~67 days
- It seems like still a long time between false packet acceptance events, but this estimate applies only to a single data link.
- A typical access chassis may support thousands of EPoC links, limiting MTTFPA to just about 9.5 minutes (across 10k data links)
- MTTFPA in 1GE is ~3 x $10^{11}$ times larger, and in 10GE with no FEC even larger than that.
- Ethernet typically assumes MTTFPA figure of merit to be at least equal to the age of universe

# Frame Loss Ratio (FLR) objective

- Comment #42 on P802.3bj D2.0 defines performance: “For a complete Physical Layer, this specification is considered to be satisfied by a frame loss ratio (see 1.4.210a) of less than $1.7 \times 10^{-10}$ for 64-octet frames with minimum inter-packet gap.”
- In P802.3bm D1.0, the performance is defined as follows: “The bit error ratio (BER) shall be less than $5 \times 10^{-5}$ provided that the error statistics are sufficiently random that this results in a frame loss ratio (see 1.4.210a) of less than $6.2 \times 10^{-10}$ for 64-octet frames with minimum interpacket gap when processed according to Clause 91.”
- A new definition 1.4.210a was also inserted: “frame loss ratio: The number of transmitted frames not received as valid by the MAC divided by the total number of transmitted frames.”
- In the 400G SG it has also been proposed to use similar performance objectives: see anslow_01_0613_logic.pdf for details.

# Where do we go from here?

- FER is a valid performance metric, but not referencing the MAC/PLS service interface for FEC enabled PHYs
- FLR should be defined at the MAC (top of the stack in slide 6), accounting for all types of errored frames
  - By the time frames reach MAC, most of bit errors have been detected by FEC decoder and resulting errored frames marked or converted into /E/ characters and then dropped.
  - Most frames with undetected errors are dropped by the MAC because the CRC does not match with the data.

# Should we use BER?

- BER as a bit error performance target was used by the majority of previous projects
- However, error distribution at the FEC decoder output is typically very bursty and is not aligned with frame boundaries in any way.
- A large frame that is not error free is likely to have multiple errors (error burst) and will probably be dropped. In such a situation, number of errored (or dropped) frames increases only by 1, while number of bit errors increases by a larger number - maybe 10 for a strong FEC code and more if there are bursts of errors at the FEC input.
- BER at the MAC/PLS service interface is not measureable if the MTTFPA is the age of the universe and the CRC detection probability is $2^{-32}$, then an errored frame appears once every 3 years.
  BER at the FEC service interface is not directly correlated with frame loss probability for this link.
- FLR as a bit error performance metric is much more meaningful, since it establishes a service-layer like performance goal, which can be readily understood by the users.

# Fixed bit error objective(s) [A]

- Assume MTTFPA for EPoC be equal to the age of the Universe (~14 billion years)
- Using simple calculations from slide 11 and assuming FLR is $10^{-6}$, we can calculate FER at MAC/PLS service interface (yellow) and probability for FEC decoder's failure to detect bit errors in decoded frame (green). This becomes **$1.33 \times 10^{-11}$ for FLR = $5 \times 10^{-5}$**

| | | | | |
|---|---|---|---|---|
| Age of the universe (seconds) | 4.42E+17 | | | |
| | | | | |
| MTTFPA after CRC32 (seconds) | 4.42E+17 | | frame size in bits (min) | 672 |
| MTT errored frame before CRC32 (seconds) | 1.03E+08 | | data rate (bit/s) | 10000000000 |
| | | | frame rate (frames/s) | 14880952.38 |
| FER at MAC/PLS SI | 6.53E-16 | | | |
| FER at FEC SI (target) | 1.00E-06 | | Requirement for FEC failure to detect | 6.53E-10 |
| | | | | |
| | | | | |

# Fixed bit error objective(s) [B]

- The calculated value for FEC error detection probability is much tighter than the probability for P802.3bj RS-FEC for 100GBASE-R PHYs
  - $10^{-6}$ FEC error detection probability (per codeword) for P802.3bj RS-FEC
  - $6.5\times10^{-10}$ FEC error detection probability (per codeword) downstream and $1.3\times10^{-11}$ probability (per codeword) upstream for EPoC
- Such performance level would be required to reach MTTFPA equal to the age of the universe

# Fixed bit error objective(s) [C]

- Proposed revision of the bit error performance objectives (changes marked in red)
  - A downstream Frame Loss Ratio better than $10^{-6}$
  - An upstream Frame Loss Ratio better than $5\times10^{-5}$
  - MTTFPA at least equal to $1.4\times10^{10}$ years (age of the Universe)
- FLR targets might need to be further modified if FEC error detection probabilities are too hard to meet
  - Right now they look challenging at best, compared to 802.3bj RS-FEC (roughly three or five orders of magnitude increase for downstream or upstream respectively)

# FEC Requirements

- Proposed FEC performance requirement:
  - The probability that the FEC decoder fails to indicate a codeword with E+1 (E = number of errors the FEC can correct) errors as uncorrected shall not exceed $6.5\times10^{-10}$ in the downstream direction and $1.3\times10^{-11}$ in the upstream direction.
    This limit is also expected to apply for E+2 errors, E+3 errors, and so on.
- Proposed FEC functional requirements:
  - FEC decoder shall detect any uncorrectable bit errors and mark all affected codewords accordingly, by setting the Sync header in the affected codewords to 0b11 (binary 11)