Encapsulation Baseline Proposal for EFM Copper

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Current Status

- Why do we need this?
- Reason: polls at New Orleans meeting showed current HDLC baseline will generate lots of NO (TR) votes
  - HDLC variable overhead the killer
- But, discussion served to elicit group's requirements for encapsulation
- This proposal satisfies these requirements

Requirements

- Low, data-independent overhead (~<3%)
- Handle ethernet-sized frames: ~1500 octets
- Compatible with DSL α/β-interface: see ITU-T Liaison
- Minimal interframe gap: ‘allow frames to be transmitted with a minimal gap between frames (IPG and preamble reconstructed at receiver)
- MTTFPA of ~10^9 to 10^{10} years: given specified BER and error distribution at the DSL α/β-interface
- Quick recovery from errors: recovery from loss of sync lock should be quick, in order to minimize the number of lost frames

Proposal highlights

- Fixed-length codewords, similar to 64b/66b
  - Satisfies "quick recovery from errors"
  - Superior to G.gfp in this regard
- Length = 65 *bytes*
  - Compatible with DSL α/β-interface
- Additional CRC added for each frame
  - Robustness compatible with error characteristics in DSL
- Small interframe gap
  - 1 byte minimum

Codeword formats

- Overhead of 1.125% - half that of 64b/66b
- C_i, i=0 to 64, code values in control codewords

Type	Frame Data	Sync Byte	Byte fields 1-64									
all data	DDDD---DDDD	$0F_{16}$	D_0	D_1	D_2	D_3	D_4	D_5	→	D_{61}	D_{62}	D_{63}
end of frame	k D's, k=0 to 63	$F0_{16}$	C_k	D_0	D_1	D_2	D_3	→	D_{k-1}	Z	→	Z
all idle	ZZZZ---ZZZZ	$F0_{16}$	C_{64}	Z	Z	Z	Z	Z	→	Z	Z	Z

Encoding Start of Frame

- How?
- A frame may arrive from MAC at MII while an End of Frame codeword is being transmitted.
  - At 100 Mbps, MII rate much faster than line rate
- Need ability to insert SOF into codeword once its transmission has started.
- Otherwise, must wait for completion of codeword transmission, and beginning of new codeword
  - May needlessly delay transmission of new frame; decreases encapsulation efficiency

Encoding Start of Frame (*cont'd*)

- Here's how:
- Designate *S* byte value as Start of Frame Marker
  - *S* just needs to be distinct from *Z*
  - Remember, *Z* is not MAC data, it's just idle codeword-fill transmitted when no MAC data is available

Type	Frame Data	Sync Byte	Byte fields 1-64									
all idle → Start of Frame	*k* D's, *k*=0 to 62	$F0_{16}$	C_{64}	Z	Z	S	D_0	D_1	→	D_{k-3}	D_{k-2}	D_{k-1}
End of Frame → Start of Frame	1st frame: *k* D's, *k*=0 to 62 2nd frame: *j* D's, *j*=0 to 62-*k*	$F0_{16}$	C_k	D_0	→	D_{k-1}	Z	→	S	D_0	→	D_{j-1}

Error Analysis (1)

- First, a word about 64b/66b:
  - Optical channels modeled as Binary Symmetric Channels (BSCs)
    - Bit errors independent
    - *N*+1 errors occur alot less frequently than *N* errors
    - 64b/66b designed to detect 3 or fewer errors, regardless of frame content
  - However, DSL α/β-interface looks nothing like this
    - Bit errors bursty, e.g., R-S decode errors average a little more than 9 errored bytes (for *t*=8)
    - Four-bit errors are just as likely to occur in a frame as 1-bit errors
  - ∴ error analysis done for 64b/66b on BSCs not applicable to EFM-Cu

Error Analysis (2)

- Robustness will depend on devising a scheme that detects most errors, rather than immunity to <*x* errors
- Fortunately, EFM-Cu is not alone in this regard,
- EPON FEC robustness analysis is similar,
- So EFM-Cu group won't be the only one proposing this to 'dot-3.

Error Analysis (3)

- Some numbers (see Backup)
  - Bit error ratio (at α/β-interface) $P_b = 1 \times 10^{-7}$
  - Byte error ratio (at α/β-interface) $P_B \approx 2 \times 10^{-7}$
  - Byte error ratio (at R-S decoder output) $P_{B'} \approx 1 \times 10^{-7}$
  - R-S decode error ratio (decoder error + decoder failure) $P_M \approx 2.8 \times 10^{-6}$
  - R-S undetectable error ratio (decoder error) $P_E < 6.2 \times 10^{-11}$

Error Analysis (4)

- Frame Error Ratio
  - R-S codewords per Ethernet Frame = 1500/239 = 6.2
  - Frame Error Ratio $P_F = 1-(1-P_M)^{6.2} = 1.7 \times 10^{-5}$
- Undetected Errored Frames
  - Ethernet FCS detects all but one in 2^{32} frame errors
  - $P_{FPA} = P_F \times 2^{-32} = 4 \times 10^{-15}$
  - 10 Mbit/s = 833 frames/s $\Rightarrow$ MTTFPA = 9500 years
- $\therefore$ Encapsulation must improve this by a factor of 10^6

Improving Robustness

- Append another CRC to the frame, before encapsulation
  - i.e., the CRC is added per frame, not per codeword
  - need to use a CRC that provides additional protection beyond that provided by Ethernet CRC
- Existing Ethernet CRC
  - $x^{32}+x^{26}+x^{23}+x^{22}+x^{16}+x^{12}+x^{11}+x^{10}+x^{8}+x^{7}+x^{5}+x^{4}+x^{2}+x+1$
  - Primitive (no factors)
  - Same as 32-bit HDLC CRC
  - d_{min}=4 for Ethernet-sized frames (catches all errors of 3 bits or less)

Additional CRC

- HDLC 16-bit CRC:

  $x^{16}+x^{12}+x^{5}+1 = (x+1)(x^{15}+x^{14}+x^{13}+x^{12}+x^{4}+x^{3}+x^{2}+x+1)$

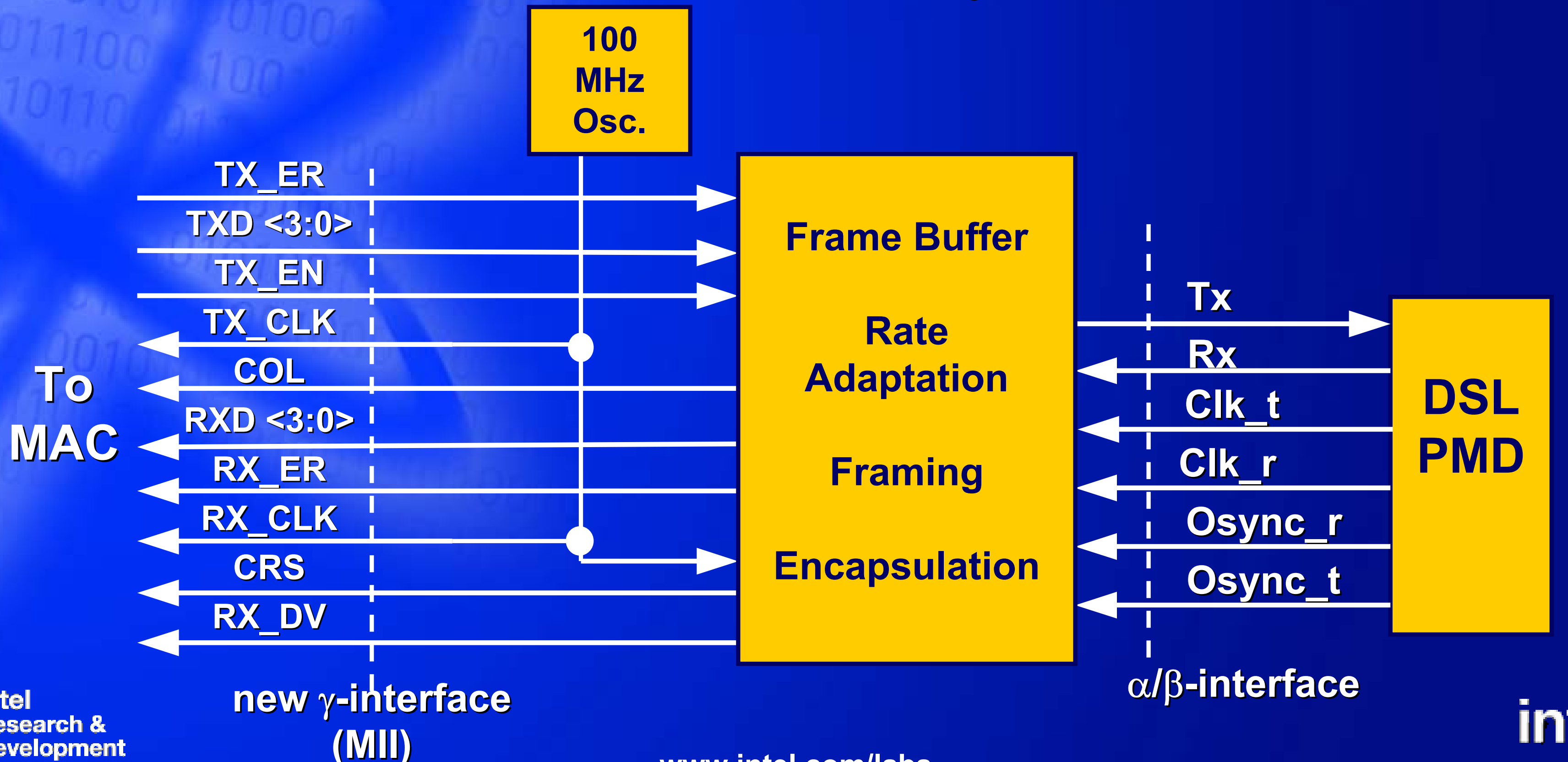
- 32-bit CRC32/4 (see ref. [9]):

  $x^{32}+x^{28}+x^{27}+x^{26}+x^{25}+x^{23}+x^{22}+x^{20}+x^{19}+x^{18}+x^{14}+x^{13}+x^{11}+x^{10}+x^{9}+x^{8}+x^{6}+1 = (x+1)(x^{31}+x^{30}+x^{29}+x^{28}+x^{26}+x^{24}+x^{23}+x^{22}+x^{18}+x^{13}+x^{10}+x^{8}+x^{5}+x^{4}+x^{3}+x^{2}+x+1)$

- Both these detect all errors with odd number of bits
  - Since they contain $x+1$ as a factor
  - Neither of these have factors in common with Ethernet CRC
  - CRC32/4 has best d_{min} profile found by [9] for polynomial in the form $(x+1)p(x)$
  - CRC32/4 used in iSCSI standard
- Propose that CRC32/4 be used as encapsulation CRC

Layering & Interfaces

- We're defining a new TPS-TC, so we define a new γ-interface
  - ITU-T Q4/15 says "Go ahead"
- Since this is Ethernet-specific, why not make it MII?



What about aggregation?

- Aggregation sublayer is below rate matching sublayer
- Aggregation would generate multiple α/β-interfaces, rather than multiple γ-interfaces
- May need to define a second *S* code for aggregation

Summary

- New framing and encapsulation method that meets all identified requirements is proposed
- This would be a new Ethernet-specific TPS-TC forwarded to ITU-T
- New γ-interface is simply MII as specified in current baseline

Backup

Error Computations

- P_b specified at 10^{-7}
- Estimate post R-S decoder scrambler error multiplication at $2\times$; so BER at R-S output $P_{b'} = 0.5 \times 10^{-7}$
- $P_{B'}$, byte error ratio $\frac{P_{b'}}{P_{B'}} = \frac{2^{8-1}}{2^8 - 1} = \frac{128}{255} \Rightarrow P_{B'} \cong 2 \times P_{b'}$ $P_{B'} = 10^{-7}$ (see ref. [1])
- $P_{B'}$ as a function of pre-R-S byte error ratio (for (255,239) code):

$$P_{B'} \cong \sum_{j=9}^{255} \frac{j}{255} \binom{255}{j} p^j (1-p)^{255-j}$$

$p = 0.00445$; see G.975 and ref. [1]

Error Computations (2)

- P_M, probability of incorrectly decoded codeword:

$$P_M = \sum_{j=9}^{255} \binom{255}{j} p^j (1-p)^{255-j} = 2.8 \times 10^{-6}$$

- If "decoder failure" codewords (i.e., uncorrectable but detectable) are excluded:

$$P_E \le P_M \times 255^{-(255-239)} \sum_{s=0}^{8} \binom{255}{s} 255^s = 2.8 \times 10^{-6} \quad \times \quad 2.2 \times 10^{-5} = 6.2 \times 10^{-11}$$

(see ref. [2])

(this would require change to α/β-interface, however)

References

[1] Sklar; B, *Digital Communications*, Prentice Hall 2001

[2] McEliese, R.J., and Swanson, L; *On the Decoder Error Probability for Reed-Solomon Codes*, NASA TDA Progress Report 42-84, 1985

[3] ITU-T G.975 (10/2000), *Forward Error Correction for Submarine Systems*

[4] ITU-T G.gfp, *General Framing Procedures*

[5] ITU-T contribution OJ-075, *Framing and encapsulation considerations for EFM*, Intel Corp., October 2002

[6] ISO/IEC-3309, *Information technology - Telecommunications and information exchange between systems - High-level data link control (HDLC) procedures - Frame structure*

[7] IETF Internet Draft draft-sheinwald-iscsi-crc-02.txt, *iSCSI CRC Considerations* (2002)

[8] Communications Statement from ITU-T Q4/15 to 802.3ah, October 2002

[9] Castagnoli, et al; *Optimization of Cycle Redundancy-Check Codes with 24 and 32 Parity Bits*, IEEE Transactions on Comm., June 1993