Burst bit-error rate calculation for GPON systems

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This paper presents a methodology to calculate the bit-error rate for the data transmission in the upstream direction of Gigabit PON systems. In traditional optical receivers, the signal consists of a continuous bit stream. In the upstream direction of a PON however, the signal consists of a succession of packets with varying amplitudes. Hence the receiver needs to quickly extract the decision threshold and clock phase from an overhead at the beginning of each packet. Such extraction results in a sensitivity penalty. To estimate how big this penalty is as a function of system parameters, burst bit-error rates need to be calculated.

Introduction

As an effective solution for broadband access, a lot of effort is made to develop PON (Passive Optical Network) systems. Fig. 1 shows a schematic view of a typical PON system. The Optical Line Termination (OLT), located in the Central Office, distributes data towards the Optical Network Terminations (ONT's), located at the user's premises. The end-user can also send data in the upstream direction towards the OLT. Note how multiple users share the same transmission medium, giving rise to contention problems. Hence, multiplexing is needed. An economical multiplexing technique in the upstream direction is TDM (Time Division Multiplexing) in which each subscriber is allocated a time slot to transmit data towards the OLT. As each ONT is located at different distances from the OLT, this implies that the signal that needs to be handled by the upstream receiver consists of a succession of packets with varying amplitude, see fig 2.

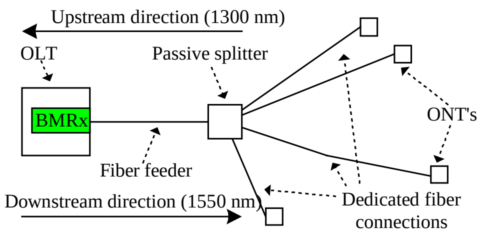

Fig. 1 – Schematic view of a Passive Optical Network.

Recent developed ITU-T standards show an interest to increase the bit rate in PON's towards the Gbit/s region [1]. Such an increase in line rate can only be economical if effort is spent to keep the number of subscribers as large as possible. This implies that the receiver located in the OLT needs to have a low sensitivity and high dynamic range. Combined with the GHz-bandwidth and packet-mode transmission, this creates several challenges for the upstream receiver.

Indeed, to be able to handle the ITU-T G.984.1 data format [1], the upstream receiver needs to be a dc-coupled burst-mode receiver. Such a receiver quickly extracts the decision threshold during a short time (hereafter called the TDF – Threshold

Determination Field, see fig. 2) at the beginning of each packet. Furthermore, the packets arrive at the receiver with an unknown clock phase (the clock frequency is derived from the downstream transmission). Hence a circuit (CPA – Clock Phase Alignment) follows the BMRx to quickly extract this phase, also from a short period (hereafter called the CPA field) at the beginning of the packet. Furthermore, to byte-align the data payload, a delimiter is needed at the beginning of the packet.

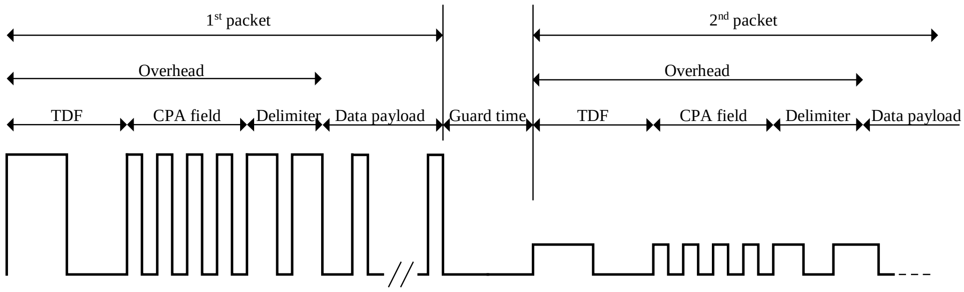

Fig. 2 – Upstream signal format (shown lengths do not correspond to real lengths).

While the ITU-T G.984.1 standard fixed the total length of the guard time and overhead, no requirements are put on the assignment of bits to respectively guard time, TDF, CPA field and delimiter. Hence the system designer should find an optimum distribution of bits between these fields. For example, increasing the TDF length can improve the sensitivity of the BMRx, but may reduce the performance of the CPA unit as it has fewer bits available to extract the correct clock phase. A detailed study of burst bit-error rates (BBERs), the subject of this paper, is needed to find an optimum.

To calculate the BBER, the problem is divided into two parts. First, the BBER is calculated after the amplitude recovery done by the BMRx. Then, using a distribution of the sampling moment obtained by the CPA circuit, the final BBER can be calculated for various settings of the system parameters.

The burst bit-error rate after the BMRx

There exists a large amount of literature on how to calculate the BER for traditional optical receivers [2]. The developed methods can be adapted to calculate the BBER for burst-mode transmission. To correctly evaluate the BBER for GPON applications, at least three points need to be included in the BMRx model. First of all, as an avalanche photodiode (APD) is used in the BMRx, a detailed model of the avalanche multiplication noise needs to be included. Secondly, note that the BMRx extracts the decision threshold with a small time constant. This implies that this threshold can no longer be treated as a fixed level, but instead shows a certain statistical distribution [3]. This gives rise to a sensitivity penalty. Last of all, as the BMRx is fully dc-coupled the model should include the influence of dc-offsets on the sensitivity.

In [4], a model was presented that can take into account the mentioned effects. Using an N-points non-classical Gaussian Quadrature Rule, the BER can be calculated for given system parameters. It is shown that the influence of DC-offsets can be the dominating effect in reducing the sensitivity of a BMRx when compared to a traditional receiver, with the same system parameters (such as avalanche gain, transimpedance gain, thermal receiver noise etc.).

The burst bit-error rate after the CPA

The CPA unit recovers timing information based on a digital input signal coming from the BMRx. The CPA determines a sample moment based on the CPA of the burst preamble, which consists of a ‘01’ sequence. The CPA will try to measure the middle of an isolated ‘1’ bit, and use those measurement results to determine a sample moment t_s.

The digital input signal is characterized by the jitter e_i on the rising and falling edges, defined as the difference between the time t_i’ that a transition is expected to occur and the time t_i that the transition actually occurs. It is divided into two categories: deterministic jitter (DJ) and random jitter (RJ). RJ is considered an unbounded component, described using a Gaussian distribution with mean 0 and standard deviation σ_{jitter}. DJ is considered bounded, and is composed of intersymbol interference, duty cycle distortion and period jitter components.

Once the input jitter characteristics are known the probability density function (PDF) of the t_s only depends on the length of the CPA field and how accurate the CPA unit can measure a sample moment. In fig. 3a and 3b the PDF of t_s is plotted for several lengths of the CPA field when the sample accuracy of the CPA unit is one tenth of the bit period. Fig. 3c-d shows the PDF of t_s for several CPA accuracies with a fixed CPA field length of 22 bits.

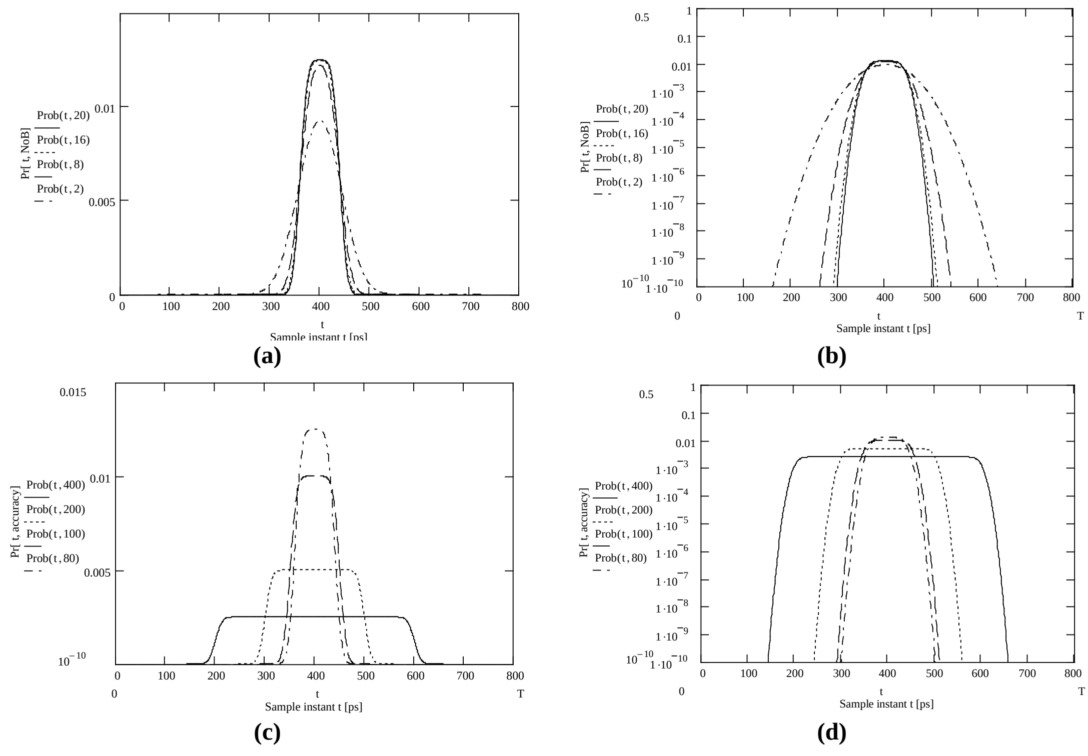

Fig. 3 PDF of sample instant t plotted in linear and logarithmic scale for several lengths of the CPA field (NoB – No of Bits) and CPA accuracies (accuracy). s_{jitter} = 50 ps, bit period T = 800 ps (a-b) CPA accuracy = 80 ps (c-d) CPA field length = 22

Based on the bathtub plot and the above distribution the total BBER can be calculated as

$$BBER = \int_0^T BBER(t_{sample}).\Pr\left[t_{sample}\right]dt_{sample} \tag{1}$$

The delimiter field

The delimiter is a unique pattern indicating the start of the burst, which can be used to perform byte synchronization. The delimiter must provide sufficient data bits to perform a robust delimiter function in the face of bit errors. The two possible problems are either the detection of a nonexistent header or the inability to detect the header due to the presence of errors.

To protect the delimiter it must be constructed in such a way that the shifted version of itself over all preamble bits has a maximum hamming distance d. It can be empirically verified [1] that for all the delimiters of sizes ranging from 8 to 20 bits this maximum hamming distance d equals int(N/2) –1, where N is the number of bits in the delimiter. Then the delimiter recognition unit will be able to handle t errors, where t is the error correcting capability of the code and is equal to int(N/4)-1.

The probability of failure to detect the delimiter is approximated by the formula [1]:

$$Pseb = \binom{N}{\mathrm{int}(N/4)} BBER^{\mathrm{int}(N/4)} \tag{2}$$

where BBER is the burst bit error rate of the CPA output signal. In order to suppress this kind of error Pseb should be less then 10^{-10} for all BBER smaller then 10^{-4}. This constraint results in a delimiter length of at least 16 bits.

Conclusion and future work

It has been shown how burst bit-error rates can be calculated for GPON's and how to take into account the properties of the burst-mode receiver chain. These calculations will be used to determine an optimum distribution of the TDF, CPA and delimiter field lengths.

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