Error rates and testability

Piers Dawe	Agilent
Mike Dudek	Picolight
Ulf Jönsson	Ericsson
Tom Murphy	Infineon Technologies
Jerry Radcliffe	Hatteras Networks
Koichiro Seto	Hitachi Cable

Vipul Bhatt

How do we achieve high MTTFPA?

- Require mean time to false packet acceptance (MTTFPA) to be very many years by:

1. Controlling raw errors on the line
2. Checking for errors e.g. Ethernet's Frame Check Sequence (FCS, a 32 bit CRC)

- Different transmission formats and rates have different limits for each of these
- How high is enough MTTFPA? FRD (next slide) implies days to months. Is 10^6 years OK? 10^9 years? Age of universe (10^10 years?)

Our rules about errors

- From 802 Functional Requirements document ("FRD", quite old)

5.6.1 MAC Frame Error Rate

The probability that a MAC Protocol Data Unit (MPDU), excluding any preamble, transmitted by one MAC entity is not reported correctly at the PHY service interface of a peer MAC entity, due to operation of the conveying Physical Layer entity, and not due to the normal operation of the MAC protocol, shall be less than 8 * 10-8 per octet of MPDU length (This error rate applies to operation within a single LAN).

5.6.2 MAC Undetected Error Rate

BER <~10^-8

The probability that a MAC Service Data Unit (MSDU) reported at the MAC service boundary contains an undetected error, due to operation of the conveying MAC and Physical Layer entities, shall be less than 5*10-14 per octet of MSDU length.

*Undetected Error Ratio <6*10^-15/bit*

*MTTFPA > 1/(6*10^-15*bit rate): days to months*

5.6.3 Hamming Distance

A minimum of four bit cells in error shall be necessary for an undetected error to occur (Hamming distance 4). *[This requirement may be waived by the EFM PAR]*

5.6.4 Burst Error Detection

In LANs (including IVD LANs) and MANs that do not by other means provide an error detection capability that will insure the MAC Undetected Error Rate probability stated in 5.6.2, the 32 bit CCITT CRC 32 shall be used as a frame check sequence for burst error detection [14]. *[We use this CRC]*

We expect to be clearly better than FRD requirements

- EFM objectives
  - –Optical: "BER <=1e-12 at the PHY service interface"
  - –Electrical: no specific objective?

BER specifications and objectives

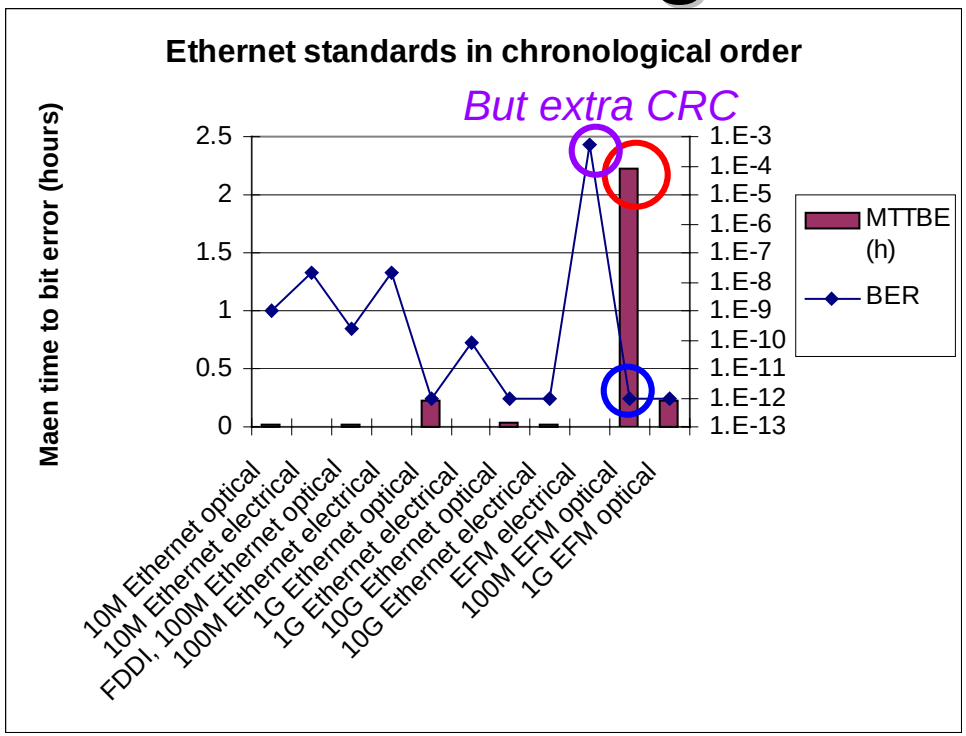
Clause	Summary of title	BER or similar	MTBE s/user
9.	Repeater unit for 10 Mb/s baseband networks	10^-10	800
11.	Broadband medium attachment unit and broadband medium specifications, type 10BROAD36	10^-8 ? 26 dB signal-to-noise ratio	8?
15.	Fiber optic medium and common elements of medium attachment units and star, type 10BASE-F	10^-9	80
16.	Fiber optic passive star and MAU, type 10BASE-FP	10^-9	80
17.	Fiber optic MAU, type 10BASE-FB	10^-9(10?)	80 (800?)
18.	Fiber optic MAU, type 10BASE-FL	10^-9(10?)	80 (800?)
23.	PCS, PMA sublayers and baseband medium, type 100BASE-T4	Mean ternary symbol error rate, at the PMA service interface 10^-8	?
FDDI	ANSI X3.184-1993 (FDDI) (SMF-PMD) 5	2.5e-10 at min and 1e-12 at 2 dB above min power	32, 8000
Annex 36A	(Annex to 36: PCS and PMA sublayer, type 1000BASE-X)	10^-12	800
38.	PMD sublayer and baseband medium, type 1000BASE-LX and 1000BASE-SX	10^-12	800
40.	Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 1000BASE-T	... 4-D symbol error rate < 10^-10 ... this specification shall be satisfied by a frame error rate < 10^-7 for 125 octet frames.	?
Annex 40A		"objective BER of 10^-10"	
44.	Introduction to 10 Gb/s baseband networks	10^-12	100

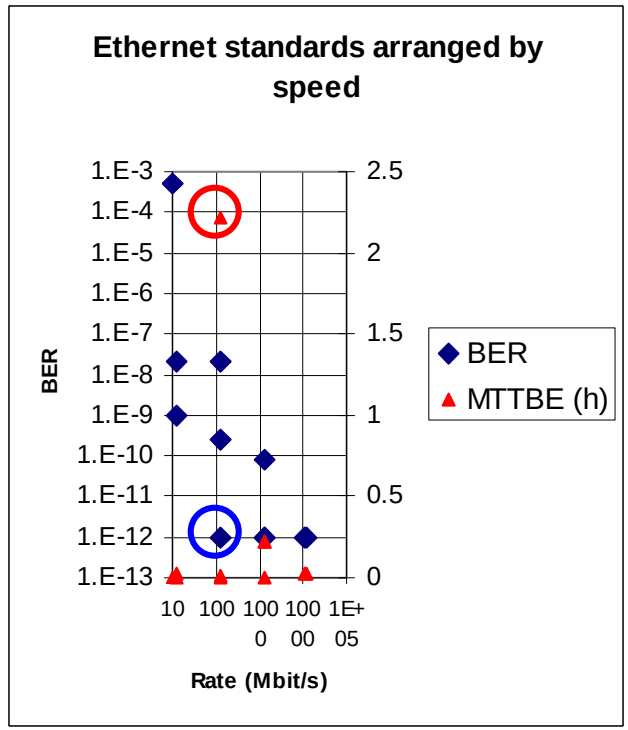
Telecoms used to be 10^-9, now 10^-10 up to 2.5 GBd, 10^-12 at 10 GBd

100BASE-BX10 equivalents: TTC TS-1000 10^-10 G.985 (need to check)

MTBE = mean time to bit error

1. Controlling raw errors on the line



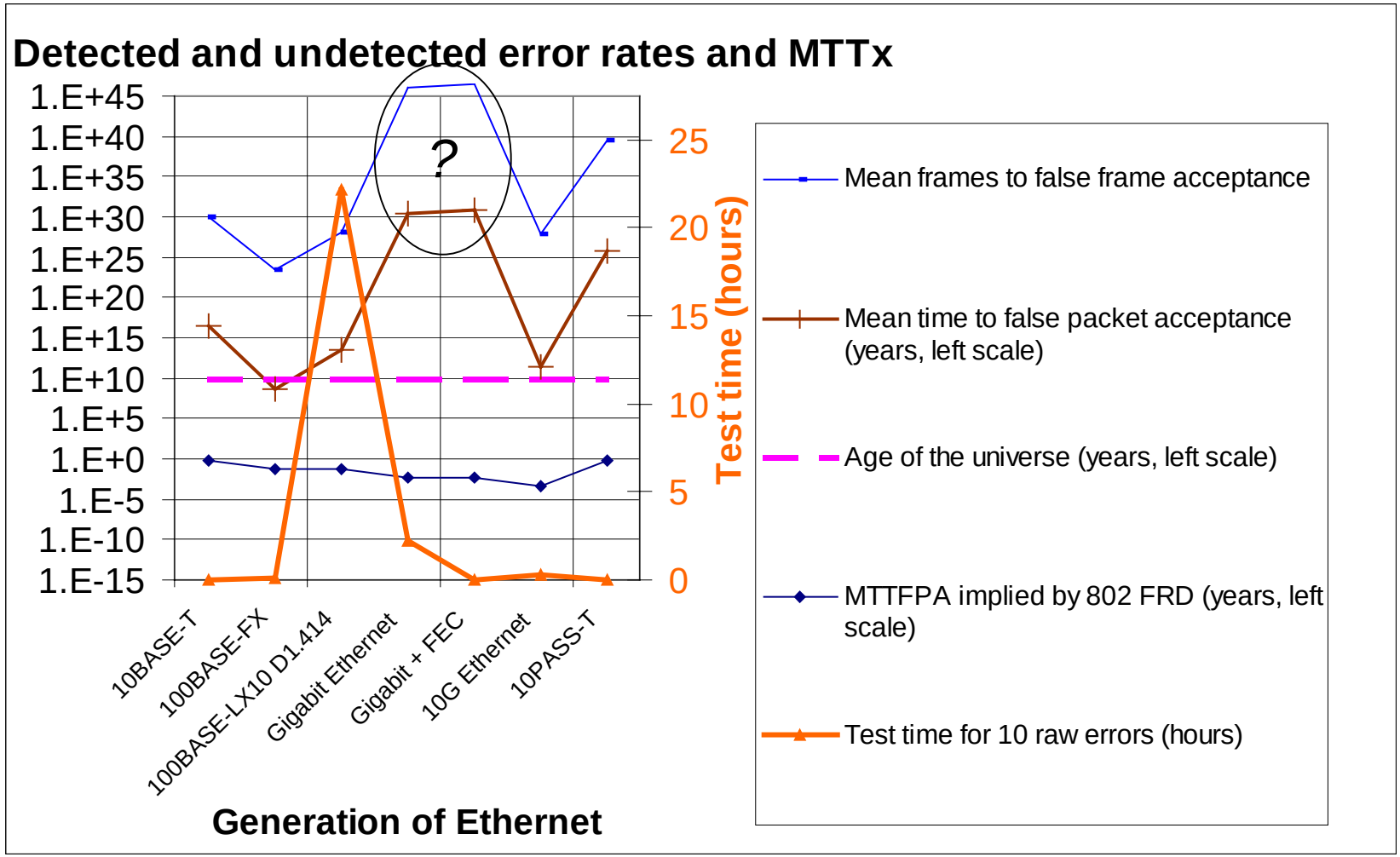


- Newer standards tend to be stricter
- Faster standards tend to have lower error ratios to achieve similar error rates
- Few errors/hour cannot be measured with economic feasibility
- Need indirect methods

2. Checking for errors

- 32 bit CRC guarantees to detect 1, 2 or 3 errors in a frame
- And detects all but one in 2^32 frame errors
- In per-bit or per-byte terms, gives better protection for short frames
  - Therefore the following analysis assumes maximum length (1518 byte) frames
- Some Ethernet links uses additional CRC
  - e.g. EFM copper -O'Mahony presentation Jan. 03
- Scrambler may cause error multiplication
- 8B10B code book gives opportunity for further error detection
- FEC corrects most line errors

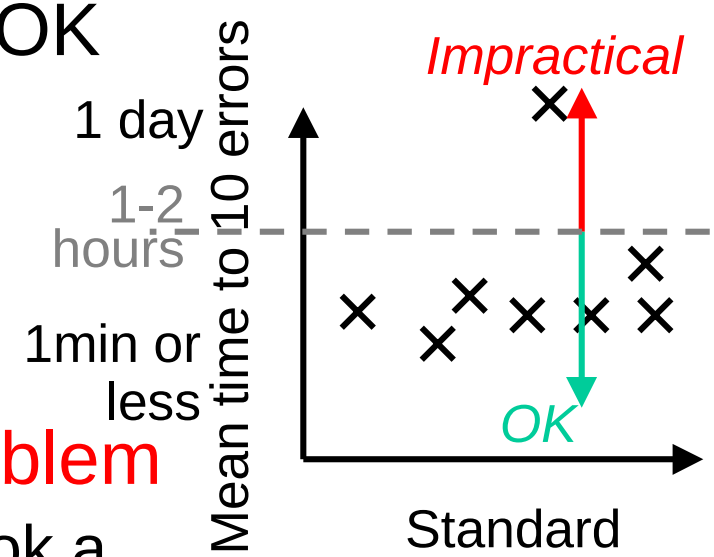
2. Checking for errors



- *Roughly, 1/Pr(packet has 4 or more errors and not caught by CRC)*

Quality assurance and testability

- If high line rate, measure low BER directly — OK
- If medium line rate, extrapolate to low BER — OK
  - Like accelerated life-testing
  - Needs good judgement
- If low line rate, would have to extrapolate further than accurate — Problem
  - Like life-testing too hot: may overlook a cause of failure in real use
- If error correction in use, count corrected errors — OK
  - Even at low line rates, corrected errors may be reasonably frequent

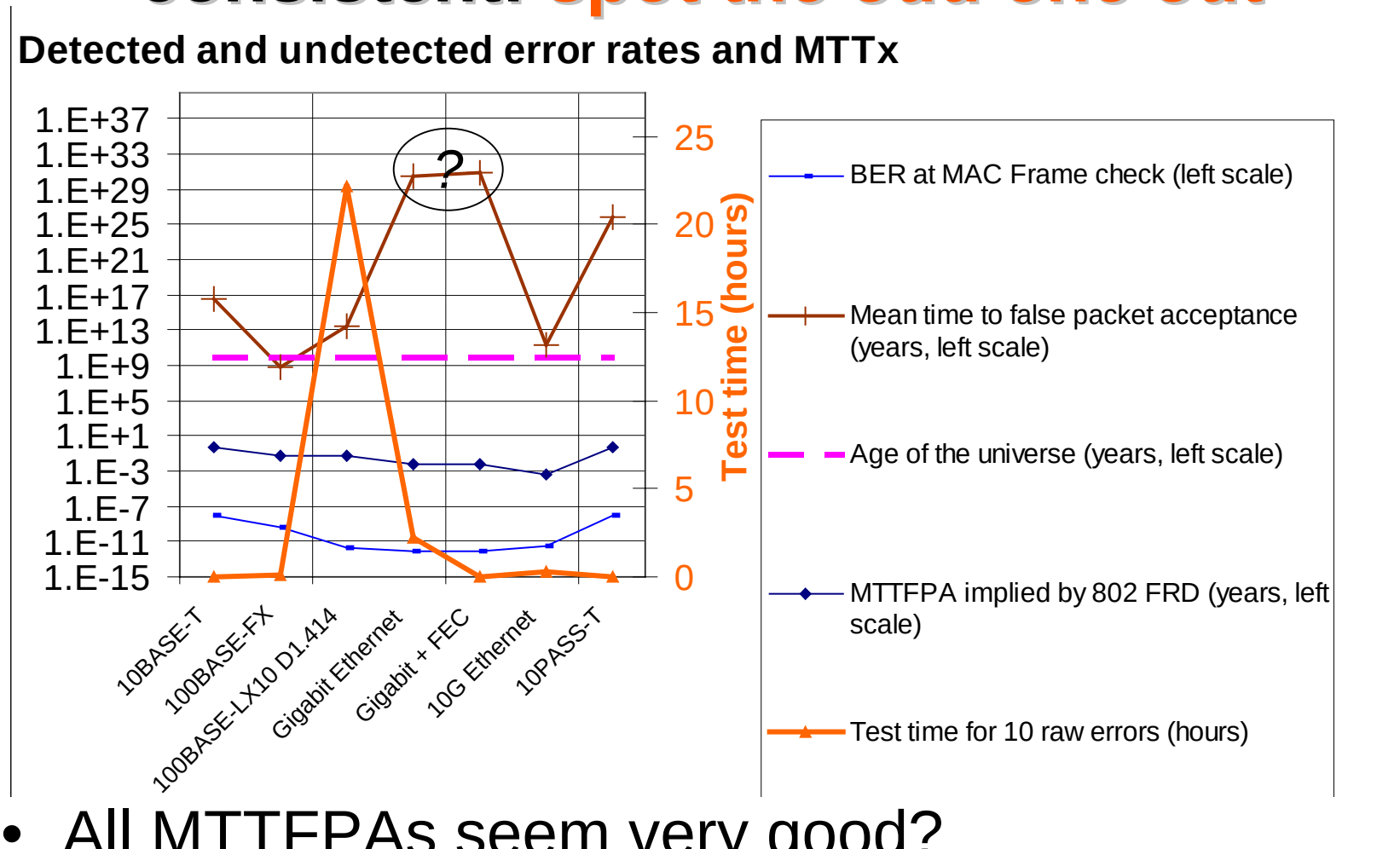


Remember the low speed links are supposed to be cheap (not compatible with long test times), and low maintenance.

Quality assurance and testability: Problem statement

- For the slower optics:
- Achieving very low BERs is commonplace
- Measuring them is impractical because very time consuming
  - General problem of proving a negative
- On the other hand, if you can't detect it, why do you care?

Different generations of Ethernet are mainly consistent: spot the odd one out



- All MTTFPAs seem very good?
- MAC error rates vary, generally per speed
- Test times vary hugely

If low line rate, would have to extrapolate further than accurate: *What to do?*

Option 1 Free for all

- Status quo
- Probably a link will be OK, as good as earlier Ethernet standards, but perhaps not as good as advertised
- Specifying something essentially unmeasurable
  - Extrapolate, use margin
  - Don't know what quality you are buying
  - If don't extrapolate in all the right dimensions, predictions wrong
- "Bad law"

Option 2 Give guidance in the standard

- Leaves fewer effects to be overlooked
  - See next slide
- Tends to more consistent quality in the market

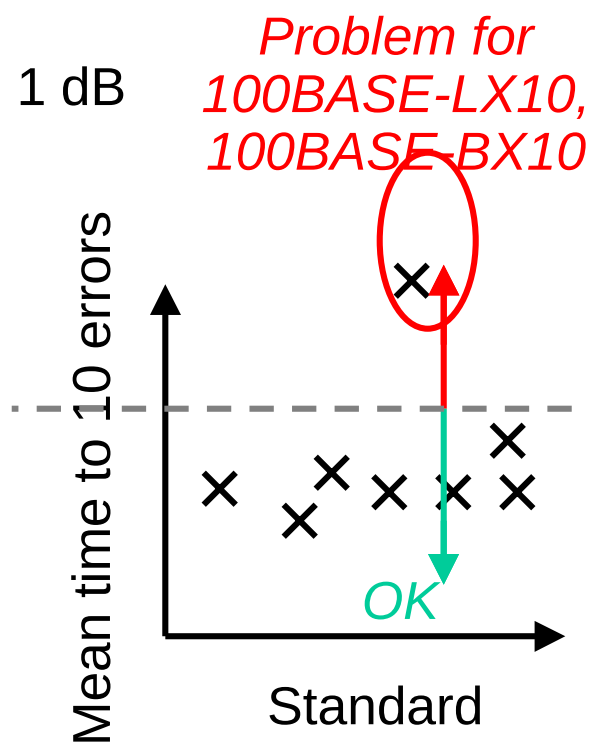
Option 3 Define measurable standard

- Define margin based on analysis of option 2
  - See next slide
- Tends to more consistent quality in the market
- Can be defended
  - Consistent across generations of Ethernet
- "Good law"

Quality of service: predictable is better than sometimes great but variable

Extrapolation and margin

- 100BASE-X error rate can depend strongly on payload!
  - Unlike 1000BASE-X or 10G Ethernet
  - Amount is implementation dependent, could be 1 dB
  - Provides a nice acceleration method
- If errors relate to Rx noise (sensitivity),
  - Stress with pattern
  - Extrapolate with optical power
    - How far? 4 orders of magnitude? ~ 1 dB?
- If errors relate to mode partition noise,
  - Stress with pattern
  - Consider extrapolation with dispersion
    - Nonlinear relation
- If errors relate to transmitter noise (RIN),
  - If SMF, might stress with back reflection - not linear
  - If MMF - ?
  - All we can do easily is stress with pattern
- If errors relate to fiber or other bandwidth,
  - Use stressed eye methodology: already in place



Solution to problem: Proposed way forward for 100BASE-xX10: Option 3

- Keep 10^-12 service BER objective
- Define two equivalent metrics
- 1. 10^-12 point (e.g. sensitivity)
  - Not accessible in practice
- 2. Tougher 10^-10 point (e.g. sensitivity) which is predicted to deliver better than 10^-12 at e.g. minimum received power
  - Set option 2 to be at least equivalent to option 1
- Let implementer use either

Proposed way forward for 100BASE-xX10 Option 3 continued

- 10^-12 sensitivity as is
- Build prediction 10^-10 -> 10^-12 into standard
  - Theory says 10^-10 sensitivity should be 0.5 dB tougher
  - Make 10^-10 sensitivity 1 dB tougher
    - If receiver is the BER limiting component, transforms 10^-10 to 6*10^-16!
  - Test with worst pattern
    - In many cases, amounts to about another 1 dB margin for random traffic, and addresses transmitter noise in these cases. As traffic may not be random, might say it is worth 0.5 dB: a few more orders of magnitude
- Suggest 1 dB of extrapolation in measurement

Proposed way forward for 100BASE-xX10 Option 3 continued

- 10^-10 is:
  - Tougher than 100BASE-T copper (10^-8?)
  - A little tougher than 100BASE-FX (2.5*10^-10)
  - Same as TTC TS-1000 (100BASE-BX10 equivalent)
  - Same as 1000BASE-T
  - Same as SONET OC-3

Pros and cons of proposal

- Disadvantages
  - Different treatments for 100BASE-xX10 and 1000BASE-xX10
    - But they really are different
  - Needs explaining
- Advantages
  - Cost
  - Quality
  - Visibility, enforceability
  - Consistency across different media
    - Similar to 100BASE-FX and TS-1000 in particular
  - Still very robust in practice

Conclusion

- For 100BASE-X,
- Allow tests to BER 10^-12 or 10^-10
- With defined margin and test pattern
- to deliver better than 10^-12 in service

Backup: When do we care about errors?

- If the payload is ephemeral, errors are tolerated
  - phone
  - TV
- If the payload is long lived, errors are more concerning
  - information, records, financial
  - software, operating system
- Ethernet takes this seriously
  - 802 Functional Requirements document
  - EFM objectives

Backup: How much do we care about errors?

- If no errors — OK
- Detected and corrected — OK
  - e.g. FEC
- Detected and retransmitted — Tolerable
  - e.g. retransmit a frame or packet
  - Wastes time
- Undetected and delivered as good — ***Not OK***
  - Each of us uses data in many systems
  - The data in each system can traverse many links
  - Therefore require very low undetected error rate
- Mean time to false packet acceptance (MTTFPA) to be very many years