Error probability thoughts

Adee Ran, Cisco

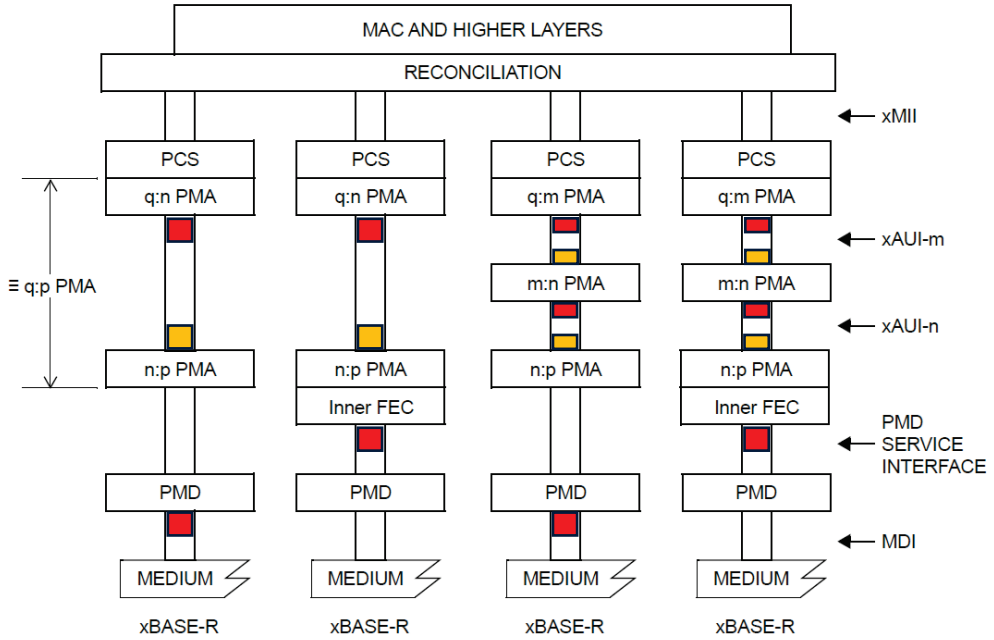
Matt Brown, Alphawave

Our objective…

- **“Support a BER of better than or equal to 10^{-13} at the MAC/PLS service interface (or the frame loss ratio equivalent)”**
- We know from previous work that
  - For 64-octet frames with minimum interpacket gap, with no FEC, uncorrelated errors BER of 10^{-13} results in a frame loss ratio of 6.2×10^{-11} (based on brown_3bj_02_0912, anslow_3bs_02_0714 and others)
  - With 4-way FEC interleaving, this corresponds to a FEC failure probability (uncorrectable codeword ratio, UCR) of FLR/4.125 = 1.5×10^{-11} (see opsasnick_3df_logic_220630a)
- We therefore define a requirement of FLR < 6.2×10^{-11} for a complete Physical Layer and consider that as satisfying the objective.
- Now we need to specify errors on each interface…

Interfaces that need error specifications

- Source of errors in the receive direction
- Source of errors in the transmit direction



xMII = GENERIC MEDIA INDEPENDENT INTERFACE
xAUI-n = GENERIC ATTACHMENT UNIT INTERFACE
FEC = FORWARD ERROR CORRECTION
MAC = MEDIA ACCESS CONTROL
MDI = MEDIUM DEPENDENT INTERFACE
PCS = PHYSICAL CODING SUBLAYER

PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT
m = NUMBER OF AUI LANES
n = NUMBER OF AUI LANES
p = NUMBER OF PMD LANES
q = NUMBER OF PCS LANES

Figure 176B–2—xBASE-R PHYs with one and two physically instantiated interfaces

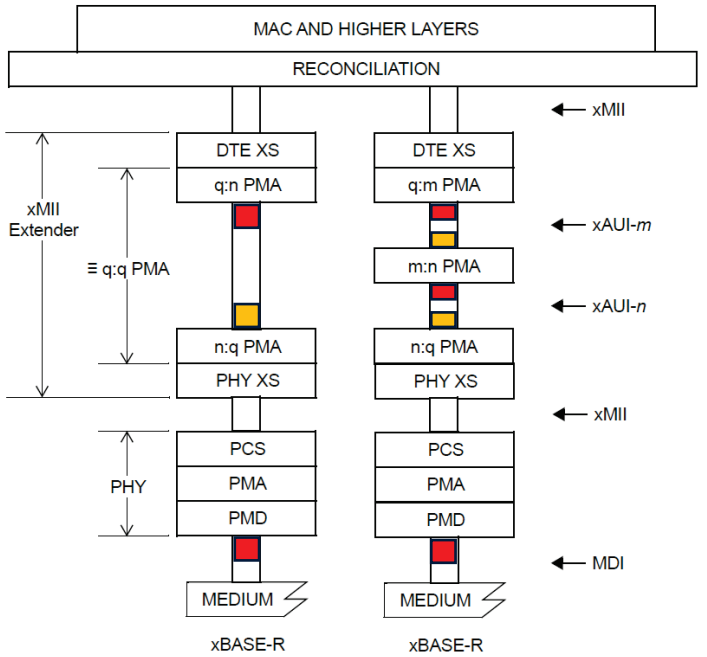


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Figure 176B–3—xBASE Physical Layer implementations with an xMII Extender with one and two physically instantiated interfaces

In the base standard…

- PMD clauses have complicated statements of error probabilities.
  - For example, 124.1.1 (as in 802.3df-2024):

    The bit error ratio (BER) for 400GBASE-DR4 and 400GBASE-DR4-2 PMDs, when processed according to Clause 120, shall be less than 2.4×10^{-4} provided that the error statistics are sufficiently random that this results in a frame loss ratio (see 1.4.344) of less than 1.7×10^{-12} for 64-octet frames with minimum interpacket gap when processed according to Clause 120 and then Clause 119.

  - BER is mentioned again in a table footnote for SRS in the receiver characteristics (Table 124–7): "for the BER specified in 124.1.1" – but SRS is typically performed with Test pattern 3 (aka PRBS31Q), which does not provide visibility into frame loss ratio.
  - Electrical PMDs have FEC symbol error ratio requirement in the receiver test, which is a proxy for BER with uncorrelated errors – and does not provide visibility into frame loss ratio.
- AUI-C2M annexes have somewhat simpler statements that do not address error statistics at all. For example, 120G.1.1 (802.3ck-2022):

  The bit error ratio (BER) when processed by the PMA according to Clause 135 for 100GAUI-1 C2M or Clause 120 for 200GAUI-2 or 400GAUI-4 C2M shall be less than 10^{-5}.

In the base standard…

- AUI-C2C annexes have no explicit statements about BER or error statistics.
  - The receiver interference tolerance test requires FEC symbol error ratio maximum of 1e-4, which is assumed to be equivalent to BER<1e-5 if errors are uncorrelated.
  - In practice, component tests are performed with PRBS31Q and the PMA-specified test pattern checkers and error counters (same goes for AUI-C2M).
  - Tests using these error counters measure average BER, but **error statistics or FLR can’t be observed**.
- AUIs within Extenders are not addressed at all.
  - It is assumed that errors on AUIs within an extender have negligible effect compared to the same AUI being within the PHY.
  - If Extenders are used to extend the distance between the MAC and the PMD beyond the PHY-AUI, with higher BER on the AUI – this assumption may not hold anymore.

Problem statement

- **BER budgeting is based on an assumption that errors are uncorrelated.**
  - Experience with 100G/lane shows that this assumption is unsafe; receivers can have correlated errors on any interface, and transmitters may cause correlated errors.
  - 200G/lane won't make it easier.
- **BER testing is understood as an average over the measurement time.**
  - This cannot discriminate correlated errors from uncorrelated errors.
  - Some devices with average BER <1e-8 (large margins) show unexpectedly high FEC failure rates (and FLR).
- **Meeting the existing component (sublayer) specs does not guarantee the objective**
  - And if better-than-standard performance is required (as is often the case), the existing metrics do not provide quantitative information.
- **Industry is using non-standard test methods and criteria, e.g., long test times with maximum bin requirements**
  - Signaling that the standard requirements are irrelevant!

What we should work on

- Find a way to divide/share/allocate the error budget without assuming errors are uncorrelated.
- Define test methods that can detect devices that exceed their error budget – either due to random BER or correlated errors
  - For both receivers and transmitters (correlated noise)
  - Consider what the industry wants, not just what we used to specify!
- Define the requirements for each interface in terms of the test methods and the budget allocation
  - Common methodology and similar specifications for PMDs/AUIs of the same class.
  - Annex 174A in Draft 1.0 allocated for this purpose.

Possible directions and open questions

- Recap from ran_3dj_01_230817 (in electrical ad hoc):
  - Budgeting using random BER equivalent for each segment
  - Specify FEC codeword error ratio with additional errors from other segments
- Alternatives
  - For each segment, specify probability of having FEC codeword with more than k errors (e.g., errors per block of specified size with PRBS, use PCS-encoded signal and check using PCS decoder)
  - Other?
- How to test components with simple patterns such as PRBS31Q?
- How to test modules with inner FEC?
- How to test transmitters?

Heads up

- This will be an important topic of discussion during task force review
- If you are interested in this area – join us for consensus building

That’s all

Discussion / questions