802.3ap MTTFPA calculations

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DFE Error Propagation & MTTFPA

- **The Ethernet CRC32 has considerable error detection capability**
  - It has a hamming distance of 4 (for large frames) allowing detection of up to 3 errored bits anywhere in a frame.
  - It can also detect any 32bit burst or any two 8-bit bursts in a packet.
  - This provides an MTTFPA in the billions of years
- **The 10GbaseR Scrambler polynomial was chosen to maintain hamming distance**
  - Allowing detection of up to 3 errored bits anywhere in a frame.
- **The self-synchronous Scrambler in the 10GbaseR PCS has error propagation properties**
  - Each error bit is triplicated : repeated 39 and 58 bits after original
    - The burst detection capabilities of the CRC32 are not maintained after PCS scrambling.
    - Any >3 bit burst error in a frame ***may*** not be detected
      - Must then rely on statistical probability of false good CRC
- **If a particular channel/DFE based receiver combination causes error bursts we have a problem**
  - Any burst error that breaks the hamming distance may not be detected

Ref: Walker_1_0300 (slide 7)

False Packet Acceptance Rate

- A key parameter of any code is the rate at which "damaged" packets are accepted as valid. In general, such a failure is capable of hard crashing a computer system.
- For 1Gb Ethernet the Mean Time to False Packet Acceptance (MTTFPA) was calculated to be approximately 60 billion years.
- Because 64b/66b has a uniform 4-bit Hamming protection, a conservative estimate can be made. Assume that packets with four or more errors will generate a false packet acceptance event. In practice, this overestimates the failure rate by about 2^{32} .

IEEE 802.3ae, Albuquerque, 3/6/00 *64b/66b coding update* Agilent Technologies Innovating the HP Way

Ref: Walker_1_0300 (slide 8)

False Packet Acceptance Rate

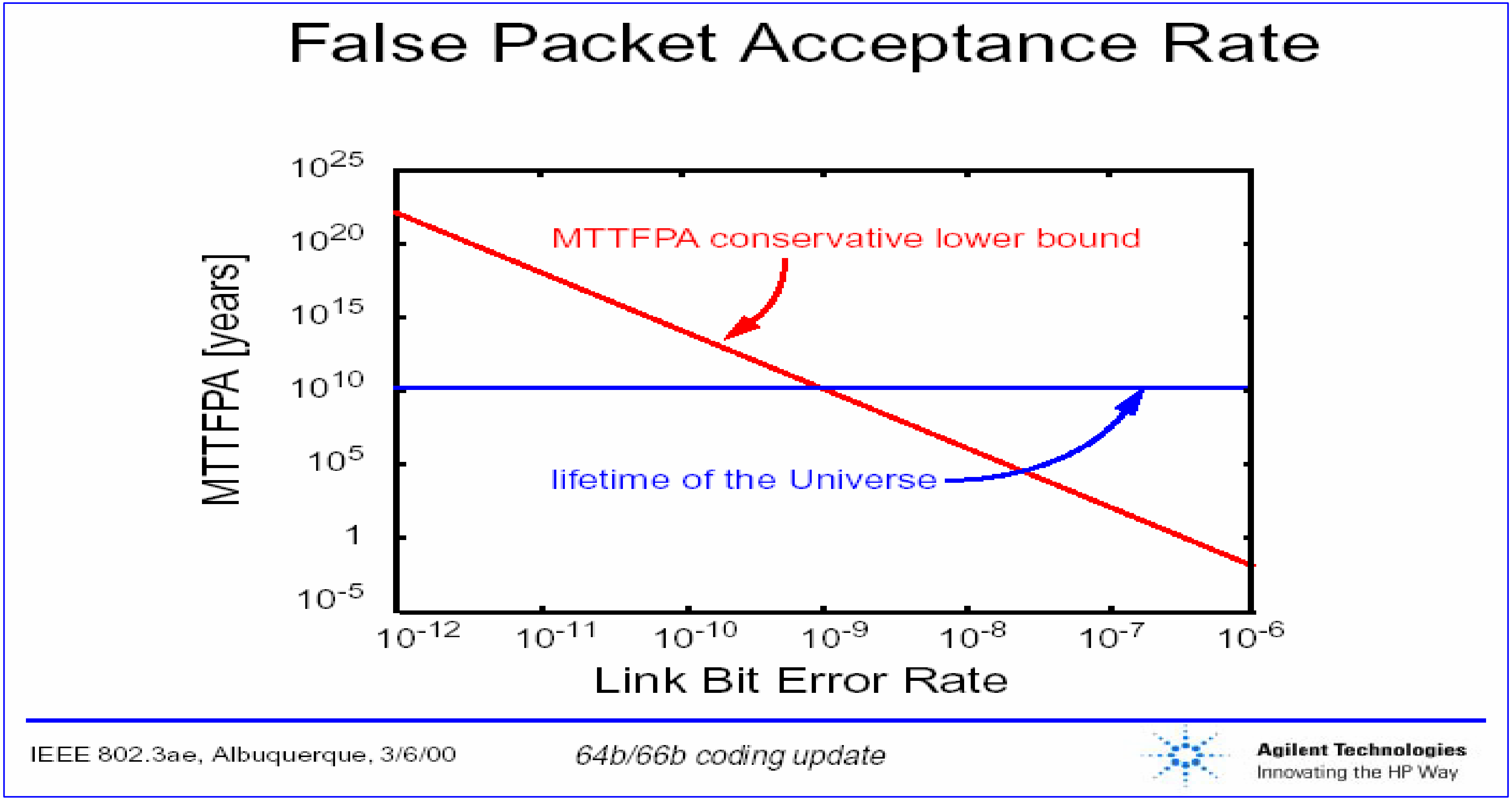
- P = coded packet size = 58+1526*8*66/64
- p_e = bit error rate, N = number of errors, t_b = bit time (1/10.3125G).
- probability of N errors in packet of size P:

$$p(N, P, p_e) = (1 - p_e)^{P-N} (p_e)^N \binom{P}{N}$$

- expected time for 4 or more errors:

$$MTTFPA > \frac{t_{bit} P}{1 - p(N,P,0) - p(N,P,1) - p(N,P,2) - p(N,P,3)}$$

Ref: Walker_1_0300 (slide 9)



MTTFPA dependency on DFE Error Propagation

- **Error propagation increases the likelihood of exceeding the hamming distance**
  - Some ways to break hamming distance of 4:
    - 4 single bit errors
    - 2 single bit errors each propagated to >1 bits
    - 1 single bit error propagated to >3 bits
- **Simulation results from Liu & Ganga show >4 bit propagation probabilities in the range 1E-3 - 1E-6 for dificult channels**
  - Best probability reported by Ganga is 1E-6 (B1)
  - All other Ganga channels in range 1.6E-4 to 2.6E-5
    - These are optimistic as they are based on a 2112 bit FEC frame
      - Need to multiply by ~6, for max Ethernet packet
  - *See associated spreadsheet szczepanek_02_1105 to see the effect of these probabilities on MTTFPA*

4bit burst probabilities from ganga_2_1105

Channel	Pr(4,2112)	Calculated Pr(4,12648)
Intel B1	1E-6	6E-6
Intel T12	7.5E-5	4.5E-4
Intel M20	2.6E-5	1.6E-4
Tyco case 3	3.1E-5	1.86E-4
Tyco case 6	1.63E-4	9.76E-4 (~1E-3)
Molex J4K4G4H4	6.75E-5	4E-4
Molex J3K3G3H3	6.75E-5	4E-4

MTTFPA Results

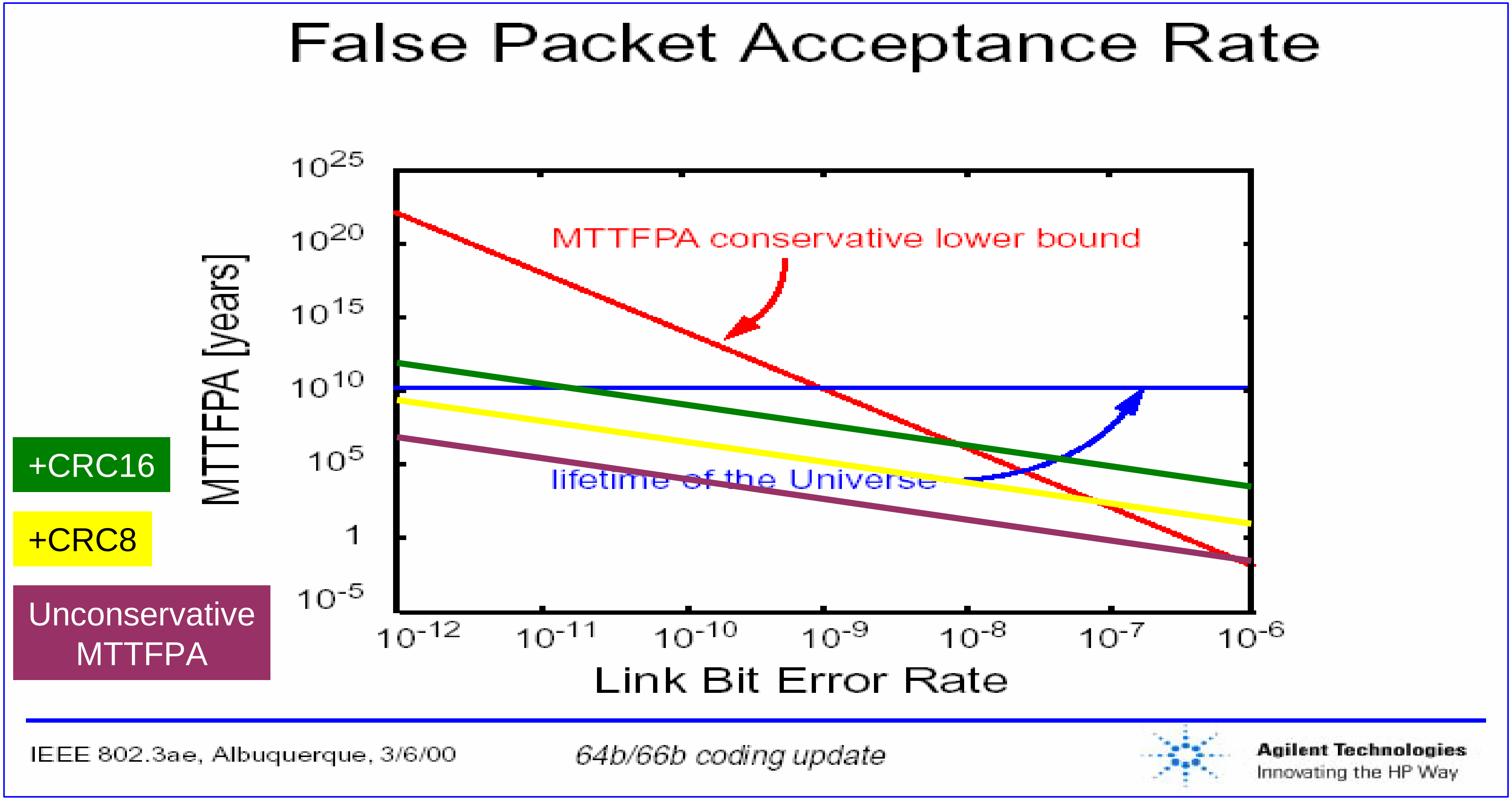
- **For BER=1E-12, & prob of 4bit burst = 1E-3**
  - MTTFPA = 3E-3 years (1.2 days) by Walker method
- **However Walker is conservative by 2^32**
  - So MTTFPA = 1.32E+7 years (13 million years)
  - CRC8 multiplies this by 256
    - CRC8 MTTFPA = 3.83+9 years (45 billion years)

- **Similarly if prob of 4bit burst = 7.5E-5**
  - MTTFPA = 4.10E-2 years (15 days) by Walker method
- **However Walker is conservative by 2^32**
  - So MTTFPA = 1.76E+8 years (176 million years)
    - CRC8 MTTFPA = 4.5E+10 years (45 billion years)

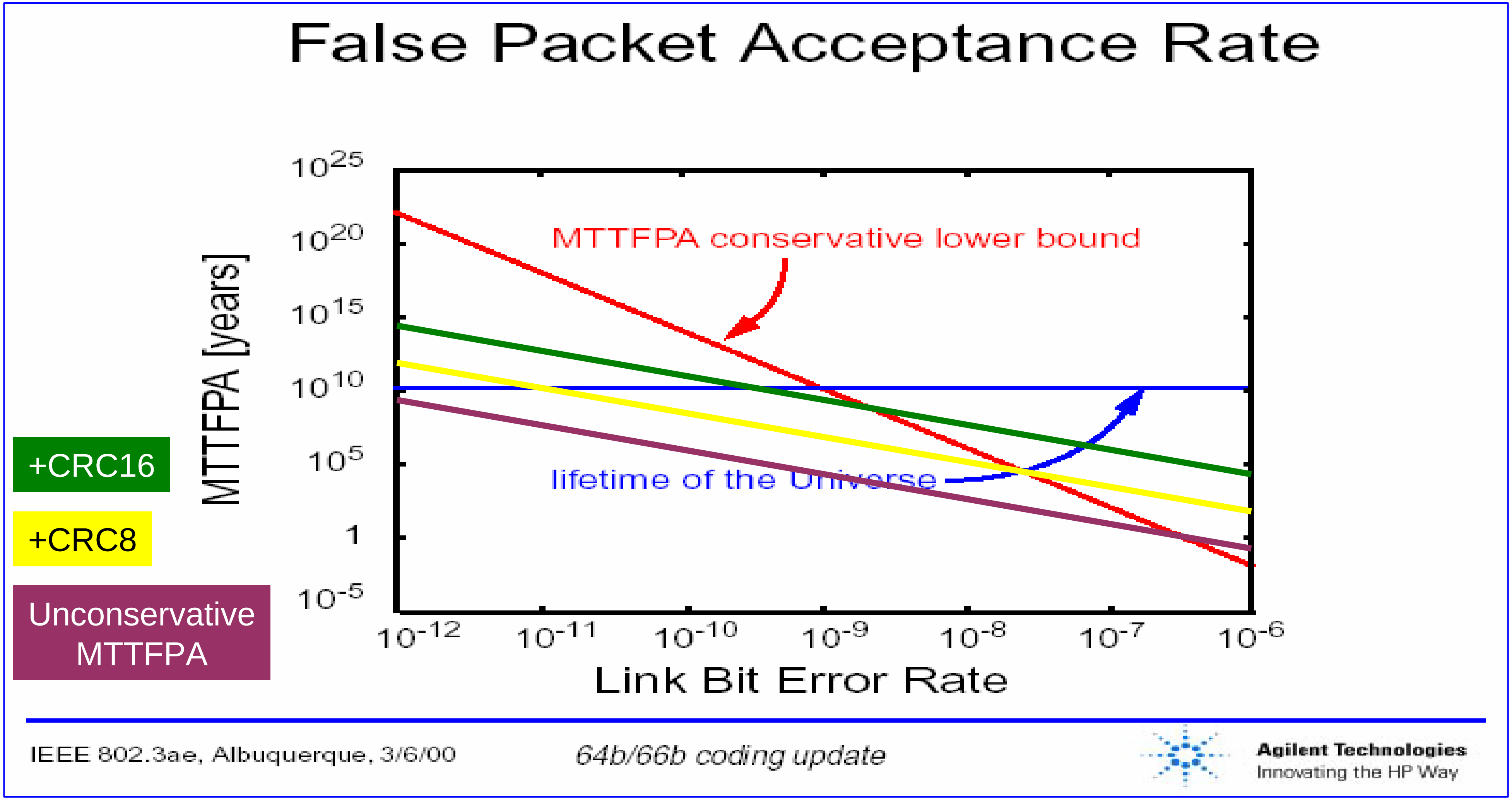
- **Similarly if prob of 4bit burst = 6E-6**
  - MTTFPA = 0.512 years by Walker method
- **However Walker is conservative by 2^32**
  - So MTTFPA = 2.2E+9 years (2.2 billion years)
    - CRC8 MTTFPA = 5.6E+11 years (560 billion years)

- **Compare to 1G Ethernet MTTFPA of 60 billion years (per Walker)**

1E-3 results overlaid over Walker graph



6E-6 results overlaid over Walker graph



Observations

- **The range of burst probability (1E-3 to 6E-6) is similar to the improvement due to CRC8**
  - Best case MTTFPA just below Lifetime of Universe (LOA) without CRC8
  - Worst case MTTFPA just below LOA even with CRC8
  - Worst case MTTFPA 13 million years without CRC8
    - One failure every 13 years with 1 million active devices

- **Use of the 2^32 factor presumes no correlation between burst patterns and the CRC32 polynomial**

- **FEC proposal will improve MTTFPA of worst channel to 67 million years (without 2^32), and 2.9E+14 with it**
  - well above LOA

Conclusion

- **MTTFPA is just acceptable with 2^32 factor**

- **Use (optional) FEC if MTTFPA is a concern**
  - Otherwise leave PCS as is (No CRC8)