

Improvement of Bit-Error-Rate in Optical Fiber Receivers

Hadj Bourdoucen and Amer Alhabsi

Abstract—In this paper, a post processing scheme is suggested for improvement of Bit Error-Rate (BER) in optical fiber transmission receivers. The developed scheme has been tested on optical fiber systems operating with a non-return-to-zero (NRZ) format at transmission rates of up to 10Gbps. The transmission system considered is based on well known transmitters and receivers blocks operating at wavelengths in the region of 1550 nm using a standard single mode fiber. Performance of improved detected signals has been evaluated via the analysis of quality factor and computed bit error rates. Numerical simulations have shown a noticeable improvement of the system BER after implementation of the suggested post processing operation on the detected electrical signals.

Keywords—BER improvement, Optical fiber, transmission performance, NRZ.

I. INTRODUCTION

OPTICAL transmission networks based on wavelength division multiplexing (WDM) architecture is dominating the all-optical data transportation with bit rates exceeding several terabit-per-second rates to serve the ever increasing demand of Internet Protocol (IP) networks [1, 2]. Thus, full optical operation of these networks will be most important features in the near future. Some of the main TCP/IP networking functions such as routing, add-drop multiplexing and demultiplexing and wavelength conversion, need to be functional to encapsulate the IP packet requirements into the optical layer [3].

The linear as well as the nonlinear characteristics of the optical fiber at higher bit rates, seriously limit the data transmission performance and it is therefore becoming necessary to develop approaches to improve regeneration of transmitted data. Experimental investigations have shown a considerable progress in this direction [4, 5, 6]. These were based on compensation techniques, filtering, developing optimized line coding, and further processing of received signal. However, lot of research work needs to be carried out to improve the increasing effective data transmission through these systems [7].

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Simulation of such systems plays an important role in determining expected behaviors of components and devices prior to their experimental implementation and testing. This is a cheaper method for evaluating their performance since experimental set-ups involved are still relatively expensive [8].

In this paper, the effect of post processing received data from an optical fiber system using a signal detection scheme is investigated for NRZ modulation code. The objective is to improve the quality of detected data by reducing embedded noise induced by linear and nonlinear effects of the transmission channel. It is worth noting that the photodetection process itself adds more complexity as it deals with signals where many interactions happen between data and noise. The train of distorted bits of data received by the photodetector and after being pre-filtered is further processed using the proposed scheme to improve the overall BER of the system. The optical channel considered in this work relays on a standard single mode fiber operating at 1550 nm with no chromatic compensation to evaluate the intrinsic effect of the suggested post processing scheme.

II. MODELING AND SIMULATION

Fig. 1 shows the main blocks of the layout diagram of the optical transmission system adopted for simulation. As it appears from the diagram, the optical transmitter is composed of a number of multiplexed WDM wavelengths λ_i varying within the ITU-standard range and centered at 1550nm. This packet of wavelengths is modulated by an NRZ driving circuit that is fed with a (2^7-1) pseudorandom bit sequence (PRBS) signal.

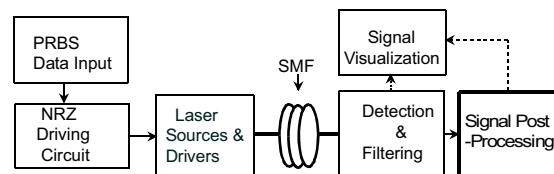


Fig. 1 Block Diagram of the system used in simulation

The laser sources used for generating these wavelengths have a full width at half maximum (FWHM) of 10MHz at data bit rates of 10Gbps. Standard Single Mode Fiber (SMF) was used for all the links considered. Their main parameters are as

follows.

The single mode fiber has an attenuation of 0.2dB/km, a dispersion of 16ps/nm/km, a dispersion correlation length of 20km and a non-linear coefficient of $1.27 \text{ W}^{-1}\text{km}^{-1}$. These parameters are given for $\lambda_0=1550\text{nm}$.

The driven data bit sequences are filtered by a low pass filter having an adequate bandwidth with respect to bit rates used. The choice of the filter characteristics at the photodetector is important for preserving the best performance of the system characteristics. It is for this reason that the filter parameters, mainly its bandwidth and its order have been studied and their effects on system performance deduced. The optical photo-detector selected consists of a pin photodiode with a quantum efficiency of 80% followed by a low pass Bessel filter of order 4.

The analysis adopted for the simulation of the system shown in Fig. 1 is based on the well known Split Step Fourier Method (SSFM). This method is used to solve the non-linear Schrödinger equation governing wave propagation through the system. The principle of the split-step Fourier method (SSFM) technique is based on the fact that the propagation of a pulse over the full length of optical fiber is considered by dividing the total length of the fiber into small segments in such a way that changes in the envelopes of optical signals can be considered sufficiently small. Within these segments, the linear and the nonlinear operators in the Schrödinger equation can be considered to act independently of each other. Hence, the effect of propagation along the fiber segment is determined by first using nonlinear operator followed by the linear operator. In this way, the accuracy and efficiency of operator splitting techniques depend on the way discretization is done in time and spatial domains [9]. A slowly varying electric field pulse $E(t)$, can be obtained by solving the following differential equation:

$$\frac{\partial E}{\partial z} = -\frac{\alpha}{2}E + i\Gamma \times |E|^2 \times E - \beta_1 \times \frac{\partial E}{\partial t} - \beta_2 \times \frac{i}{2} \times \frac{\partial^2 E}{\partial t^2} + \frac{\beta_3}{6} \times \frac{\partial^3 E}{\partial t^3} \quad (1)$$

where, E is the amplitude of the envelope of $E(t)$, β_1 , β_2 and β_3 , are respectively the inverse group velocity, the first and the second order group dispersion velocities. α is the absorption coefficient, and Γ the nonlinear coefficient of the optical fiber for a given span.

From the solution of equation (1), the quality factor Q , the eye diagram and the bit error rate are derived and used as performance estimators for the simulated system.

Note that the Q factor is approximated using mean values and standard deviations of the signal samples as indicated by the equation (2) below.

$$Q = \frac{m_1 - m_0}{\sigma_1 + \sigma_0} \quad (2)$$

where m_1 , m_0 , σ_1 , σ_0 are the mean values and standard deviations of the signal samples when a "1" or a "0" is received respectively. The bit error rate (BER) that resulted from simulations has been calculated from the above Q parameter using the well known expression indicated below:

$$BER \approx \frac{1}{2} \operatorname{erfc} \left[\frac{Q}{\sqrt{2}} \right] \quad (3)$$

In order to examine the effects of the post processing algorithm on the system performance quantitatively, a set of computer simulations have been programmed.

The suggested post processing scheme applied to the received bits is first suggested. It is based on considering the received random bit stream at the photoreceiver after passing through a fourth order low pass filter. Since these sets of bits are NRZ encoded with known bit rate of 10Gbps, the duration of each bit was set to 10^{-10} seconds to correspond to this bit rate. The bits were labeled according to the total fiber spans they went through. These spans range from 10km to 200km. The received signal waveforms were sampled at a rate of N samples per transmitted bit. It is worth noting that all numerical processing afterwards was done on the received sampled signal.

The waveform for the entire bit sequence vector y which might be expressed as $y = [y_0, y_1, \dots, y_N]$ is delayed by D samples to compensate for the induced jitter effect. This delay is set depending on the fiber length and transmission rate. Then, the DC component of the entire data sequence is removed by subtracting the average of all samples. Such an average can be estimated from sending and receiving a training sequence where ones and zeros occur with almost equal probabilities. After removing the DC component, the waveform is passed through a detector which processes the waveform according to the below approach.

If we let the input to the detector be the sequence y , then instead of passing the signal through a matched filter or a standard bank of correlators, only the K middle samples are used. These correspond to the widest opening of the lid in the eye diagram of the filtered photodetected signal. A quantity r_n corresponding to the area under the curve of the middle area of the received signal is calculated using the following expression for r_n

$$r_n = \sum_{i=A+1}^{A+K} y_i \quad (4)$$

Where, $A=(N-K)/2$.

One might note that that when $K=N$, then the samples of a specific bit are all used. The quantity r_n given by equation (4), for each bit n is then compared to the threshold level 0 and a decision is made whether a logic zero 0 or 1 was transmitted. It is also possible to pass r_n as soft information to an error control decoder if channel codes such as low density parity check, LDPC, are used for example.

III. RESULTS

Some of the obtained results are shown below in figures 2 through 7. The BER of the system considered, before applying the post processor, for different filter bandwidths (BW) of the receiver is shown in Fig. 2. Note the slight changes of the BER with bandwidth of the low pass filter for fiber spans

varying from 50 km to 200 km. The best performance is obtained for a bandwidth BW of 6.5 GHz for the receiver low pass filter.

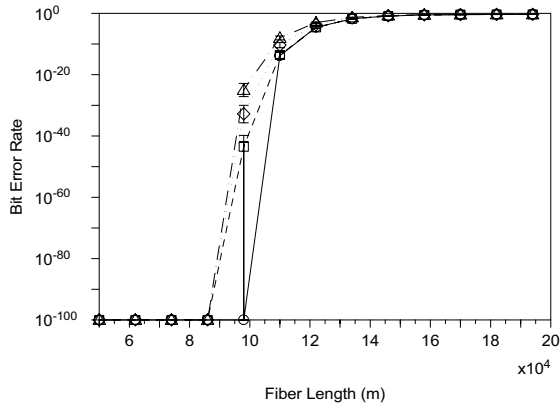


Fig. 2 Bit error rate (BER) of the transmission system of Fig. 1 when the bandwidth (BW) of the receiver LPF changes from 4GHz to 10 GHz.

The quality factor Q of the transmission prior to post processor in dB, is shown in Fig. 3. This figure shows a noticeable change in the quality factor for spans varying from 70km to 80km. Beyond these fiber lengths, the quality factor deteriorates and its changes become very small. This trend may also be seen from the results of the eye opening profiles shown in Fig. 4.

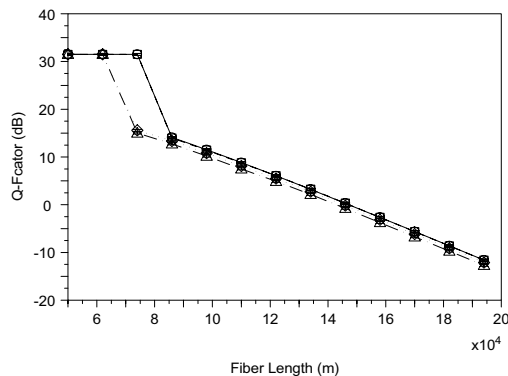


Fig. 3 Quality factor Q (dB) of the transmission system of Fig. 1 when the bandwidth (BW) of the receiver LPF changes from 4GHz to 10 GHz.

The Eye diagram of the received signal at 160km for non-processed signal is shown in Fig. 5. It clearly shows a closed eye diagram, and therefore the received signal is of no use. This corresponds to a BER value higher than 10^{-2} , which is well above the standards known in optical communication which are of the order of 10^{-9} or less. However, after processing the data with the post processing approach suggested above, the value of the BER becomes around 10^{-18} which improves considerably the performance of the system. A set of eye diagrams for non post processed received signals are shown in Fig. 5 for fiber lengths varying from 10km to 160km. Note that the eye diagrams for lengths around 120km

and beyond are almost completely closed, and hence their BER is very high.

As for the order of the Bessel low pass filter at the receiver, it has been also studied to see its effects on performance of the system. The changes considered for the filter order m were from $m=2$ to $m=10$. It appears from all the various results obtained by simulation, that the order of the LPF within this interval has practically no significant effect on the system performance. The BER obtained for the system of Fig. 1, is shown in Fig. 6 for filter orders, 2, 4, and 10. Because of its non significant effect on system performance, the default filter order was set to 4 in subsequent simulations to reduce computing time.

Thus, the algorithm suggested in this work has been applied to photodetected data after being filtered by the Bessel LPF of order 4 as stated above. The BER has been calculated for the post processed signal and compared to that obtained without post processing and the obtained results are shown in Fig. 7.

For instance Curve A shown in this figure, represents the profile of the BER as a function of fiber length for a typical transmission system like the one above without post processing.

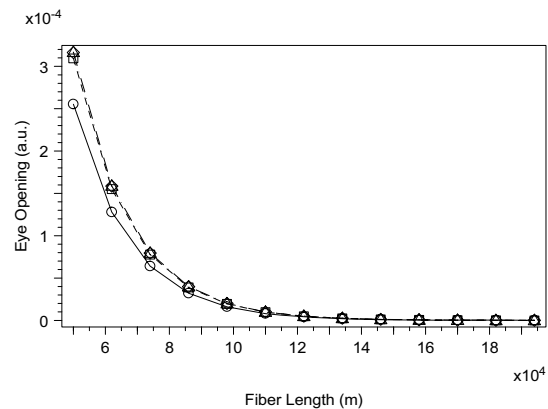


Fig. 4 Eye opening (EOP) of the transmission system of Fig. 1 when the bandwidth (BW) of the receiver LPF changes from 4GHz to 10 GHz.

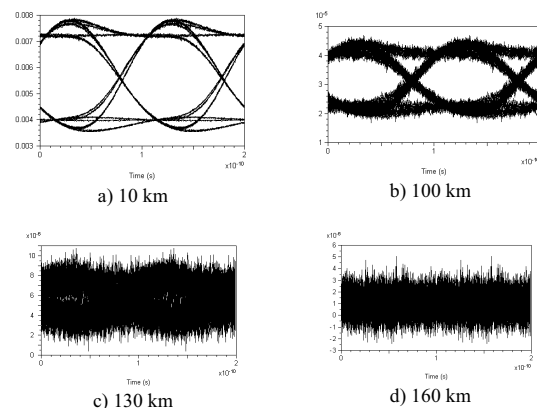


Fig. 5 Eye diagrams of the received signal at 10, 100, 130 and 160 Km with no post processing.

However, Curve B shown on the same figure depicts the BER of the post processed signal using the approach described above. One can note the important improvement in the BER after the post processing has been performed. This improvement in the BER allows expanding the fiber spans to longer lengths, reducing the overall cost of transmission systems.

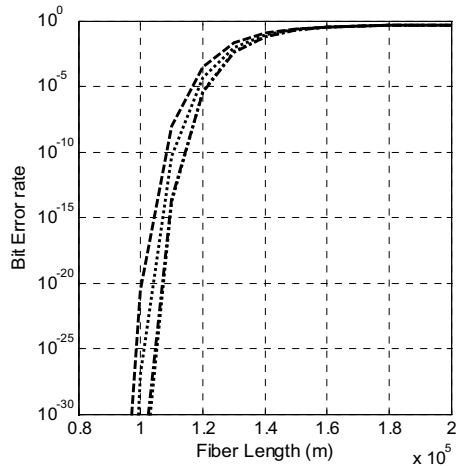


Fig. 6 BER as a function of fiber length with no post processing using a LPF with orders varying from 2, 4, and 10.

From the results of Fig. 7, a theoretical increase of the fiber span by up to about 30% can be obtained. However, this value is computed for wavelength of 1550 nm and in the absence of any nonlinear effect that appears in the channel for higher power values and which will increase the BER.

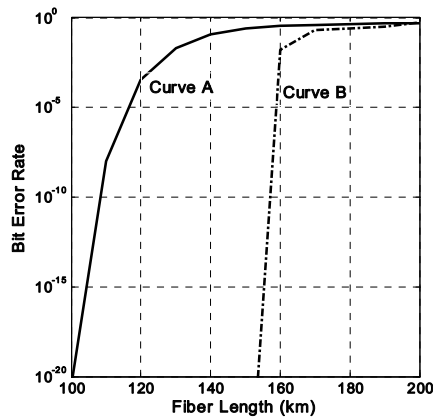


Fig. 7 BER as a function of fiber length, "Curve A" with no post processing, "Curve B" with post processing as suggested in this work.

Numerical simulations have shown a noticeable improvement of the system BER after performing the suggested post processing on the photo received signal. This approach allows increasing fiber spans to become longer and therefore reducing the overall cost of the transmission system.

IV. CONCLUSION

A signal post processing approach has been suggested and tested on photodetected data signals that have been transmitted through single mode fiber transmission system. The approach was simulated on systems operating at 10Gbps with an NRZ modulation format. These transmission systems have been built using standard transmitters and receivers operating at central wavelengths of 1550 nm. Performance of improved system has been evaluated via the analysis of quality factor and bit error rate

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