

NEW TRANSPARENT OPTICAL MONITORING OF THE EYE AND BER USING ASYNCHRONOUS UNDER-SAMPLING OF THE SIGNAL

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Abstract We experimentally validated a new transparent monitoring method based on asynchronous under-sampling enabling eye-diagram reconstruction and BER estimation. It gives very accurate BER estimation in presence of chromatic dispersion and non-linear effects without requiring knowledge of the bit rate.

Introduction

In transparent WDM networks, it is mandatory to have performance monitoring of optical signals in order to detect and localise signal degradations. This performance monitoring must be transparent to signal framing (SDH/SONET, G.709 frame, GbEth, ...) and bit-rate (1 Gbit/s, 2.5 Gbit/s, 10 Gbit/s...), especially in optical metropolitan networks in which various kinds of transmission formats and even various bit-rates will coexist in the same network.

Different transparent monitoring methods have already been studied (1). Optical Signal-to-Noise Ratio (OSNR), though simple to measure, does not take into account other degradations (e.g. chromatic dispersion). The most appropriate parameter to monitor is the Bit-Error-Rate (BER) and the corresponding Q-factor. Different Q-factor monitoring techniques were proposed: Q-factor chip (2), or amplitude histogram based on asynchronous sampling (1, 3-5). Compared to the Q-factor chip method which requires electronic clock recovery, the asynchronous sampling method has the advantage of being transparent to the bit-rate. But until now, it does not give accurate BER estimation because some of the sampled points correspond to the transition between marks and spaces, which makes the estimation of the mean and standard deviation values inaccurate. To overcome this drawback, cut & flip (1, 4) and cut & delete (1, 5) methods have been proposed. They aim at retrieving the samples corresponding to the transition, but a correction factor on the estimated Q-factor is still needed. Moreover this correction factor depends on the signal (3-5). A way to get a good agreement between estimated and actual BER is to have synchronous sampling (see fig.3 of ref. 4), but then a clock recovery compatible with all bit rates is required.

In this paper, we show a new technique developed within a collaboration between INRIA and Alcatel. It still uses an asynchronous sampling, but succeeds in accurately estimating the BER by reconstructing the eye diagram without any knowledge of the bit-rate of the signal. Such a method combines the advantages of both asynchronous and synchronous methods

without their respective drawbacks. In addition, unlike previous techniques, our approach enables a full recovery of the eye diagram which, beyond the quantitative information of the BER, provide additional knowledge on the signal degradation such as distortion type. The following part of the paper briefly explains this eye diagram reconstruction and the BER estimation (more details on the algorithms will be given in ref. 6), and the last part reports for the first time an impressive accuracy of the estimated BER even in presence of chromatic dispersion and non-linear effects, without adding any correction factor.

Eye diagram reconstruction and BER estimation with asynchronous sampling

The asynchronous sampling is performed at a given frequency f_s , which is not correlated with the frequency of the signal f_b . Provided there is little jitter between the sampling clock and the signal, consecutive samples will be correlated at an aliased frequency $\lambda_b = |(f_b/f_s) - \text{round}(f_b/f_s)|$. To extract the value of λ_b from the samples, we use a periodogram. It corresponds to the Fourier transform of the samples after applying a non-linear function, which allows to extract the aliased frequency (see 6). Fig. 1 shows such a periodogram obtained with experimental asynchronous sampling.

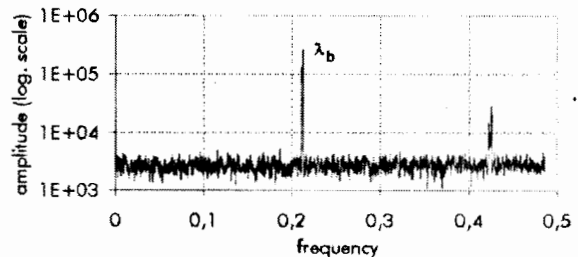


Fig.1 : Periodogram of asynchronous sampling

Nevertheless the value of λ_b may not be enough to reconstruct the eye-diagram. The uncorrelation between the sampling clock and the signal rate and their natural jitters imply that the longest the time between two samples the biggest the uncorrelation between them. So we calculate the time position of a sample in the eye-diagram by considering the calculated λ_b and several neighbouring samples (see 6). Fig. 2 shows the reconstructed eye-diagram

thanks to this "sliding window" method with the value of the aliased frequency derived from fig. 1.

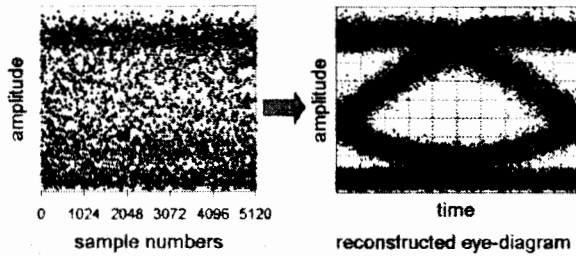


Fig.2 : Eye-diagram reconstruction

Then we divide the eye-diagram into slices with the same number of samples, and on each slice we perform the "Expected Maximisation" algorithm to fit the slice sample distribution by the mixture of N-Gaussian functions. Finally we derive the corresponding BER thanks to the estimated N means and N variances (see 6). We take N=2 and N=8 to compare the classical 2-Gaussian model with the 8-Gaussian model which will give better BER estimation in presence of Inter-Symbol Interference (ISI) due for example to chromatic dispersion.

Experimental validation with optical noise, chromatic dispersion and SPM

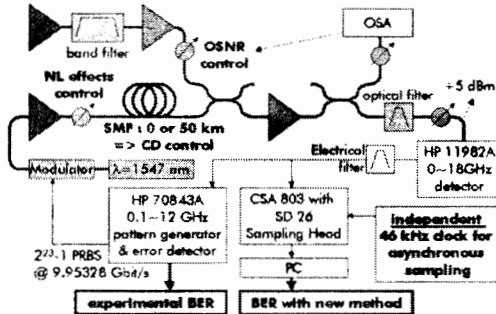


Fig.3 : Experimental set-up

The experimental set-up is shown in Fig.3. We used a single laser externally modulated at 9.95328 Gbit/s. We controlled the OSNR and the non-linear effects thanks to attenuators, and the chromatic dispersion by choosing the length of the Single Mode Fibre. A photo-detector with a 10 Gbit/s electrical filter are used for both experimental and estimated BER. We set +5dBm optical input power to make thermal noise negligible. $2^{23}-1$ Pseudo-Random Bit Sequence pattern is generated by the transmission analyser which is also used for the experimental BER measurement (optimised threshold and time decision). The estimated BER is calculated by a PC using the described new method with 10×5120 samples coming from a Communication Signal Analyser (CSA) with a sampling head. Note that the CSA is not used as usual: it is triggered by a fully independent 46 kHz clock, so we perform true

asynchronous under-sampling (about 1 sample each 200000 bits). Moreover, the CSA was used as a lab tool to realise the asynchronous sampling in order to validate the method but it would be not required in an actual system where the sampling function would be realised by a dedicated board.

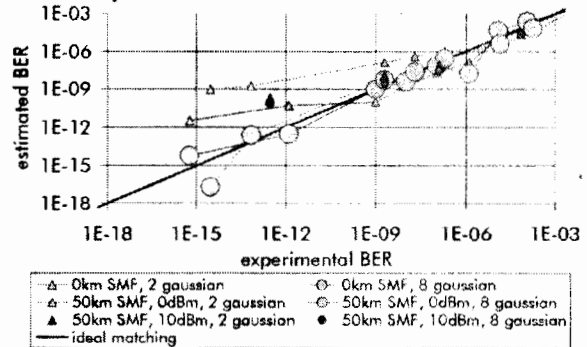


Fig.4 : estimated BER versus experimental BER

Fig. 4 compares the estimated BER with 2 and 8 Gaussian models with the experimental BER, for optical noise only (0 km SMF), for optical noise + chromatic dispersion (50 km SMF, P=0 dBm), and for optical noise + chromatic dispersion + non-linear effects (50 km SMF, P=10 dBm). We see that the proposed method gives very accurate BER estimation without adding any correction factor. As expected (see 4), for low BER, the 8 Gaussian model gives the best estimation, whereas the 2 Gaussian model overestimates the BER due to inter symbol interferences (this is enhanced in the chromatic dispersion case). Note that with non-linear effects, there is no difference between the 2 models, and they both slightly overestimates the BER (2 decades at BER = 10^{-12}). This point is under investigation.

Conclusions

In this paper, we experimentally validate a new transparent optical monitoring method which allows accurate BER estimation without introducing any correction factor even in presence of chromatic dispersion, thanks to a software-based eye-diagram reconstruction which is possible despite asynchronous sampling.

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