Using Asynchronous Histograms for Characterizing and Evaluating Optical Systems

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***Abstract*— In this paper we will show the application of the asynchronous histograms for monitoring and characterizing, at low sampling rate, very high data rate systems. We will describe the method and its results for two transition functions, which correspond to two different pulse shapes. From the results we show the possibility of obtaining an amplitude description of the eye diagram from one completely closed eye observed by asynchronous, under-sampled eye diagram and/or amplitude histograms.**

I. Introduction

The increasing use of DWDM as a way to increment nowadays systems capacity is leading DWDM technology to a point where it is being widely used in very different situations and configurations. With the advent brought by the versatility of this technique, the migration to all-optical transparent photonic networks is already on the way. Within these future networks, it is possible to observe many different signal formats and data rates, since all processing and routing functions are performed transparently and optically. Due to the advantages of this technique, the optical layer has grown its interest and is now considered in the networks hierarchy. However, protection is now one of the greatest difficulties within this kind of systems, due to the referred amount of formats and data rates that can flow within this technology.

This fact brings many difficulties to the implementation of channel BER monitoring techniques. The different bit rates, require a very broadband and precise cock recovery system, which is quite difficult to implement and if available, can be very expensive. On the other hand the different pulse formats require a very habile receiver and decoder with quite large margins to achieve synchronization and pulse shaping in order to obtain the widest decision time window.

Also, the network management, control and survivability in a multi-vendor, multi-operator and multi-costumer all-optical environment requires the ability to measure the optical data performance, detect degradation, failure and provisioning means of failure location and isolation in order to constantly maintain the quality of service (QoS) [1]. Actually the current DWDM networks are managed, protected and monitored in the digital domain. This requires channel termination and decoding at an optical receiver. Several examples of this are currently implemented in the networks, for example, the detection of the parity bits related with payload or frame checking and error checking (however, those codes cannot supply channel performance data). An example is the BIP-8 (bit interleaved parity) mechanisms from synchronous digital hierarchy (SDH) / synchronous optical network (SONET) that allows error monitoring and the consequent use of the management capabilities of these standard transmission protocols for protection providing. This method, due to the need of the decoding at the rate of transmission, synchronization and processing is quite expensive and therefore limitative due to transparency loss. Transparency is beginning to be one of the network requirements, due to the surge of many widely used formats, such as: SDH / SONET, plesiochronous digital hierarchy (PDH), Gigabit Ethernet, asynchronous transfer mode (ATM), internet protocol (IP), etc. Thus, the ability to monitor the in-service signal quality independently of the signal format is essential.

These facts lead the industry and the researchers to look for other ways of monitoring the system performance with less cost and complexity and that at the same time could give enough information for the needs in each situation. Optical performance monitoring (OPM) is an approach that allows characterization of some of the channel parameters without prior knowledge of the origin, transport history, format or contend of the data at arbitrary points of the network without decoding the data. Furthermore OPM should be unobtrusive, accurate, unambiguous, comprehensive and cheap [2].

One can divide the present methods into three main tiers of channel analysis: OCM, OCA and OCD, as shown in Fig. 1.

Optical amplifiers and other components in the light path can induce signal distortions and these are even worst when aging and environmental effects affect their optical profile, also when power varies sharply, due to add/drop of channels. OCM's were specially developed for these cases and to be aggregated with dynamic gain

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equalizers, however, they will also find use in applications such as fault isolation and channel routing supervision allowing the characterization of channel presence/absence. This technique provides the first tier of optical monitoring capability.

As predictable, the effect of gain equalizing, brings some system stability but does not improves necessarily the optical signal to noise ratio (OSNR), so, its is needed to have a tighter control over the DWDM wavelengths in order to accommodate higher spectral efficiency. Precise information of channel power, wavelength, OSNR, is needed for increased functionalities of the networks, such as precise tuning of wavelength and power adjust at the transmitter/intermediate node, by means of information travelling in an optical supervisor channel. These functionalities are performed by the OCA’s, which are slightly more costly than the OCM’s and therefore should be paced in a less massive way through the networks. However, since OSNR is not directly related with data quality [3], BER testing devices will always be needed for qualifying, troubleshooting, and turning up of networks. This is the reason for the existence of the third tier of monitoring capability, where getting a permanent BER test functionality in certain network elements is needed, complying in this way with service level agreements. Since this last method when performed in a synchronous way, is quite complex and expensive, cheaper alternatives are needed, which is the case of asynchronous monitoring, subject of this paper.

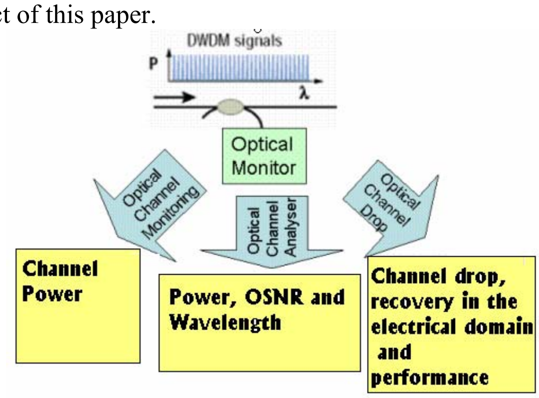


Fig. 1- Three tiers optical monitoring: OCM- Optical Channel Monitoring, OCA- Optical Channel Analyser, OCD- Optical Channel Drop.

This paper will start by a brief description of the method and its theoretical model will be presented. Following, two examples of asynchronous histograms will be shown and analysed, by relating some of the main parameters to the original waveform. In the end some conclusions of the methodology will be outdrawn.

II. Asynchronous Histograms

The asynchronous histograms can be obtained from the original signal by tapering the line where the signal to be analysed is travelling. A 10% taper or even less, depending on the signal level and the optical channel discriminator filter transfer function, is needed to obtain a copy of the signal in the monitoring device. After, this tap signal is passed by the discrimination filter and dumped to an opto-electrical conversion device, like a PIN or APD, that should be at least as wide as the bandwidth of the highest rate signal in the network (this data is know by the operator). This signal is then sampled at a given rate, smaller than the lowest bit rate available in the network (also known by the network operator). The acquisition time for the samples is the tightest requirement of the method since it needs to be small enough for observing the smaller signal change possible during sample acquisition time, in order to preserve its sample quality. An example of this is: a signal with rise time of the order of 10ps should have sample durations smaller than 100fs for 1% time resolution.

Due to the absence of synchronization, the samples time/amplitude map of a nice eye diagram (Fig. 2 b), when observed in a high bandwidth resolution oscilloscope looks like (Fig. 2 a), as shown in Fig. 2.

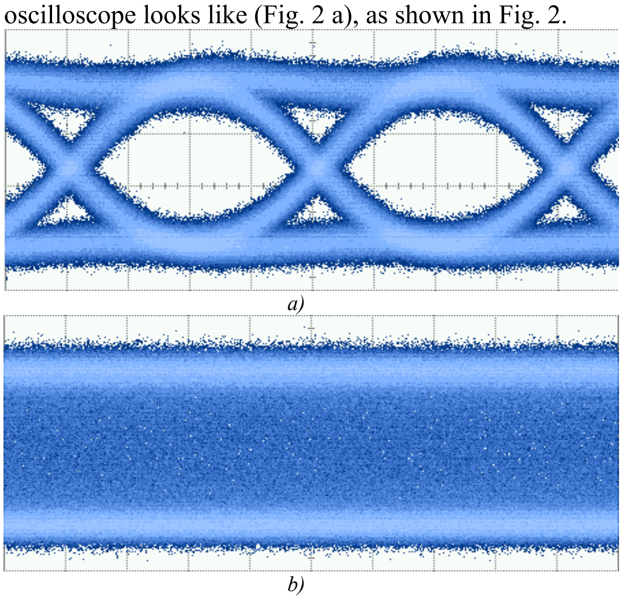
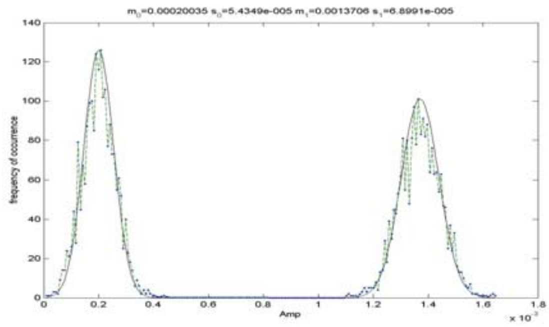


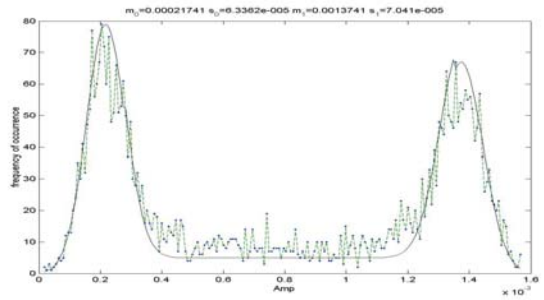
Fig. 2- Asynchronous eye diagram (b) of a nice clean optical signal from which the eye diagram is shown. Both images obtained with a very high bandwidth digital oscilloscope.

One can clearly notice, form Fig. 2 b), that if the signal is not correctly triggered with the incoming signal, the eye diagram, is nothing more than a bunch of samples from which little information can be extracted. However, it can be noticed that the signal “1” and “0” levels can be identified by a more intense presence of samples, the rest of the almost uniform distribution of sampled is due to the transitions.

In order to have a better insight into the results, two amplitude histograms extracted synchronously and asynchronously from the same signal, referent to the two eye diagrams of Fig. 2 a) and b) are presented in Fig. 3.



a)



b)

Fig. 3- a) Synchronous amplitude histogram and b) asynchronous amplitude histogram with superimposed Gaussian approximations. In b) only a floor was added in between the two shapes.

The histogram in Fig. 3 a) is the common two gaussian shapes ("1" and "0") with averages and standard deviations (μ_1, μ_o, σ_1 and σ_0 respectively for the "1" and "0" levels). From these parameters one can determine with a certain degree of confidence the Q factor:

$$Q = (\mu_1 - \mu_0)/(\sigma_1 + \sigma_0) \qquad (1)$$

that can be correlated with the BER and therefore one can extract clear conclusions about the systems performance.

However, with respect to the Fig. 3 b) one can not infer with such certainty the values of the mean and standard deviations due to the presence of intermediate values and the two shapes are a distorted form of two normal distributions.

Therefore, a theoretical model that can account for these new conditions is needed, observing not only the "on" and "off" states, but also the transition between them.

III. MODELLING ASYNCHRONOUS HISTOGRAMS

In order to obtain a model for these histograms, the schematic diagram of two eye diagrams of two different shapes (Fig. 4 a)- Raised cosine, Fig. 4 b)- Linear transition) are used as example.

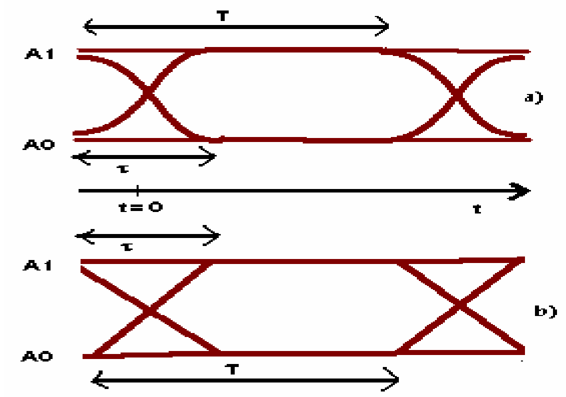


Fig. 4- Schematic eye diagram of a) raised cosine and b) linear transition.

Considering the two shapes, the time that those shapes take from A0 to A1, or back, is τ, in a periodic repetition rate of T. $A1$ and $A0$ are the "1" and "0" power levels.

A histogram is a count of the number of samples, or a relative count of the time passed between two amplitude limits, known as amplitude bins. So, in order to obtain the histogram the functions that represent the transitions and the "on" and "off" states should be known.

In the absence of noise, if the bit stream is long enough and completely random, the probability of staying in a "on" or "off" state for more than one bit is the same of transiting to the other state. Thereafter, the time in A1 or A0 is then:

$$t_o(a) = \frac{T}{2} + \frac{T-\tau}{2} + \frac{1}{2}\left(f^{-1}(a) - f^{-1}(a-\Delta)\right) \qquad (2)$$

for a=A1 or A0+Δ, and f^{1}transition function. For the remaining bins, (A0+Δ →A1-Δ), with bins interval Δ, the times are given by:

$$t_i(a) = \frac{1}{2}\left(f^{-1}(a) - f^{-1}(a-\Delta)\right) \qquad (3)$$

since the functions are normally similar in the A1→A0 and A0→A1 transitions. In terms of relative presence, which will be corresponding to the bins height, the result should be normalized to the bit period, T.

The transition functions considered are:

$$f(t) = \left(\frac{A1+A0}{2}\right) + \frac{A1-A0}{\tau}t \qquad (4)$$

for the linear transition and :

$$f(t) = \frac{A1-A0}{2}\left(\sin\left(\frac{t}{\tau}\pi\right)+1\right) + A0 \qquad (5)$$

for the raised cosine function, if the time referential is considered as shown in Fig. 4, and $t \in [-\tau/2, T-\tau/2[$.

The inversion of the functions is straight forward:

$$f^{-1}(a) = \left(a - \frac{A1+A0}{2}\right)\frac{\tau}{A1-A0} \qquad (6)$$

for the linear transition and

$$f^{-1}(a) = \frac{\tau}{\pi}\arcsin\left(2\frac{a - A0}{A1 - A0} - 1\right) \qquad (7)$$

considering that the ascending and descending functions are similar and symmetrical, therefore contributing similarly on the up and down transitions. Also, the value of f^{1} shall never return a value higher than T (these cases will not be considered in this work).

After having the histograms without noise, the noise function can be added by convolving this histogram without noise with a histogram of the noise distribution. Considering that the variance of the noise is dependent on the detected intensity one should do, bin by bin, a calculation of the value of the noise variance and its convolution with the corresponding bin, and only after the sum of the individual convolution results. In this paper we will analyse only the case of fixed (or small variation) noise variance.

IV. MODEL RESULTS

By applying what has been described in the previous section, the histograms can be obtained for the two cases for different situations, and some conclusions can be gathered.

In Fig. 5 it is represented the evolution of the histograms for a given noise and several values of the transition time (τ) for the two cases of transition functions. Several important characteristics can be enhanced from the results. Taking first the case, the raised cosine, we can see that the centre region (around 6mW) is low and tends slowly to its maximum value, that in this case is around 0.2 a.u.. However, the two main lobes become more and more distorted as τ increases. This is expected since the contribution of the transition is non-linear. It is also observed in the experimental results shown in Fig. 3 a). This fact will limit to some extent the ability to extract the value of the means and standard deviations from the curves.

The case of the linear transition, results in a inter lobe floor, but the maximum value of this is around 0.4 a.u., that is, in this case, twice the obtained for the raised cosine shape. This leads to smaller relative amplitude of the lobes. However, in this case, the lobes remain practically unchanged with the increasing τ.

Comparing both the curves one can say that they have two main differences: the shape; and the intermediate floor level Therefore, the asynchronous eye diagrams should be treated differently in order to give good trustable results in both cases. It should be reminded, as comment, that the expected Q factor of the two curves is the same, since the means and standard deviations are the same.

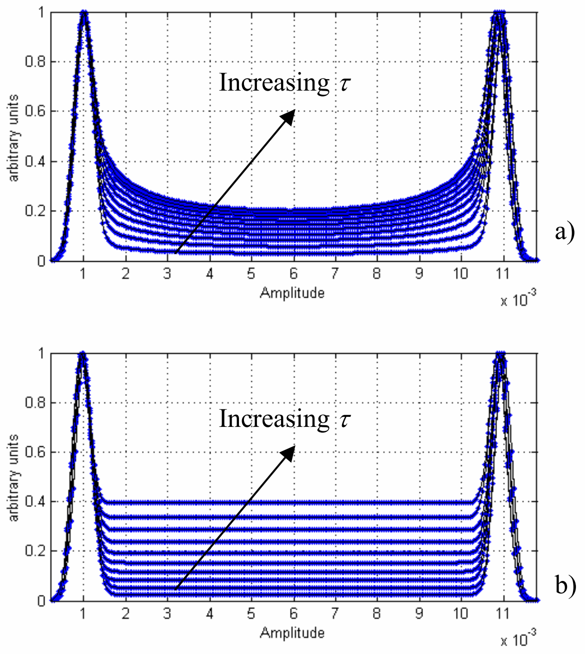


Fig. 5- Representation of the model for $\tau \in$ {10%--> 90%} of T, for a standard deviation of 2% of T. On the top figure (a) the case of the raised cosine, and in the bottom the triangular (b). We considered in this cas A1=11mW, A0=1mW.

V. CONCLUSIONS

The asynchronous histograms method has been described. It allows very low data sampling, is bit-rate and shape transparent, however some precautions should be taken for different pulse shapes. A theoretical model for the histograms has been obtained and two transition shapes have been analysed. The results are quite interesting giving the possibility, from an asynchronous collection of samples, to obtain important information of the signal.

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