ESTIMATION OF BEP IN ALL-OPTICAL NETWORKS

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Abstract: A histogram-based technique allows to estimate the bit error probability (BEP) of an optical signal suffering from distortion. At 10Gbit/s, we obtain good results even for high optical signal-to-noise ratios, i.e. for low BEP.

Introduction

A common technique to estimate the bit error probability (BEP) in optical communication systems uses a histogram generated by sampling the photocurrent corrupted by noise and intersymbol interference (ISI) at bit centre. From this histogram, the mean values μ_1 and μ_0 and the standard deviations σ_1 and σ_0 of marks and spaces are obtained. Assuming Gaussian noise distributions and equally likely marks and spaces, the BEP then calculated as

$$\mathrm{BEP} = \frac{1}{2}\,\mathrm{erfc}\left[\frac{\mu_1 - \mu_0}{\sqrt{2}\,(\sigma_1 + \sigma_0)}\right] \tag{1}$$

where erfc denotes the complementary error function[1]. However, this technique delivers poor to useless results if applied to real world signals suffering from distortion and crosstalk [1]. In particular in case of high signal-to-noise ratio (i.e. low BEP), this method yields too high BEP. The reason is the averaging over ISI patterns: The actually observed probability density functions for marks and spaces are clearly narrower than the Gaussian function underlying eqn. (1). Below we introduce an improved estimation method which takes into account not only noise but also signal distortion.

Modelling

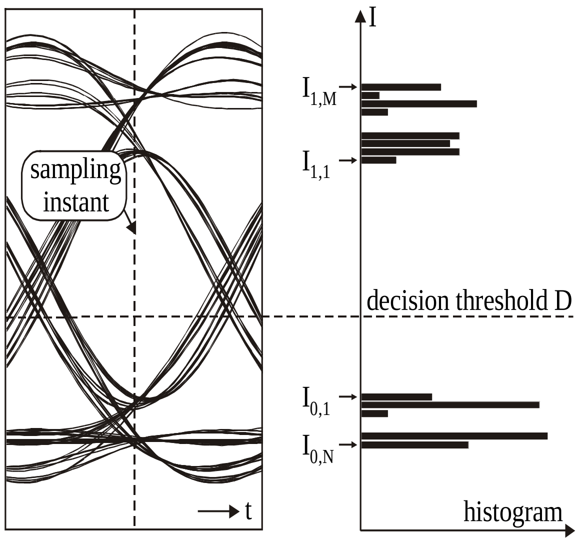
Our model bases on the fact that even in a noisefree system the sampling value of mark (or space) is different for each bit (see Fig.1). This is due to, e.g., distortion and subsequent intersymbol interference. Each mark (space) has its distinct mean photocurrent value $I_{1,m}$ ($I_{0,n}$). We hence describe the data signal by a histogram where each possible level is classified into one of M classes of mark levels or into one of N classes of space levels (n = 1...N, m = 1...M). Noise is taken into account by ascribing to each value $I_{1,m}$ ($I_{0,n}$) Gaussian noise with variance [2]

$$\sigma_{0,n}^2 = 2SI_{0,n}p_N B_e + S^2 p_N^2 B_e (B_o - (B_e/2)), \tag{2}$$

$$\sigma_{1,m}^2 = 2SI_{1,m}p_N B_e + S^2 p_N^2 B_e (B_o - (B_e/2)). \tag{3}$$

This covers a transmission system with optical preamplifier and/or optical inline amplifiers. In eqns. (2) and (3) S is the photodiode responsivity, B_e the electrical bandwidth, B_o the optical bandwidth and p_N the spectral power density due to amplified spontaneous emission (ASE) of optical amplifiers. The first terms represent signal-ASE beat noise, the second ASE-ASE beat noise; for practical systems further contributions due to thermal and shot noise can be neglected. Our model thus presents the signal available at the regenerator as a non-stationary process.

Figure 1: Example of an eye diagram (left) and corresponding photocurrent histogram (right) of a distorted, noisefree signal.



Determination of BEP

The bit error probability results from the sum of the probabilities that $I_{0,n}$ and $I_{1,m}$ fall above or below, the decision threshold D, respectively, as

$$\mathrm{BEP} = \frac{1}{2}\left[\sum_n H(I_{0,n})\,\mathrm{erfc}\left(\frac{D - I_{0,n}}{\sqrt{2}\sigma_{0,n}}\right) + \sum_m H(I_{1,m})\,\mathrm{erfc}\left(\frac{I_{1,m} - D}{\sqrt{2}\sigma_{1,m}}\right)\right] \tag{4}$$

where H(I) is the relative occurrence of the photocurrent amplitudes within the histogram, normalized as

$$\sum_n H(I_{0,n}) = \sum_m H(I_{1,m}) = 0.5\ . \tag{5}$$

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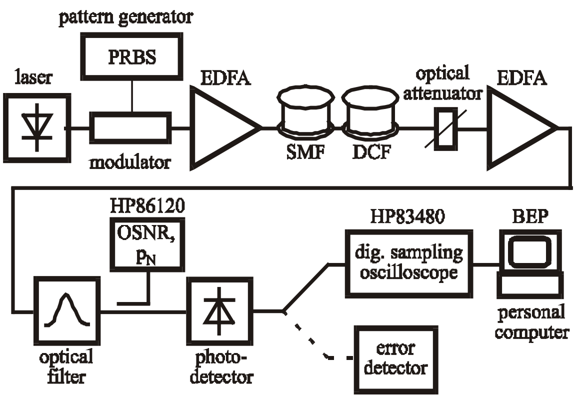
1 $\mathrm{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-z^2}\,dz$

This assumes equal probabilitiy for marks and spaces. After an apt choice of the number of photocurrent classes (M,N) the histogram values $I_{0,n}$ and $I_{1,m}$ are found with the help of a sampling scope. The corresponding σ values are calculated using eqns. (2) and (3) with the knowledge of S, B_e, and B_o. An optical spectrum analyser may be used to first determine the spectral power density p_N. To find the minimum BEP, the decision threshold D has to be optimized.

Experimental setup

We assessed the performance of the BEP estimation technique by comparing the results with measurement results obtained by either bit-error counting or by employing the decision threshold technique [3]. A laser emitting at 1.55µm was modulated with a 2^7-1 pseudo-random bit sequence (PRBS) at 10Gbit/s (see Fig. 2). This signal passed a fiber link consisting of G.652 singlemode fiber (SMF) and dispersion compensating fiber (DCF) which served to vary residual chromatic dispersion and hence distortion of the signal.
The ratio of optical signal power to p_N in a 0.1 nm bandwidth (OSNR) was set by an optical attenuator in front of an EDFA. The bandwidth of the optical filter was B_o = 1.4 nm, the electrical bandwidth of the photoreceiver B_e = 6 GHz. A digital sampling oscilloscope in the “eyeline” mode served to generate the histogram, which was processed by a personal computer to calculate the BEP according to eqns. (2) to (4). The numbers of histogram classes were chosen as M=N=20.

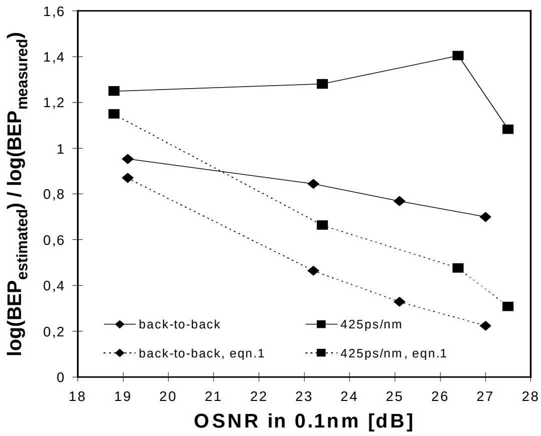
Figure 2: Experimental setup



Results

Various measurements at different levels of signal distortion (induced by different values of residual chromatic dispersion) were performed as a function of OSNR. The full lines in Fig. 3 show just two results in the form of the ratio of the estimated and the measured BEP. For comparison we also give - as broken lines - the results obtained by the conventional method, i.e. by modelling the process by a single distribution for marks and spaces according to eqn. (1). When taking into account the choice of the ordinate scale, a pronounced improvement becomes evident, especially for high OSNR.

Figure 3: Ratio of estimated and measured BEP at 10Gbit/s for zero residual chromatic dispersion (back-to-back) and for 425 ps/nm residual chromatic dispersion. Full lines are for the method presented here, broken lines for the conventinal method, eqn. (1).



Conclusion

We presented a technique which gives improved BEP estimates compared to the conventional technique based on single Gaussian noise processes for marks and spaces. The main advantage of the algorithm is the capability to yield good estimates down to very low BEP. Employing the technique for supervision in optical networks allows to reliably detect slow degradations before any client application does.

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