Requirements for EFM encapsulation technique

Proposes some specific requirements to the encapsulation technique for EFM copper

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Agenda

- This presentation proposes some parameters of the EFM encapsulation, including those to meet the requirements on Mean Time To False Packet Acceptance (MTTFPA)

- The goal of this presentation is to assist selection of the appropriate encapsulation technique for EFM copper

Main objectives

- The MTTFPA of 10^9 years per link was suggested as a generic requirement
- The IEEE 802.3 CRC-32 coding and appropriate encapsulation technique allow to meet the MTTFPA in lines with BER of about 10^{-9} - 10^{-11}
- xDSL loops are not so predictable and stable as standard TIA cabling used for LANs. Therefore, a nominal 6 dB noise margin is introduced over the performance level with BER of 10^{-7}
- The BER of xDSL lines with even 3 dB margin is usually at least 3-4 orders lower than 10^{-7}. Respectively, the MTTFPA for all installations with nominal margin and even 3 dB lower margin, is much higher than the required

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Network-based approach

- **Since nominal 6 dB margin is generally maintained, only few installations with reduced margin (usually temporarily) are expected to be an intensive source of false packets. Thus, a statistical approach considering MTTFPA for a whole network, rather than MTTFPA for a particular link is suggested**

- **Assume that *at any time* 10% of EFM lines in the network has their margin reduced to 0 dB. If each of these lines will provide MTTFPA of 10^8 years per direction, the total MTTFPA for the network will be the same as generally required.**

  Assuming all links are 10 Mb/s with average length of packet 750 bytes, we get the required probability of false packet:

  $$P_{FP} \approx 1/(10^8 \text{years} \times 5.25 \cdot 10^{10} \text{ packets/year}) \approx 2 \times 10^{-19}.$$

FP probability: more details

- **Two factors causing False Packets (FP) are considered:**
  1. Bit errors (BE) inside the transmit frame
  2. Loss or false detection of frame delimiters (LFD)

- **The FP due to #1 are independent of those due to #2, and may be reduced by additional coding in TPS-TC. Since coding in TPS-TC usually helps to detect LFD as well, it is suggested:**

  - first, to get a coding technique to provide $P_{FP\text{-}BE} < 2\times10^{-19}$

  - second, to find the encapsulation method providing probability of LFD at least 10 times lower than $P_{FP\text{-}BE}$

  Thus, encapsulation method will have insignificant impact on FP acceptance.

- $P_{FP\text{-}BE} < 2\cdot10^{-19}$

  $P_{FP\text{-}LDF} < 0.1\cdot P_{FP\text{-}BE} = 2\cdot10^{-20}$

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FP probability: bit errors

- To analyze FP probability due to bit errors (BE), two cases were considered:
  - Randomly distributed single errors: usual in xDSL links where error correction coding is not used

  - Packets of multiple errors (correlated errors): usual in xDSL links employing forward error correction (FEC). If Reed-Solomon coding RS(*Q*,*Q-2t*) is used, there are usually *t*+1 to 2*t*+1 errored octets located in a *Q*-octet block of the received frame

- Regardless of the particular error distribution, the standard BER at α/β interface in both cases doesn't exceed 10^{-7}

- xDSL uses scrambling for data randomization (prior to FEC if FEC used). Since scrambling polynomial is not divided by the CRC generating polynomial, error propagation due to the descrambler doesn't impact the FP probability

Is CRC-32 sufficient?

- A standard IEEE.802.3 CRC-32 is capable to detect all single, double and triple errors, and most of quad errors in Ethernet packets of maximum length (1538 bytes)
- If multiple errors (~8 or more) appear in the frame, CRC-32 misses FP with probability of about 2^{-32}
- It may be shown [1, 2] that error detection capabilities of CRC-32 are not sufficient to meet the required FP probability ($P_{FP\text{-}BE} < 2 \cdot 10^{-19}$) if bit errors are either randomly distributed (no FEC) or correlated (FEC is used)
- Additional coding in TPS-TC is necessary regardless of the encapsulation technique used!

Adding CRC-16 in TPS-TC

- CRC-16 (ISO/ITU-T) can detect all odd error patterns, all double errors, and most of quad errors in the frame of maximum length. When concatenated with CRC-32, all quad errors may be expected to be detected

- If multiple errors appear in the frame, CRC-16 concatenated with CRC-32 misses FP with probability of $2^{-32-16} = 2^{-48}$

- Detailed calculation of FP probability in [2] shows that *in the worst case* P_{FP-BE} doesn't exceed:

  - $6.6 \cdot 10^{-24}$ in the case of randomly distributed errors

  - $7.8 \cdot 10^{-20}$ in the case FEC RS(255,239) is used

  Both values are below the requirement $P_{FP-BE} < 2 \cdot 10^{-19}$

Conclusions - 1

- Regardless of the encapsulation technique used, additional coding for error detection in TPS-TC is necessary
- ISO/ITU CRC-16 used in addition to IEEE 802.3 CRC-32 provides sufficiently low probability of FP

FP due to LFD: scope

- In the case of loss or false detection of the frame delimiters (LFD) the received frame, from the CRC operation perspective, will contain random data. Since the concatenated CRC-16 and CRC-32 miss the errored frame with probability of 2^{-48}, the required FP probability due to LFD will be met if the probability of LFD in the EFM link doesn't exceed:

$$P_{LFD} < P_{FP\text{-}LFD} / 2^{-48} = 2 \cdot 10^{-20} / 3.55 \cdot 10^{-15} = 5.6 \cdot 10^{-6}$$

If a primitive technique is used...

- **Consider the most primitive encapsulation technique:**

  - Start of Frame (SoF) and End of Frame (EoF) are marked with the same 1-byte code word (such as in HDLC and COBS, for instance)

  - The minimum Hamming distance between SoF/EoF and other data bytes equals to 1

- **LFD may be result of the following events:**

  1. False EoF or SoF occur in the middle of the frame. Since the same pattern is used for both SoF and EoF, two sequential FP will be created

  2. Loss of SoF. In this case frame will either merged with the previous frame, or will use inter-frame filling as a false SoF

  3. Loss of EoF. Similar to case 2

  Other cases with double events are not considered as lower probable

If a primitive technique is used...(2)

- To calculate the probability of at least one false SoF or EoF, assume that any octet of the PTM-TC frame gets all possible values (except 0x7E) with the same probability $P \approx 2^{-8}$.

- In the Case 1 and randomly distributed errors, the probability to get a false SoF/EoF in an N-octet frame equals:

$$P_{LFD} = \sum_{m=1}^{N} \binom{m}{N} \cdot P_{SoF}{}^{m} \cdot (1 - P_{SoF})^{N-m} \quad \text{where} \quad P_{SoF/EoF}(1) = P \cdot \binom{1}{8} \cdot p \cdot (1-p)^{7}$$

For bit error probability p=10^{-7} and N=1538 (worst case), $P_{LFD} \approx 4.8 \cdot 10^{-6}$, which complies the required $P_{LFD} < 5.6 \cdot 10^{-6}$.

The P_{LFD} for Case 2 and Case 3 will be even lower, [2]

- In the case RS(255,239) FEC is used, the probability to get a false SoF/EoF is much lower than the probability of errored RS codeword. The latter, as shown in [1, 2], is itself usually less than $5.6 \cdot 10^{-6}$.

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Conclusions - 2

- After an appropriate encoding (CRC-16 or equivalent) is introduced into TPS-TC, even a very primitive one-byte frame delimiters are sufficient to avoid any significant impact of the encapsulation technique on the probability of false packet

- All the considered encapsulation techniques: HDLC, COBS, GFP and 64b/66b are not expected to violate the target MTTFPA, accepted for Ethernet transport

- MTTFPA should be not an issue for selection of the encapsulation technique, unless it uses frame delimiters shorter than one byte

Error detection in LAH

- Loop Aggregation Header (LAH) delivers information necessary for proper aggregation of the received fragments of the frame
- If the received fragment is discarded due to an error, the Loop Aggregation Entity (LAE) will hold and not discard for a certain time t_h all other received fragments, delaying all the consequent frames by t_h, respectively
- If an error is detected in the LAH of the received fragment, it is still uncertain what frame it belongs and which of already received fragments may be discarded. Thus, the same hold time of t_h should be applied

Conclusions - 3

- Usage of CRC in Loop Aggregation Header in addition to the CRC for the whole frame doesn't increase robustness. Therefore, it is not actually necessary

Remove the IPG and Preamble?

- A standard Ethernet frame contains a 7-byte Preamble and a 1-byte SDF. These 8-byte and a 12-byte IPG may be reduced prior the transmission, then reconstructed on the other side of the line

- Reduction of the Preamble/IPG overhead can reduce the required line rate. Although, to support transport of long frames (1518 bytes) the reduction can't be more than:

  $q < (8+12)/(1518+8+12) = 0.013$ (1.3%),

  and probably doesn't worth the effort.

Keep the IPG and Preamble?

- Frame encapsulation adds an overhead prior the transmission, which is removed at the receive site
- The encapsulation overhead may use the time slots of IPG bytes. If the encapsulation overhead is less than 12 bytes, it is fully accommodated in the IPG space. After overhead reduction IPG is automatically reconstructed
- If the encapsulation overhead is more than 12 bytes, it is worth to remove the Preamble/SDF
- If the encapsulation overhead is more than 20 bytes, it is also necessary to increase the line bit rate

Conclusion - 4

- Keep IPG/Preamble if maximum encapsulation overhead doesn’t exceed 12 bytes.
  This relates to encapsulation techniques such as GFP, COBS, 64b/66b

- Remove IPG/Preamble/SDF if maximum encapsulation overhead exceeds 12 bytes.
  This relates to HDLC, for instance

Proposal

The following principles of encapsulation technique are proposed

- At least ISO/ITU CRC-16 or equivalent encoding shall be added for each transmitted Ethernet packet or a fragment of it
- MTTFPA should be not an issue for any encapsulation technique, if this technique uses frame delimiters of at least one byte long
- Error detection capabilities in the Loop Aggregation Header doesn't improve, in general, robustness of the aggregation process
- Keep IPG/Preamble if encapsulation overhead is less than 12 bytes, and remove prior the transmission if it is more

Simplicity and effectiveness should be considered as the main parameters for the encapsulation technique

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References

- [1] Barry Mahony "EFM-Cu Framing & Error Detection". IEEE 802.3ah, Edinburgh, May 2002
- [2] V.Oksman "On Ethernet transport over DSL". Contribution ITU-T OJ-94R1, Osaka, Japan, October 2002
- [3] rfc.3385 "Internet Protocol Small Computer System Interface (iSCSI). Cyclic Redundancy Check (CRC)/Checksum Considerations"