

# Improvement of RMSE in Optical Fiber Communication Systems Using RBF ANN Post Processing Approach

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**Abstract**— In this paper, improvement of Bit Error-Rate (BER) in optical fiber data transmission using an Artificial Neural Networks (ANN) post processing approach is developed. The approach has been tested on optical fiber systems operating at bit rates of up to 10Gbps for a non-return-to-zero (NRZ) modulation formats. The transmission system considered is built using standard optical transmitters and receivers operating in the region of 1550 nm using a standard single mode fiber (SSMF). Performance of signals detected and post processed has been evaluated through Numerical simulations and have shown a very good improvement in the system RMSE after applying the RBF ANN post processing scheme on the detected electrical signal.

**Keywords**— Artificial Neural Networks, ANN, RBF, transmission performance, NRZ coding.

## I. INTRODUCTION

OPTICAL fiber transmission communication systems and networks based on wavelength division multiplexing (WDM) will be dominating the all-optical data transportation with bit rates exceeding several terabit-per-second rates to serve the ever increasing demand of Internet Protocol (TCP/IP) networks [1, 2]. Thus, full optical operation of these networks will be most important features in the near future. Some of the main networking functions such as routing, add /drop multiplexing and demultiplexing as well as 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 therefore, it is necessary to develop approaches to improve regeneration of transmitted data at such high bit rates. 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, considerable amount of research effort needs to be carried out to improve the increasing effective data transmission through these systems [7].

Simulation of such systems plays an important role in determining expected behaviors of components and devices prior to their implementation and testing. This is a cost effective 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 recover transmitted data by reducing the linear and nonlinear effects and noise of transmission system.

The photodetection process itself adds more complexity as it deals with signals where many interactions happen between data and noise throughout the transmitting distance of the fiber link. The train of distorted bits received by the photodetector and after being pre-filtered are further processed using ANN scheme to improve the overall BER of the system. ANN are algorithms that can learn in a self organizing way that emulates the human brain [9]. The optical channel considered in this work is based on a standard single mode fiber operating in the region 1550 nm with no use of chromatic compensation to evaluate the intrinsic effect of the suggested post processing scheme.

## II. MODELING AND SIMULATION

Fig. 1 shows a simplified layout diagram of the optical transmission system adopted for our simulation. As it appears from the diagram, the optical transmitter is composed of a number of multiplexed WDM wavelengths  $\lambda_i$  varying within the ITU-standard range and centered at 1550 nm.

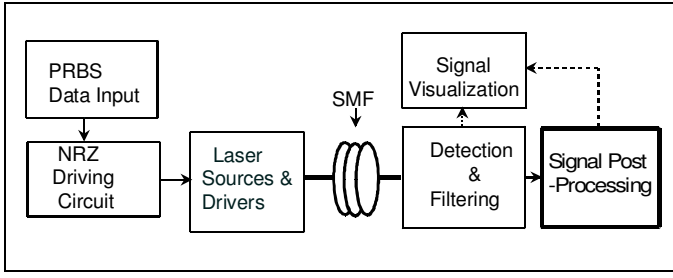


Fig. 1. Simplified Layout of the system used for numerical simulation.

This packet of optical signals is modulated by a non return to zero driving circuit that is modulated by a  $(2^7-1)$  pseudorandom bit sequence signal (PRBS). The optical laser sources used have a full width at half maximum (FWHM) of 10MHz at the data bit rates considered. Standard Single Mode Fiber (SSMF) was used for all the simulated links. Their main parameters are as follows.

The SSMF has got 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 for the central operating wavelength  $\lambda_0=1550\text{nm}$ .

The driven data bit sequences are filtered by a low pass filter having an adequate bandwidth that matches the requirements of the data bit rates used. The choice of the filter characteristics at the photodetector is important for preserving the best performance of the system. It is for this reason that the filter parameters, mainly its bandwidth and order have been studied and their effects on system performance deduced. The optical photodetector is 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 of Fig. 1 is based on the well known Split Step Fourier Method (SSFM). It is used to solve the non-linear Schrödinger equation that governs wave propagation through the system. Assuming that  $E(t)$  is a slowly varying electric field pulse, its solution 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  $E(t)$ ,  $\beta_1$  is the inverse group velocity,  $\beta_2$  and  $\beta_3$ , are respectively the first and second order group dispersion velocities.  $\alpha$  is the absorption coefficient, and  $\Gamma$  the nonlinear coefficient of the optical fiber for a given fiber 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 can be approximated using mean values and standard deviations of the signal samples as

indicated by the equation below.

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

where  $m_1$ ,  $m_0$ ,  $\sigma_1$ ,  $\sigma_0$  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:

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

The received signal obtained from the solution of equation (1) above is further processed using radial basis functions (RBF) ANN that are described in the following sections.

In order to quantitatively examine the effects of the post-processing algorithm on the optical system performance, the root mean square error (RMSE) of the post processed signal is calculated.

The radial basis functions is an algorithm that determines a set of output values depending on a previous training knowledge that utilizes a set of inputs and outputs [ 10]. Fig. 2 shows the block diagram of the RBF learning and evaluation processes used. The inputs used for training are the fiber length, input signal samples at the transmitter and the corresponding output signal at the receiver for that specific fiber length. In the training process, the output signal was used as the input to the ANN whereas the corresponding set of input signal was used as an output.

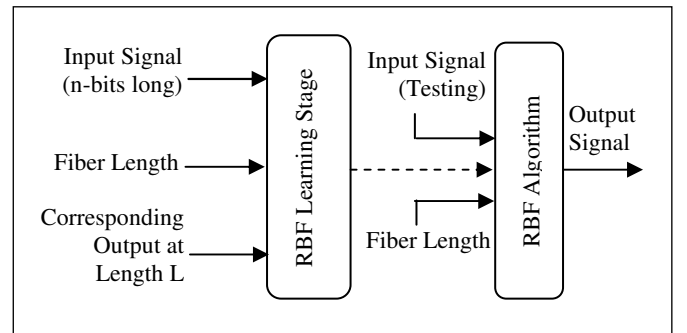


Fig. 2. Block Diagram of the RBF ANN Post processing

The input and output signals' formats are sets of bits that are NRZ encoded with known bit rates. The duration of each bit was set to e.g.  $10^{-10}$  seconds, to correspond to the bit rate of 10Gbps. The packets of data bits travel through optical fibers with spans ranging from 50km to 150km.

The Artificial Neural Networks were trained using different numbers of bits, namely, 16, 32, 64, 80, 96 and 112. These have been performed for optical fiber spans of 50, 100, 120, 130, 140 and 150kms. These various figures in number of bits and fiber lengths will give rise to 42 possible combinations.

The radial basis based post processing applied to the received bits at the receiver can be expressed by the following equations [11]:

$$o_2 = \text{Inf} (J m + v) \quad (4)$$

and

$$m = \text{rdf} (\|K - i\| b) \quad (5)$$

Where:

$o_2$  : second layer output of the radial basis network

$\text{Inf}$  : linear transfer function (linear filter)

$J$  : weights vector for second layer

$m$  : first layer output fed to the second layer

$v$  : second layer bias vector

$\text{rdf}$  : radial basis function (in the form of  $e^{-n^2}$ )

$K$  : input weight matrix

$i$  : input vector

$\|K - i\|$  : vector distances between the input vector and the input weight matrix vectors

$b$  : first layer bias vector

The Matlab algorithm used in this paper is the -more efficient design- algorithm.

### III. RESULTS AND DISCUSSION

Some of the obtained results are shown below in figures 3 through 5 below. In addition to signal attenuation and noise generation, the transmission channel introduces dispersion to the original signal sent at the transmitter end.

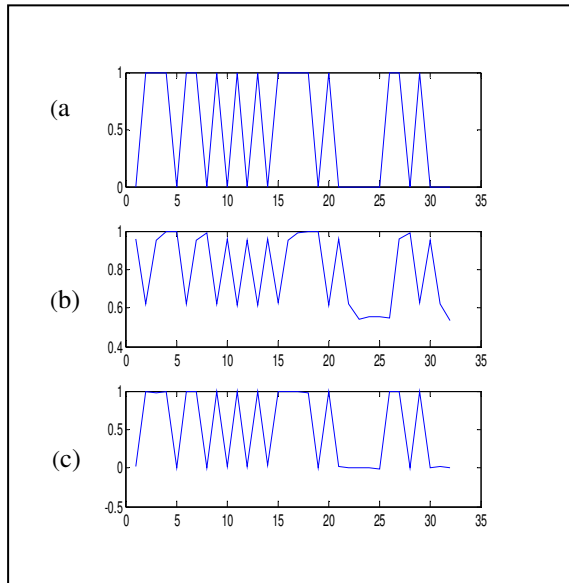


Fig. 3 A sample of a transmitted signal (a), received pre-processed signal (b) and a post-processed signal (c) for a fiber span of 50 km and using 96 bits for training the ANN.

This is clearly observed in Fig. 3. The RMSE between the signal at the transmitter end and the post-processed signal

was calculated by determining the error of the two signals superimposed on the top of each other. Note that each bit has 128 samples and the RMSE was applied to the two vectors representing the back to back signal and the output signal at a given fiber length.

It is worth mentioning here that the ANN post-processing takes care of signal degradation mentioned above, namely, attenuation, noise and dispersion.

Fig. 4 shows the RMSE obtained at different fiber length using different numbers of bits for the RBF ANN training process.

The upper most curve, for instance, indicates that if only 16 bits of the 128 bits sent (where each bit is represented by 128 samples) are used to train the RBF block, the RMSE of the post-processed signal is lower than the unprocessed signal (RMSE=0.5) up to a fiber length of nearly 130km.

As the number of bits used for training increases, the performance, in terms of RMSE improves even further. For the highest number of bits used for training *i.e.* 112 bits, this superiority extends to fiber lengths of about 150km. This figure is practically impossible to reach using the well known techniques for signal regeneration.

The obtained results clearly indicate that the ANN post processing increases the maximum distance the signals that can be transmitted without introducing additional amplifiers or repeaters.

Up to a fiber length of about 100km, the different curves are easy to distinguish in Fig. 4 as the improvement in the RMSE values is very apparent for all curves. The RMSE values for all curves, except the 16 and 32 bits curves, are almost zero.

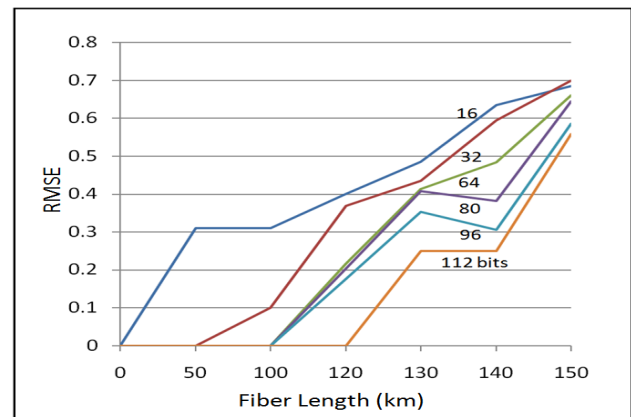


Fig. 4 RMSE profile for different fiber lengths and different lengths of training bits.

However, for larger lengths the curves separations tend to become smaller.

Despite this fact, it is very evident from Fig. 5 that the

higher the number of bits used for training, the longer the fiber can be extended in the range considered in this study.

The issue of whether the added distance is worth the additional computational complexity introduced by the post processing has to be considered and might be application dependent.

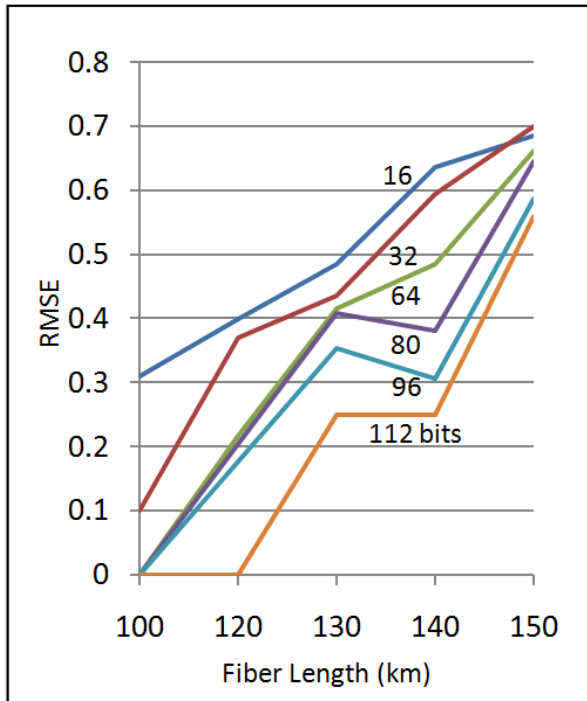


Fig. 5 RMSE profile for different fiber lengths (100 km-150 km) and different lengths of training bits.

Fig. 6 illustrates the fiber length at which the RMSE reaches a value of 0.5. It enforces the previously concluded remarks of RMSE improvement with increasing the number of bits used for training.

#### IV. CONCLUSION

A Radial Basis Functions Artificial Neural Network based 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 tested on systems operating at 10Gbps with a NRZ modulation format. These transmission systems were built using standard transmitters and receivers operating at wavelengths in the region of 1550nm. Performance of the improved system was evaluated via the analysis of Root Mean Square Error. Several fiber segments of up to a length of 150km were used for the simulation with no repeaters or amplifiers added to the original network.

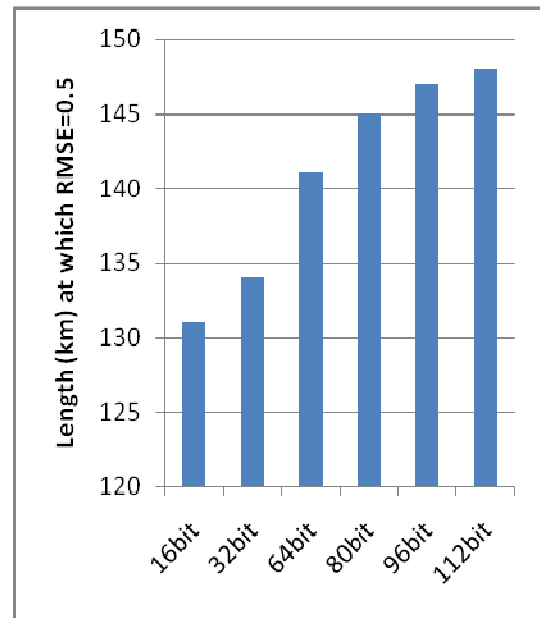


Fig. 6 Lengths at which the RMSE reaches 0.5 for different lengths of training bits

Different lengths of bits used for training the RBF ANN were also investigated. Numerical simulations have shown a noticeable improvement of the system RMSE after performing the suggested post processing on the photo-detected data signal.

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