HDLC framing of Ethernet packet

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Abstract

• HDLC framing, used in QAM VDSL, is analyzed here in terms of error packet acceptance, and overhead.

• We show here that:
  – The probability of Erroneous packet received by upper layer is in the order of $10^{-36}$ for QAM-256.
  – HDLC overhead is reasonable and provides adequate ability for packet length forecasting.
HDLC Background

- The VDSL PHY uses HDLC framing for the packet transmitted/received to/from the higher layer.
- HDLC Frame includes:
  - Opening Flag  7E hex
  - Address field  FF hex
  - Control field  03 hex
  - Information field  Original Ethernet Packet, 1522 octets max.
  - FCS  CRC16 (2 octets)
  - Closing Flag  7E hex
- To avoid Opening/Closing Flag within the Information field, Byte-stuffing is used:
  - 7E hex  \(\Rightarrow\)  7D 5E  hex
  - 7D hex  \(\Rightarrow\)  7D 5D  hex
Calculation of Probability of Erroneous Packet acceptance

The probability we look for depends on the following factors:

- P1: Pre-decoder error probability
- P2: Post-decoder error probability
- P3: Erroneous generation of a HDLC Flag probability
- P4: HDLC & Ethernet CRC un-detection probability

The resulting probability for false acceptance of erroneous Ethernet packet is:

\[ P_{\text{total}} = P_1 P_2 P_3 P_4 \]
P1- Pre-decoding error probability

The pre-decoding error probability is given by:

\[ P_{in,rs} = P_{SE} \cdot \alpha \cdot \beta \]

Where:

\[ P_{SE} = 10^{-4} \]

is a conservative symbol-error probability of VDSL line

\[ \alpha \]

- Is the ratio of Byte rate to Symbol rate, depending on the constellation.

\[ \beta \]

- Increases the probability due to Symbol splitting into 2 Bytes, in QAM-8, 32, 64, 128. In QAM-4, 16, 256 a Symbol is never split over symbol boundary. We increase the Byte error probability according to the percentage of cases of Symbol split.
P2: post-decoder error probability

P2 is given by (see ref. 1 and 2):

\[
P_{\text{out,rs}} = \frac{1}{N} \sum_{i=N_c+1}^{N} i \cdot \binom{N}{i} \cdot P_{\text{in,rs}}^i \cdot (1 - P_{\text{in,rs}})^{N-i}
\]

Where:

\( P_{\text{out,rs}} \) is the post-decoding Byte error probability of the Reed-Solomon

\( P_{\text{in,rs}} \) is the pre-decoding Byte error probability of the Reed-Solomon.

\( N = 255 \) and \( N_c = 8 \) For (255,239) Reed-Solomon
The probability of at least one Byte-error in a frame of length $F$, at the output of the RS-decoder is:

$$P_1 = 1 - (1 - P_{\text{out,rs}})^F \approx F \cdot P_{\text{out,rs}}$$

Where:

$$F = 1536 \text{ Bytes, as a max. limit.}$$
P3 and P4

• **P3** - The probability of an erroneous Byte to be an HDLC flag, 7E hex, is:

\[ P_3 = 2^{-8} \]

• **P4** - HDLC frame contains 16-bit CRC. The Ethernet packet contains 32-bit CRC:

\[ P_4 = 2^{-16} \cdot 2^{-32} \]
Using the above process and parameters yields the following:

<table>
<thead>
<tr>
<th>Constellation</th>
<th>$P_{\text{total}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>QAM-4</td>
<td>$1.97 \cdot 10^{-30}$</td>
</tr>
<tr>
<td>QAM-8</td>
<td>$3.87 \cdot 10^{-31}$</td>
</tr>
<tr>
<td>QAM-16</td>
<td>$4.02 \cdot 10^{-33}$</td>
</tr>
<tr>
<td>QAM-32</td>
<td>$2.05 \cdot 10^{-32}$</td>
</tr>
<tr>
<td>QAM-64</td>
<td>$4.02 \cdot 10^{-33}$</td>
</tr>
<tr>
<td>QAM-128</td>
<td>$4.02 \cdot 10^{-33}$</td>
</tr>
<tr>
<td>QAM-256</td>
<td>$8.02 \cdot 10^{-36}$</td>
</tr>
</tbody>
</table>
Error calculation: Summary

- For QAM-256 @ Symbol-error rate of $10^{-4}$, the probability is $8.02 \cdot 10^{-36}$. For QAM-4 we get $1.97 \cdot 10^{-30}$.

- For 10M EoVDSL, this is about $10^{24}$ years of endless long Ethernet packet transmission. (For QAM-4 we get $10^{18}$ years).

- For 1Gig Ethernet to achieve such performance, BER better than $10^{-19}$ is needed (see ref 3).

- For 10Gig Ethernet to achieve such performance, BER better than $10^{-12}$ is needed (see ref 3).

- Thus, the probability of an erroneous packet being transferred to upper layer, is very low, and well compared to other protocols.
HDLC overhead compared to 64b/66b

- HDLC Frame includes:
  - Opening Flag 7E hex
  - Address field FF hex
  - Control field 03 hex
  - Information field Original Ethernet Packet, 1522 octets max.
  - FCS CRC16 (2 octets)
  - Closing Flag 7E hex

- To avoid an Opening/Closing Flag within the Information field, HDLC uses Byte-Stuffing:
  - 7E hex ⇒ 7D 5E hex
  - 7D hex ⇒ 7D 5D hex

- Overhead = 6 Bytes (fixed) + Byte-stuffing (statistical)
HDLC components

- The fixed overhead is 6 Bytes and ranges from 9.375% for shortest packet, to 0.3942% for longest packet.

- Byte Stuffing: each appearance of 7E or 7D adds one Byte overhead to the packet.

- The probability for M appearances of 7E or 7D in a packet of length L:

\[ P = \sum_{i=1}^{M} \binom{L}{i} \cdot P_1^i \cdot (1 - P_1)^{L-i} \]

Where: \( P_1 = 2 \cdot 2^{-8} \)
HDLC overhead vs. probability  (fixed + statistical)

HDLC overhead (octets) vs. probability, for various packet lengths

overhead, octets

probability, %

0  5  10  15  20  25  30  35  40  45  50  55  60  65  70

5  7  9  11  13  15  17  19  21  23  25  27  29

64  128  256  512  1522
HDLC overhead probability vs. % of packet length

HDLC overhead probability

Overhead, % of packet length

Probability, %

0 2 4 6 8 10 12 14 16 18 20 22 24

0 10 20 30 40 50 60 70

0 512 256 128 64

1522 0
64b/66b Framing overview

- In 10Gig Ethernet, the 64b/44b framing is used to encapsulate the packet.

**In 64b/66b:**
- Each frame starts with a SOP flag, and ends with an EOP flag.
- Each frame is divided into 8-octet codewords.
- There are: Data codeword, Mixed Data/Control codeword.
- Data codeword has “01” sync preamble.
- Mixed Data/Control codewords have
  - “10” sync preamble
  - Data octets
  - Control octets, as needed to fill a 64-bit codeword.
64b/66b Codeword structure

- S=SOP, T=EOP, Z=Control, D=Data
- Two possible SOP: - S D D D, D D D D
  - Z Z Z Z, S D D D
- Pure data: - D D D D, D D D D
- Pure control: - Z Z Z Z, Z Z Z Z
  - D D D T, Z Z Z Z - D D D D, D D D T
Taking all this together yields:

\[ \Delta_L = \left\lceil \frac{L + 2}{8} \right\rceil \cdot (8 + \frac{1}{4}) - L \]

Where:

- \( \Delta_L \) is the overhead, in octets, best-case. For worst-case: need to add 4 octets, due to SOP alignment.

- \( L \) is the packet length, in octets.
64b/66b Overhead in octets, Periodic behavior

The periodic overhead of 64b66b framing, in octets
Min. & Max. Overhead of 64b66b framing, in %

Deviation of 64b/66b overhead, % of packet length

% of packet length

packet length
Average HDLC overhead vs. 64b66b overhead

HDLC vs. 64b66b overhead

% of packet length

packet length

HDLC
64b66b
$3\sigma$ of HDLC overhead vs. 64b66b overhead

![Graph showing HDLC vs 64b66b overhead comparison.](graph.png)
Summary

- HDLC overhead is influenced by:
  - Control (6 octets, fixed)
  - Packet length (statistical Stuffing)
- 64b66b overhead is influenced by:
  - SOP & EOP (2 octets, fixed)
  - SOP alignment (0 or 4 octets, statistical)
  - Packet length modulu 8 (periodic behavior, up to 7 octets)
  - Preamble (0.25 octet per 8 octets of the new frame)

- Both framing schemes have fixed & statistical behavior of the overhead.
- Prediction of packet length is problematic in either case.
- The average HDLC overhead is lower than the 64b/66b overhead.
References


Pre-decoding error probability

The following table summarizes the above:

<table>
<thead>
<tr>
<th>Constellation</th>
<th>Number of splits</th>
<th>$\beta$</th>
<th>$\alpha$</th>
<th>$P_{\text{out,rs}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>QAM-4</td>
<td>0</td>
<td>1.0</td>
<td>4</td>
<td>$9.23 \cdot 10^{-17}$</td>
</tr>
<tr>
<td>QAM-8</td>
<td>2 out of 8</td>
<td>1.25</td>
<td>2.667</td>
<td>$1.82 \cdot 10^{-17}$</td>
</tr>
<tr>
<td>QAM-16</td>
<td>0</td>
<td>1.0</td>
<td>2</td>
<td>$1.88 \cdot 10^{-19}$</td>
</tr>
<tr>
<td>QAM-32</td>
<td>4 out of 8</td>
<td>1.5</td>
<td>1.6</td>
<td>$9.64 \cdot 10^{-19}$</td>
</tr>
<tr>
<td>QAM-64</td>
<td>2 out of 4</td>
<td>1.5</td>
<td>1.333</td>
<td>$1.88 \cdot 10^{-19}$</td>
</tr>
<tr>
<td>QAM-128</td>
<td>6 out of 8</td>
<td>1.75</td>
<td>1.143</td>
<td>$1.88 \cdot 10^{-19}$</td>
</tr>
<tr>
<td>QAM-256</td>
<td>0</td>
<td>1.0</td>
<td>1</td>
<td>$3.76 \cdot 10^{-22}$</td>
</tr>
</tbody>
</table>