MTTFPA Considerations for No-FEC Operation

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Introduction

- Mean Time to False Packet Acceptance (MTTFPA) is targeted to be longer than Age of the Universe.
- As IEEE 802.3 CRC32 and self sync scrambler do not share common factors, CRC32 burst error detection capability is maintained although the descrambler multiplies the errors by 3 times. CRC32 can detect the following errors for Ethernet packets up to 9K Bytes [2].
  - Up to three random errors
  - Two bursts of up to 8 bits
  - One burst of up to 32 bits
- However CRC32 burst error detection capability can be compromised,
  - If 64B/66B block sync head or type field is corrupted, or
  - If there is error spill-in/spill-out. In case of error spilling, 4-bit hamming distance of CRC32 has been certified by exhaustive simulations. walker_1_0100.pdf

Introduction

- An Ethernet packet:

	Preamble	Start Delimiter	DA	SA	T/L	LLC (OPT)	Payload	Pad (opt)	FCS	IPG
Octets	7	1	6	6	2	46-1500			4	>=12

- The frame from DA to FCS is checked by CRC32.
- A basic Ethernet frame is between 64 to 1518 octets.
- After 64B/66B coding, a 64-octet frame consists of 10 blocks.

Start	Data	Data	Data	Data	Data	Data	Data	Data	Term

64B/66B Code Overview

- Pure data block has a “01” sync head and eight 8-bit data.

0	1	D0	D1	D2	D3	D4	D5	D6	D7

- Pure command block has “10” sync head, one 8-bit type field and 8 7-bit commands.

1	0	0X1E	Z0	Z1	Z2	Z3	Z4	Z5	Z6	Z7

- Mixed command/data block has “10”, one 8-bit type field and 8 7-bit field. Start of packet (SOP) and end of packet (EOP) are implicitly transmitted. The following two blocks have EOP at different locations:

1	0	0X87	T0	Z1	Z2	Z3	Z4	Z5	Z6	Z7

1	0	0X99	D0	T1	Z2	Z3	Z4	Z5	Z6	Z7

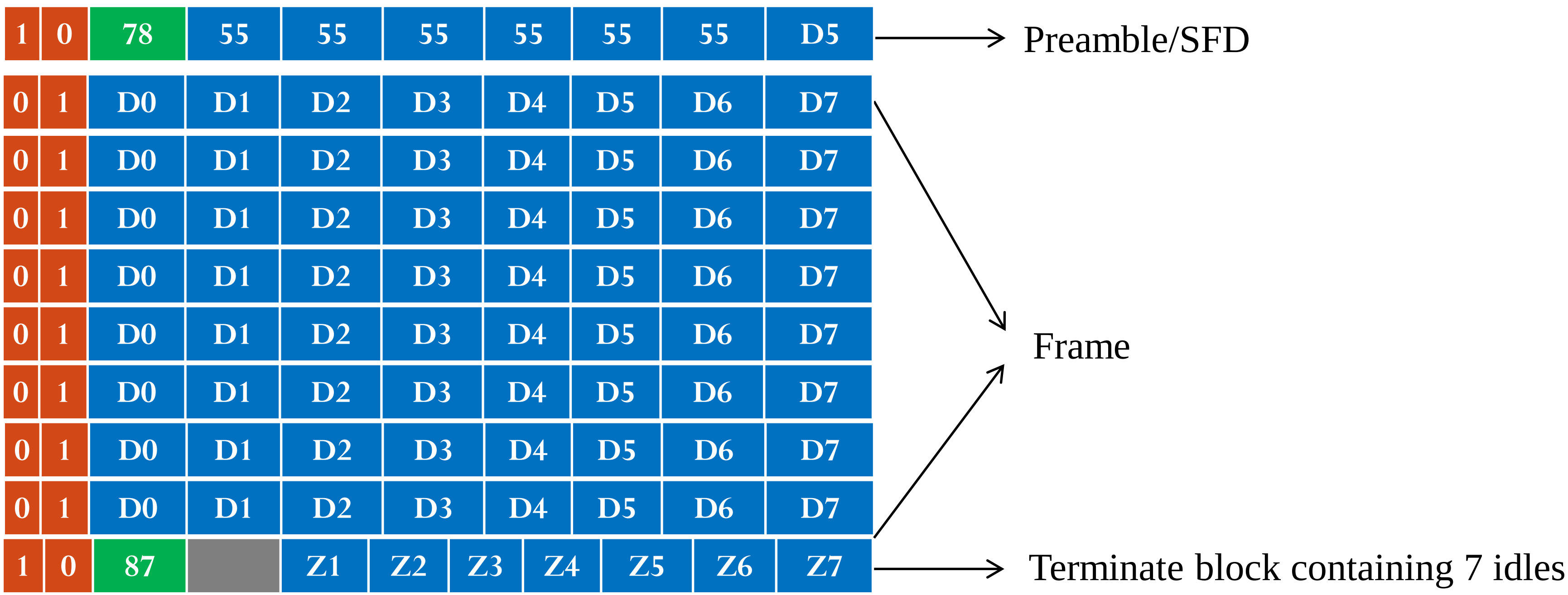
- “00” or “11” are invalid sync heads.

64B/66B Blocks in 10GBASE-R

Input Data	Sync	Block Payload								
Bit Position:	0 1	2								65
Data Block Format:										
$D_0 D_1 D_2 D_3/D_4 D_5 D_6 D_7$	01	D_0	D_1	D_2	D_3	D_4	D_5	D_6	D_7	
Control Block Formats:		Block Type Field								
$C_0 C_1 C_2 C_3/C_4 C_5 C_6 C_7$	10	0x1e	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7
$C_0 C_1 C_2 C_3/O_4 D_5 D_6 D_7$	10	0x2d	C_0	C_1	C_2	C_3	O_4	D_5	D_6	D_7
$C_0 C_1 C_2 C_3/S_4 D_5 D_6 D_7$	10	0x33	C_0	C_1	C_2	C_3		D_5	D_6	D_7
$O_0 D_1 D_2 D_3/S_4 D_5 D_6 D_7$	10	0x66	D_1	D_2	D_3	O_0		D_5	D_6	D_7
$O_0 D_1 D_2 D_3/O_4 D_5 D_6 D_7$	10	0x55	D_1	D_2	D_3	O_0	O_4	D_5	D_6	D_7
$S_0 D_1 D_2 D_3/D_4 D_5 D_6 D_7$	10	0x78	D_1	D_2	D_3	D_4	D_5	D_6	D_7	
$O_0 D_1 D_2 D_3/C_4 C_5 C_6 C_7$	10	0x4b	D_1	D_2	D_3	O_0	C_4	C_5	C_6	C_7
$T_0 C_1 C_2 C_3/C_4 C_5 C_6 C_7$	10	0x87		C_1	C_2	C_3	C_4	C_5	C_6	C_7
$D_0 T_1 C_2 C_3/C_4 C_5 C_6 C_7$	10	0x99	D_0		C_2	C_3	C_4	C_5	C_6	C_7
$D_0 D_1 T_2 C_3/C_4 C_5 C_6 C_7$	10	0xaa	D_0	D_1		C_3	C_4	C_5	C_6	C_7
$D_0 D_1 D_2 T_3/C_4 C_5 C_6 C_7$	10	0xb4	D_0	D_1	D_2		C_4	C_5	C_6	C_7
$D_0 D_1 D_2 D_3/T_4 C_5 C_6 C_7$	10	0xcc	D_0	D_1	D_2	D_3		C_5	C_6	C_7
$D_0 D_1 D_2 D_3/D_4 T_5 C_6 C_7$	10	0xd2	D_0	D_1	D_2	D_3	D_4		C_6	C_7
$D_0 D_1 D_2 D_3/D_4 D_5 T_6 C_7$	10	0xe1	D_0	D_1	D_2	D_3	D_4	D_5		C_7
$D_0 D_1 D_2 D_3/D_4 D_5 D_6 T_7$	10	0xff	D_0	D_1	D_2	D_3	D_4	D_5	D_6	

- Block type field has 4-bit hamming distance.
- Errors on type field could corrupt frame structure.
- 64B/66B validity is checked in PCS

A 64-octet Frame with Minimum IPG

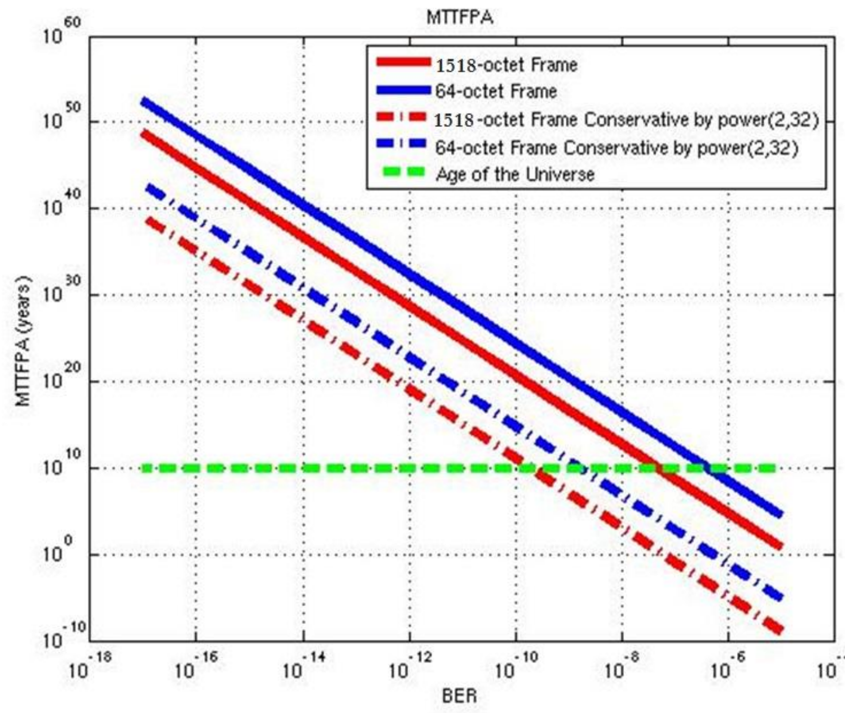


PCS checks 604 bits for a 64-octet frame:

- 10 bits in the start block
- 66*8 bits in the data blocks
- 66 bits in the terminate block. (Invalid control codes are marked as errors)

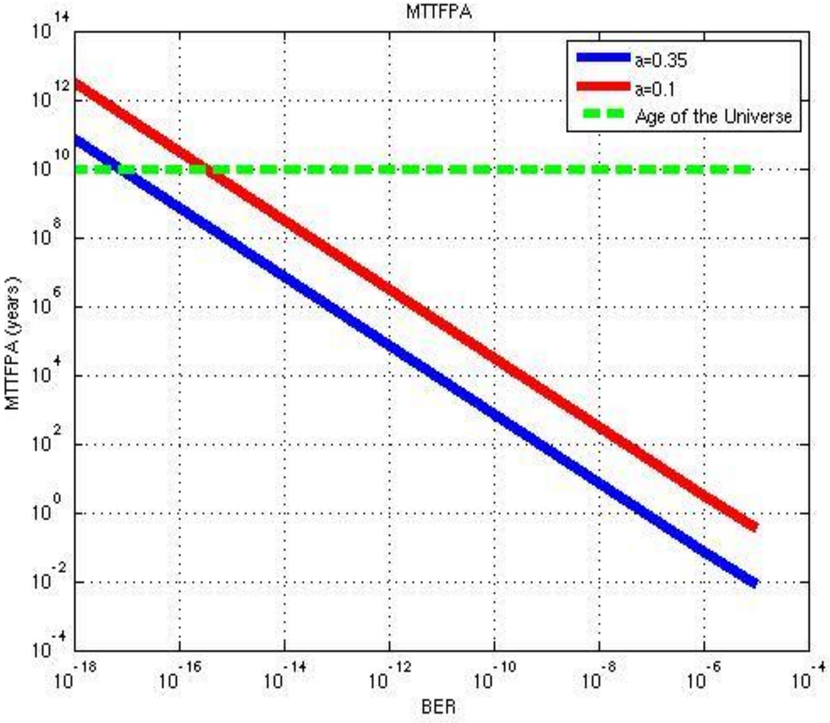
MTTFPA for Random Errors

- A conservative estimation can be made by assuming any four or more errors will generate a false packet acceptance event (walker_1_0300).
- Walker's result is conservative by 2^32 as CRC32 random error detect capability is not considered.
- Due to the error multiplication effect o the descrambler, the "packet size" for the error rate calculation is roughly:
  64-octet frame: 58+66*9=652 bits
  1518-octet frame: 12648 bits
- MTTFPA is not a problem when there is no DFE error propagation.



MTTFPA with DFE EP

- Adding DFE error propagation in Walker's analysis as in 802.3ap [3, 5]. Not conservative by 2^32.
- Gilbert error propagation model is used to DFE error propagation analysis. Suppose parameter "a" (P_{EP}) can be constraint to 0.35 for no-FEC operations. [6]
- At DER=1e-12, MTTFPA is 5.25e6 years for "a"=0.1 and 1.23e5 years for "a"=0.35.



MTTFPA Estimation for 64-octet Frames

MTTFPA Calculation Analysis

- MTTFPA calculation on slide 8 is conservative because bursts longer than 4bits can be detected in most cases if there is no 64B/66B sync head/type field corruption.
  - CRC32 burst detection capability is maintained after the self sync descrambler if all the errors are contained in the same frame.
  - When there is error spilling, 4-bit burst detection capability is conservative. In this case, only certain error patterns are undetectable [4].
  - A burst caused by a 1-tap DFE contains only all 1's. Exhaustive simulations for bursts up to 32 bits have been performed and show that this kind of burst is always detectable even with error spilling.

Errors on Transcodes/Type Fields

- Type field has hamming distance 4. Errors on sync head/type field could corrupt the structure of a frame. Therefore, CRC32 detection capability may be comprised. There are mainly 4 cases:

1. If the sync head of a data block is corrupted to “10” and the type field happens to be valid. A data block could become a terminate block and a packet is “shortened”.
2. If the sync head of a terminate block is corrupted to “01”. A terminate block becomes a data block.
3. Type field corruption of a start block could change the location of the SOP between S0 and S4.
4. Type field corruption of a terminate block could change the location of the EOP.

64B/66B Validity Check:

- Some transcode and type field errors can be detected by validity check in PCS.
- Case 1, if a data block is corrupted to a terminate block. Its following block is a data/terminate block instead of a control/start block. This block is invalid.
- Case 2, a corrupted terminate block do not cause a problem as the following block is a control block. A control block inside of a packet is invalid.
- Case 3, changing the location from s0 to s4 would create 4 control characters that must valid, so it very unlikely. Changing from s4 to s0 requires changing type field from 0x33 to 0x78. This is not possible for a simple burst (caused by a 1-tap DFE), but possible for a burst from a unconstrained DFE.
- Case 4, a shorten framed is not a problem for the same reason in case 3. However elongated packet is a problem.

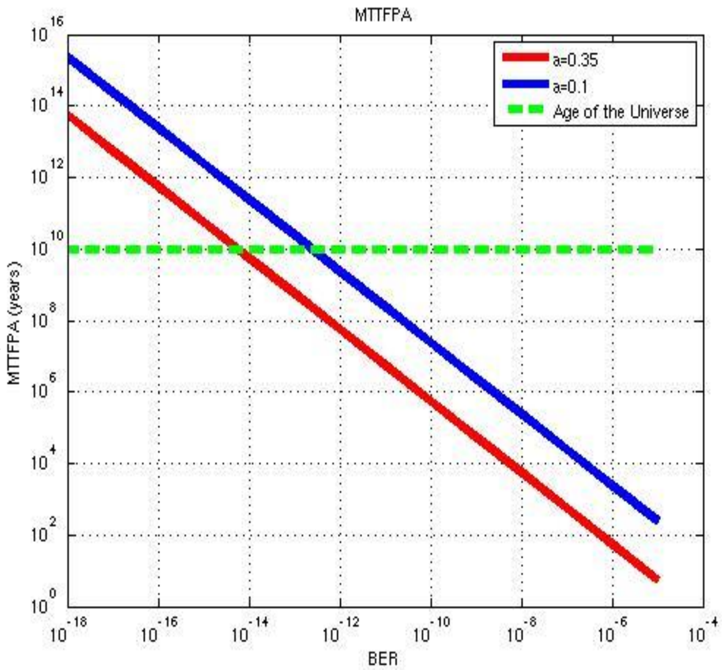
Case 4:

- There are 8 possible cases that a packet can be elongated by a simple burst 4'b1111 and still valid.
- Due to the 3x error multiplication effect of descrambler, the probability for this to happen is: P_T=DER*3*P_{EP}^3*(1-P_{EP})*8/8

Type Field	87 10000111	99 10011001	aa 10101010	b4 10110100	cc 11001100	d2 11010010	e1 11100001	ff 11111111
87	10000111	10000111	10000111	10000111	10000111	10000111	10000111	10000111
99	10011001	10011001	10011001	10011001	10011001	10011001	10011001	10011001
aa	10101010	10101010	10101010	10101010	10101010	10101010	10101010	10101010
b4	10110100	10110100	10110100	10110100	10110100	10110100	10110100	10110100
cc	11001100	11001100	11001100	11001100	11001100	11001100	11001100	11001100
d2	11010010	11010010	11010010	11010010	11010010	11010010	11010010	11010010
e1	11100001	11100001	11100001	11100001	11100001	11100001	11100001	11100001
ff	11111111	11111111	11111111	11111111	11111111	11111111	11111111	11111111

MTTFPA Estimation for 1-tap DFE:

- A single burst up to 32 bits is always detectable.
- All frame structure corruptions can be detected by PCS except case 4.
- MTTFPA achieves AOU when DER=1e-15. MTTFA at DER=1e-12 for “a”=0.35 is 4.05e7 years; for “a”=0.1 is 1.25e9 years.
- At DER=1e-12, “a”=0.35 and 0.1 are corresponding to normalized DFE coefficients 0.54 and 0.44. DFE coefficient limit 0.5 in Table 110-10 indicates “a”=~0.35 due to the existence of multiple taps. [6]
- To meet MTTFPA at DER=1e-12, “a” needs to be ~0.05 corresponding to DFE tap value 0.41.



DFE Coefficient Constraints

- DFE coefficient constraints are needed to guarantee MTTFPA but this may impact DER.
- We tried test case 1 and 2 in COM model. All settings are default for CR4 except DER_0 is set to 1e-12.
- Considering there are multiple DFE taps, DFE coefficients are constrained to 0.35 for bmax(1) and 0.1 for bmax(2…n).
- For DFE with feedback taps [0.35, 0.1], the probability to have 4-bit bursts at DER=1e-12 is about 1e-4. This is similar to a single tap DFE with tap value 0.41 (“a”=0.05).

TE 3m Cable Results

AWG	DFE Constraints	Test Case 1		Test Case 2	
		COM	DFE b1	COM	DFE b1
24	No	3.436	0.547	2.674	0.449
	Yes	3.119	0.34	2.678	0.32
26	No	3.118	0.565	2.342	0.422
	Yes	2.855	0.35	2.333	0.34
28	No	2.178	0.485	1.335	0.450
	Yes	1.764	0.35	1.129	0.35
30	No	1.407	0.482	0.247	0.591
	Yes	1.053	0.35	0.095	0.35

- Without constraints, DFE coefficients are larger than the limit.
- There is ~0.3dB COM loss due to the constraints.
- The victim is P2_TX2 in [7].

Amphenol 3m Cable Results

RX	DFE Constraints	Test Case 1		Test Case 2	
		COM	DFE b1	COM	DFE b1
P1RX1	No	2.720	0.61	1.943	0.45
	Yes	2.372	0.35	1.790	0.35
P1RX2	No	3.070	0.51	2.244	0.44
	Yes	2.821	0.34	2.179	0.35
P1RX3	No	2.874	0.51	1.983	0.5
	Yes	2.542	0.35	1.833	0.35
P1RX4	No	2.939	0.59	2.110	0.48
	Yes	2.774	0.33	2.026	0.35

- Without constraints, DFE coefficients are out of the limit for MTTFPA.
- COM loss due to the constraints is ~0.3dB.

MTTFPA Improvement

- If we add length check in PCS, case 3 and 4 no longer can be caused by a single burst.
  - MTTFPA is dominated by double bursts and is not a problem.
- On PCS TX side, extra 14 length information bits need to be inserted after EOP to replace 2 idles. PCS validity check needs to be changed for length check instead of idles for these two control codes after EOP. For example, the terminate block of the 64-octed frame needs to be changed to:

1	0	87		LEN	LEN	Z3	Z4	Z5	Z6	Z7

- Alternative, 16 bit length information can be added before EOP. Type field needs to be changed. PCS validity check rule stays the same.

1	0	AA	LEN	LEN		Z3	Z4	Z5	Z6	Z7

MTTFPA Improvement

- Alternatively we can add another layer of CRC:
  - With CRC8, MTTFPA = 4.05e7*2^8=1.04e10 Years for a=0.35 and MTTFPA=1.25e9*2^8=3.20e11 years for a=0.1.
  - With CRC16, MTTFPA = 4.05e7*2^16=2.65e12 Years for a=0.35 and MTTFPA= 1.25e9*2^16=8.19e13 years for a=0.1.
- A unscrambled CRC 8 has been adopted in 10GBase-T clause 55.
- As in the length check, extra 8 or14 CRC parity bits need to be inserted after EOP to replace 1 or 2 idles. 64B/66B validity rule needs to be modified for the control codes after EOP.

1	0	87		CRC	CRC	Z3	Z4	Z5	Z6	Z7

- CRC8 or CRC16 parities can also be added before EOP to keep 64B/66B validity check rules. But type field content needs to be changed.

1	0	AA	CRC16	CRC16		Z3	Z4	Z5	Z6	Z7

Conclusions and Proposals:

- DFE error propagation has a huge impact on MTTFPA. DFE shape is suggested to be constrained to guarantee MTTFPA at certain DER.

- MTTFPA at DER=1e-12 is not a problem if there is no DFE error propagation.

- With DFE error propagation, MTTFPA fails at DER=1e-12. We suggest to take one of the following actions for no-FEC operations.

  1. Add extra length or CRC check.
  2. Set COM parameters: bmax(1)<0.35 and bmax(2…n)<0.1.
  3. Set DER target to 1e-15.

References:

[1] P. Koopman, "32-bit cyclic redundancy codes for internet applications," Conf. Dependable Systems and Networks (DSN), July 2002.

[2] http://www.ieee802.org/3/bj/public/jul12/cideciyan_01_0712.pdf

[3] http://www.ieee802.org/3/ap/public/nov05/szczepanek_01_1105.pdf

[4] http://grouper.ieee.org/groups/802/3/10G_study/public/july99/figueira_1_0799.pdf

[5] 10GBASE-KR FEC Tutorial.pdf

[6] ran_020415_25GE_adhoc.pdf

[7] shanbhag_020415_25GE_adhoc_v2.pdf