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 ⇒ 7D 5E hex
  - 7D hex ⇒ 7D 5D hex

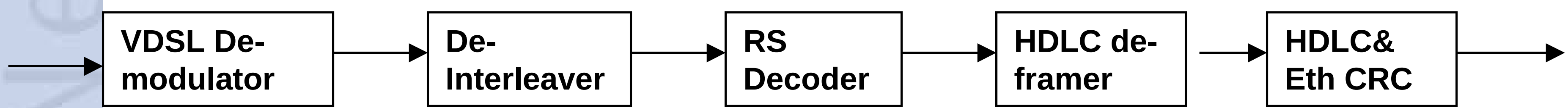
Calculation of Probability of Erroneous Packet acceptance

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:

$$P_{total} = P_1 P_2 P_3 P_4$$



P1- Pre-decoding error probability

The pre-decoding error probability is given by:

$$P_{\mathrm{in},rs} = P_{SE} \cdot \alpha \cdot \beta$$

Where:

$P_{SE} = 10^{-4}$ **is a conservative symbol-error probability of VDSL line**

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

β **- 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):

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

Where:

$P_{out,rs}$ **is the post-decoding Byte error probability of the Reed-Solomon**

$P_{in,rs}$ **is the pre-decoding Byte error probability of the Reed-Solomon.**

$N = 255 \quad and \quad N_c = 8$ **For (255,239)Reed-Solomon**

P2 (cntd')

The probability of at least one Byte-error in a frame of length ***F***, at the output of the RS-decoder is:

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

Where:

$$F = 1536$$ **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:**

$$P_4 = 2^{-16} \cdot 2^{-32}$$

Calculating $P_{total} = P_1 P_2 P_3 P_4$

Using the above process and parameters yields the following:

Constellation	P_{total}
QAM-4	$1.97 \cdot 10^{-30}$
QAM-8	$3.87 \cdot 10^{-31}$
QAM-16	$4.02 \cdot 10^{-33}$
QAM-32	$2.05 \cdot 10^{-32}$
QAM-64	$4.02 \cdot 10^{-33}$
QAM-128	$4.02 \cdot 10^{-33}$
QAM-256	$8.02 \cdot 10^{-36}$

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 $\Rightarrow$ 7D 5E hex
  - 7D hex $\Rightarrow$ 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.

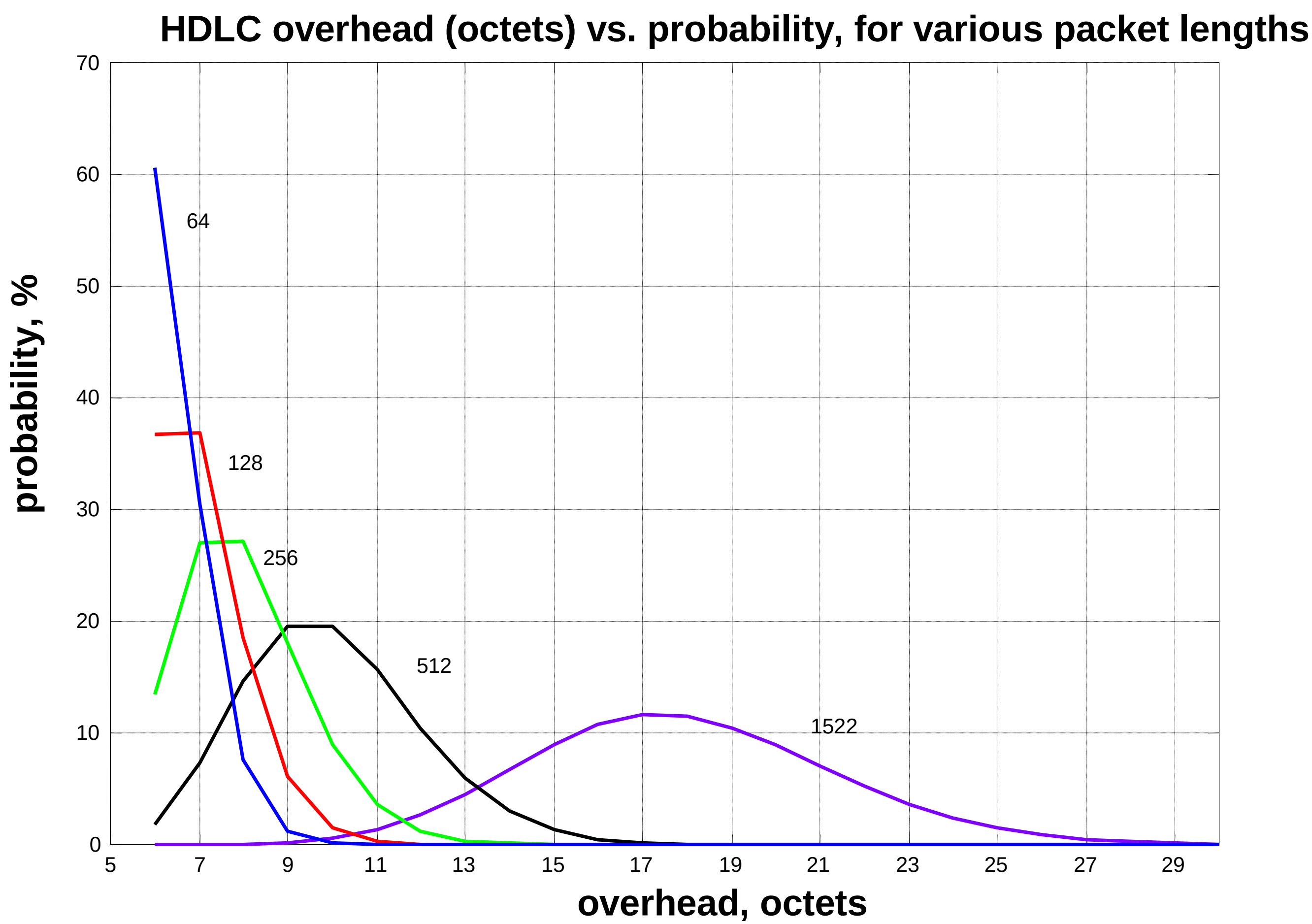
- Byte Stuffing: each appearance of 7E or 7D adds one Byte overhead to the packet.

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

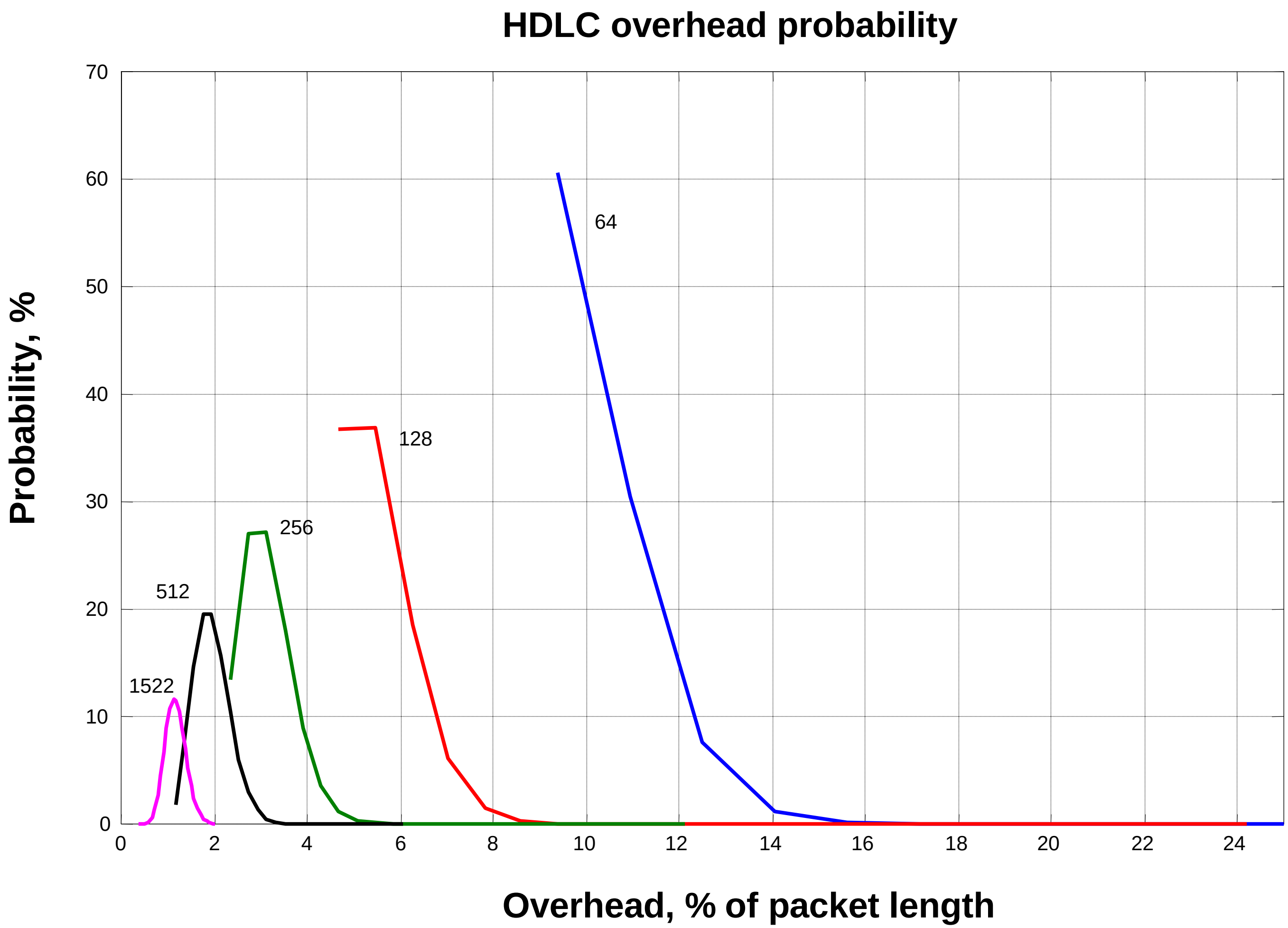
$$P = \sum_{i=1}^{M} \binom{L}{i} \cdot P_1^{\,i} \cdot (1 - P_1)^{L-i}$$

Where: $P_1 = 2 \cdot 2^{-8}$

HDLC overhead vs. probability (fixed + statistical)



HDLC overhead probability vs. % of packet length



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 a 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
- Eight possible EOP:

- T Z Z Z, Z Z Z Z	- D D D D, T Z Z Z
- D T Z Z, Z Z Z Z	- D D D D, D T Z Z
- D D T Z, Z Z Z Z	- D D D D, D D T Z
- D D D T, Z Z Z Z	- D D D D, D D D T

64b/66b overhead

Taking all this together yields:

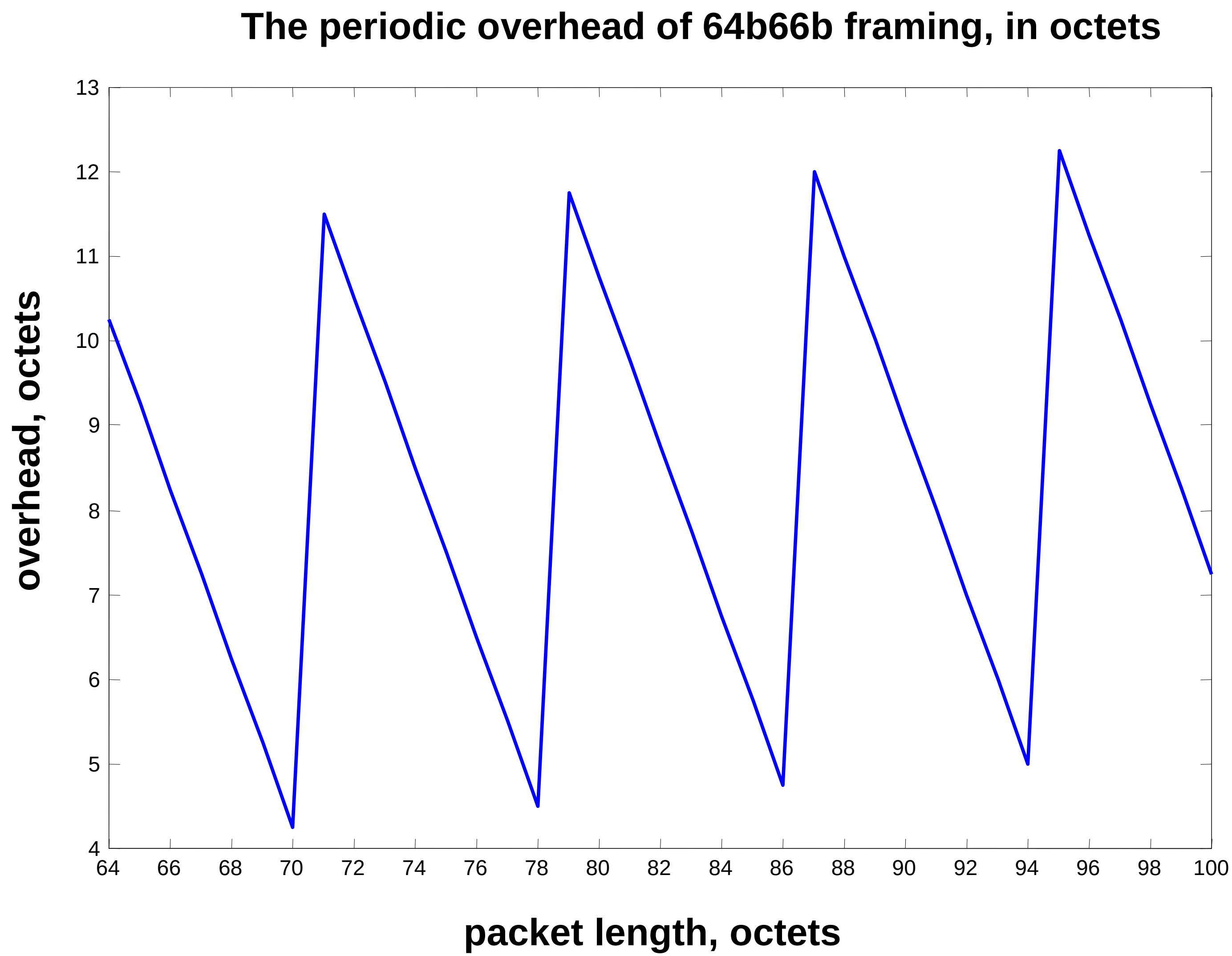
$$\Delta_L = ceil(\frac{L+2}{8}) \cdot (8 + \frac{1}{4}) - L$$

Where:

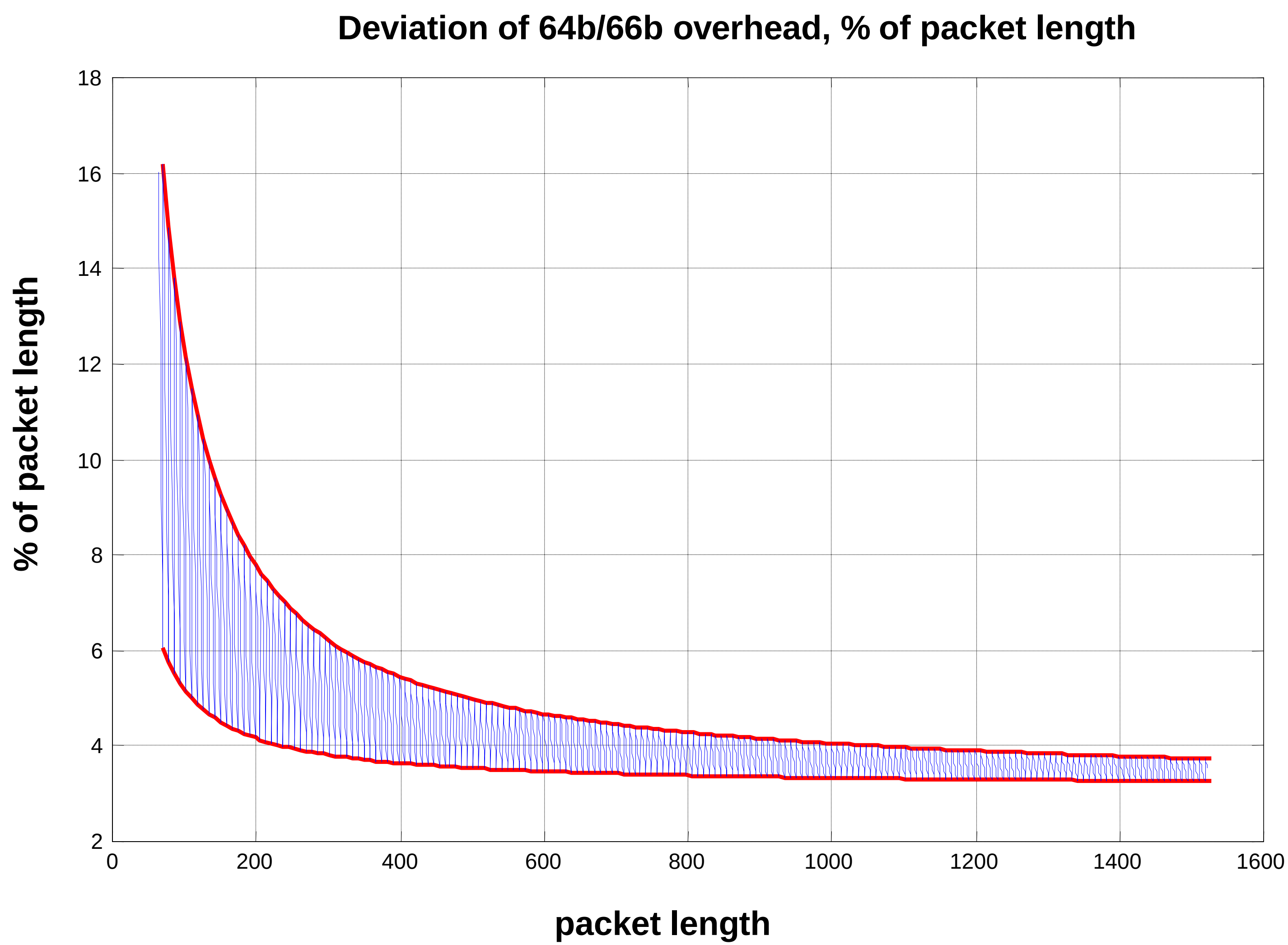
Δ_L -**is the overhead, in octets, best-case. For worst-case: need to add 4 octets, due to SOP alignment.**

L - **is the packet length, in octets.**

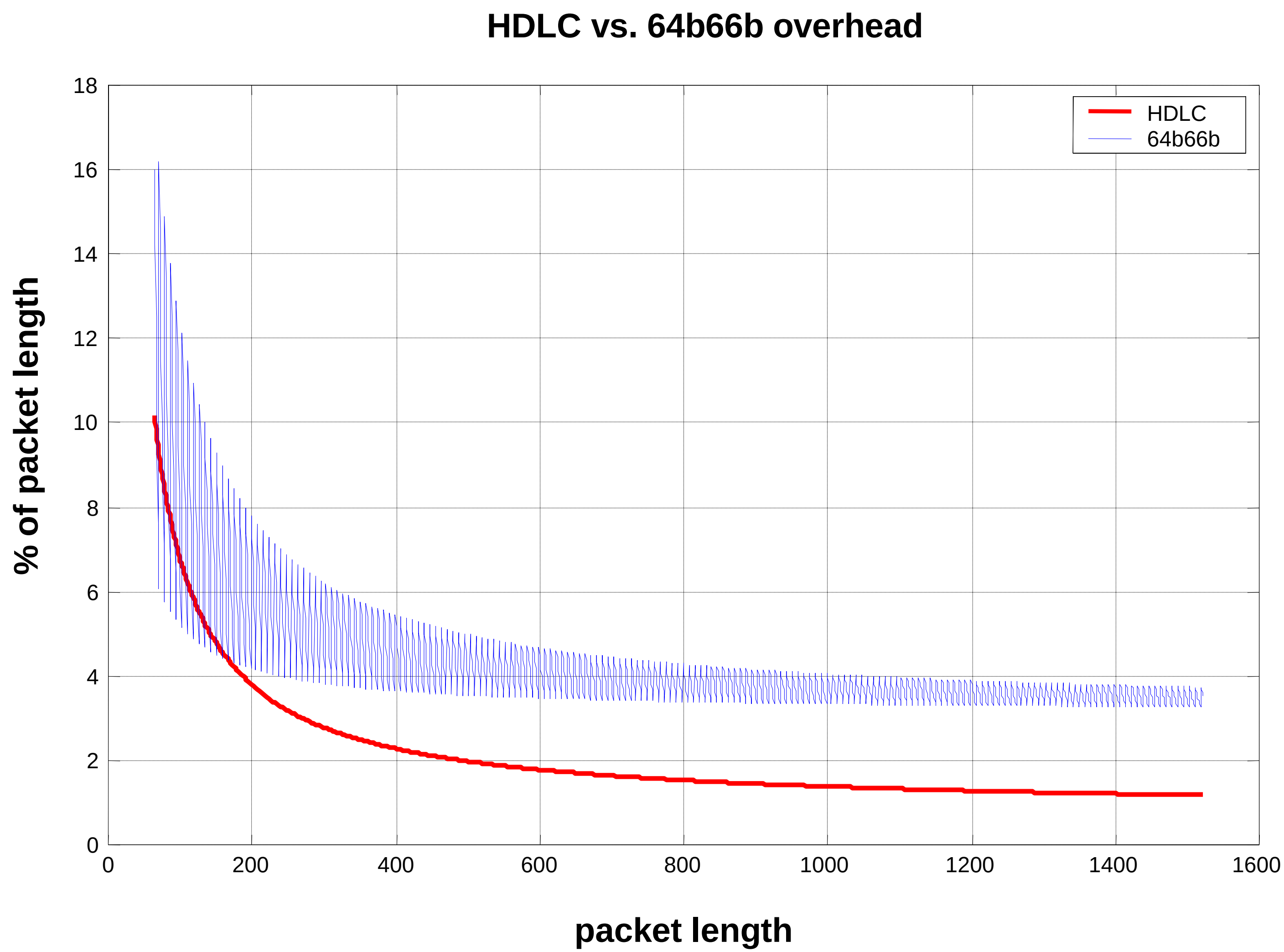
64b/66b Overhead in octets, Periodic behavior



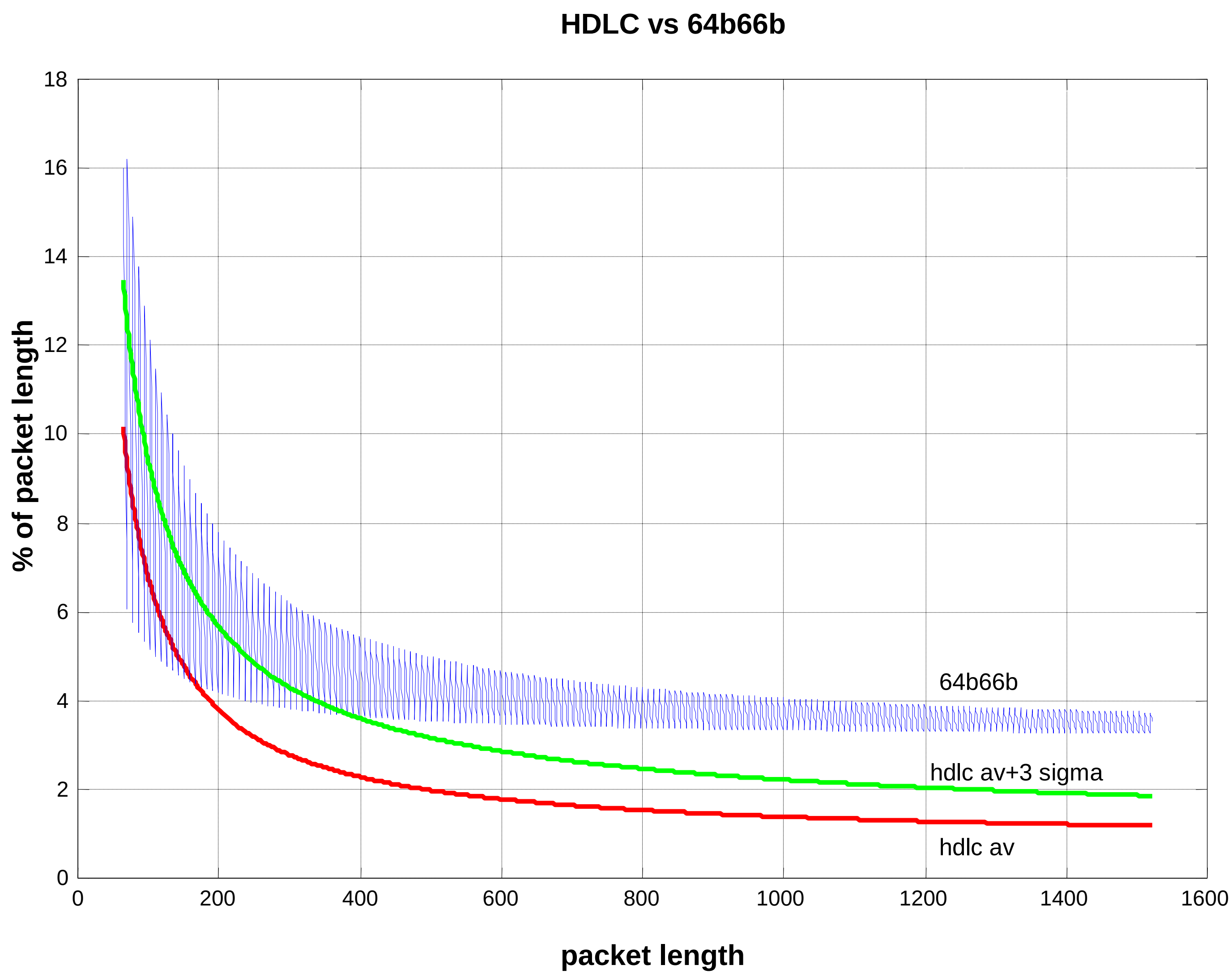
Min. & Max. Overhead of 64b66b framing, in %



Average HDLC overhead vs. 64b66b overhead



3σ of HDLC overhead vs. 64b66b overhead



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

1. ITU-T Draft Recommendation G.975, Series G, "Forward Error Correction for Submarine Systems", April 2000.
2. John G. Proakis, "Digital Communication", third edition, chapter 8-1-8, p. 465. (McGraw-Hill, 1995)
3. Rick Walker, Birdy Amrutur, Tom Knotts, Richard Dugan, (Agilent) "64b/66b coding update", 802.3ae Albuquerque, March 3/6/2000.

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Pre-decoding error probability

The following table summarizes the above:

Constellation	Number of splits	β	α	$P_{out,rs}$
QAM-4	0	1.0	4	$9.23 \cdot 10^{-17}$
QAM-8	2 out of 8	1.25	2.667	$1.82 \cdot 10^{-17}$
QAM-16	0	1.0	2	$1.88 \cdot 10^{-19}$
QAM-32	4 out of 8	1.5	1.6	$9.64 \cdot 10^{-19}$
QAM-64	2 out of 4	1.5	1.333	$1.88 \cdot 10^{-19}$
QAM-128	6 out of 8	1.75	1.143	$1.88 \cdot 10^{-19}$
QAM-256	0	1.0	1	$3.76 \cdot 10^{-22}$