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Artificial Neural Network based Non-Linear Equalizer for PON systems

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Abstract: **To meet the demand of high data rates and high bandwidth in telecommunication networks, Passive Optical Networks (PONs) are widely recognised as an efficient and cost-effective way. PON systems are highly penalised due to fiber and splitter losses. Spectral efficiency and robustness to chromatic dispersion in PON systems can be improved by using Orthogonal frequency division multiplexing(OFDM). However, high peak to average ratio of OFDM signals make them vulnerable to fiber non-linearities. In this paper, an artificial neural network based non-linear equalizer has been proposed for a 10 Gbps OFDM PON system.**

***Index Terms*—** **ANN, BER, OFDM, PON**

I. Introduction

With exponential traffic growth, transmission capacity and transmission distance in passive optical networks(PON) are being expanded [1]. New schemes are being implemented for next generation of optical access networks(NG-OAN) to increase capacity of network. These networks should be highly reliable, scalable and efficient both in terms of bandwidth and power consumption. OFDM is used in PON systems because of its high spectral efficiency and robustness to polarization mode dispersion and chromatic dispersion.

But at higher bitrates, OFDM systems are severely affected by fiber Kerr effect [2], resulting in SPM (self-phase modulation), XPM (cross phase modulation) & FWM (frequency wave mixing). This causes degradation of optical fiber system performance. Thus, it is important to mitigate fiber non linearities to enhance the system performance.

Several optical domain nonlinearity compensation(NLC) techniques have been proposed to deal with the nonlinear effects. But there is also a new dimension to mitigate non-linearities which is use of digital signal processing (DSP) techniques. Some of the techniques such as digital back propagation(DBP) [3], Volterra based non-linear equalizer (VLNE) [4], phase conjugation (PC) [5] and artificial neural network based non-linear equalizer (ANN-NE) are being used. DBP, VNLE, PC techniques are more complex and less flexible than ANN-NLE technique for real time implementation [6]. As ANN-NLE is less complex and flexible than other non-linear compensation techniques. It has been used in various optical communication systems such as Millimetre-wave Mobile fronthaul systems [7], High-Baud rate IM/DD systems [8] and adaptive wireless transceivers which has resulted in improvement of system performance. But use of ANN-NLE in PON systems has not been mentioned in literature.

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In this paper, an ANN based non-linear equalizer is proposed to improve the performance of PON systems. This paper is organised as follows: Section II describes an OFDM PON system, proposed nonlinear equalizer is described in Section III, section IV presents system description, simulation results are shown in section V. Finally, Section VI concludes the paper.

II. OFDM - PON System

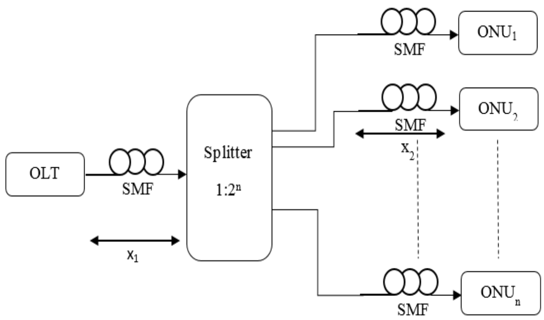

Fig.1**.** Scheme of a PON system

A passive optical network is shown in Fig.1. It comprises of an Optical line transmitter (OLT), a splitter and a number of optical network units (ONUs), depending on number of users in the network. In an OFDM PON system, OLT consists of OFDM transmitter and an ONU consist of OFDM receiver. An OFDM transceiver is shown in Fig.2. First, data is generated using a pseudo- random binary sequence (PRBS) generator which is then modulated using a digital modulation scheme. These data symbols are then parallelized in N different sub-streams. These sub-streams are passed through IFFT block and a cyclic prefix is added to eliminate inter symbol interference (ISI). A cyclic prefix is a circular extension of a symbol which is obtained by copying the last N samples of the symbol in front of it. The data is again converted to serial form and is modulated using a Mach Zehnder modulator(MZM) in combination of a laser diode. Optical fiber is used as transmission medium. At receiver end, inverse operations are performed to get output: optical

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signal is converted to electrical signal using a photodetector & CP is removed. Data is passed through a FFT block to retrieve exact form of transmitted symbols. An appropriate demodulation scheme is used to estimate the received symbols.

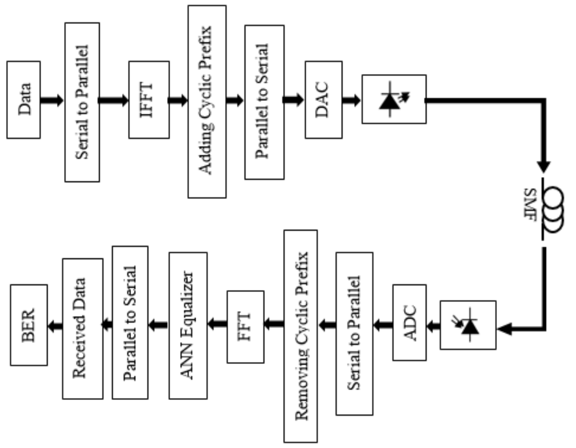

Fig.2. OFDM transceiver block diagram

III. Artificial Neural Network based Non-linear Equalizer

ANN is an attractive replacement for conventional methods such as analytical models, numerical methods or empirical models for solutions, as it learns from observations. ANNs can model multi-dimensional non-linear relationships & are very easy to use. Their response is fast & are generic i.e. same modelling technique can again be reused for active/passive systems or devices [9]. A simple ANN is shown in Fig.3.

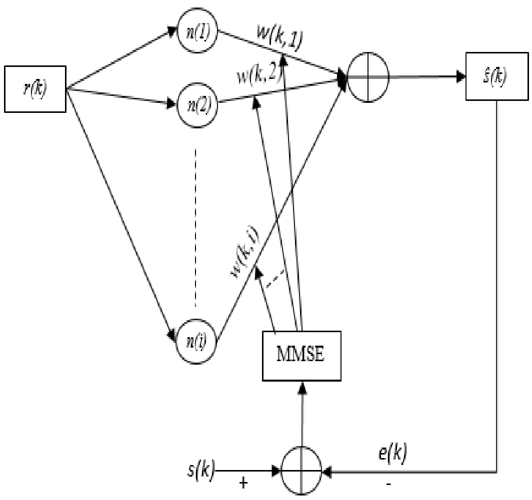

Fig.3: ANN equalizer schematic

s(k): Transmitted Signal (training vector)

r(k): received signal

The symbols received for r*(k)* are given to nonlinear equalizer neurons which are then multiplied with the weight values *w(k, i)* of the neurons. Then, the output of all the neurons is summed to generate signal $\hat{s}(k)$. During training of network, minimum mean square error (MMSE) algorithm is used to determine the error signal & to update the weights. Until desired error is reached, weights are updated iteratively. Error is signal is calculated as follows:

$$e(k) = s(k) - \hat{s}(k) \qquad (1)$$

Weights & bias are updated according to Riedmiller's resilient back propagation (RRBP) algorithm.

Weights are updated as follows:

1. Initialization of weights & thresholds is done to small random numbers.
2. Feed input vector - *r (k)*, and the desired output vector - *s(k)* to the network.
3. Calculate $\hat{s}(k)$ from the *r(k)* & compute error - *e(k).*
4. Weights are updated.
5. If error is above threshold value, go back to *step-2.*

In our work, OFDM data is divided into two parts, real part $\hat{s}_{final}(k)$ & imaginary part $\hat{s}_{imaginary}(k)$ are fed to two different ANN-networks. Output from two networks is recombined as in (2)

$$\hat{s}_{final}(k)= \hat{s}_{real}(k)+ \hat{s}_{imaginary}(k) \qquad (2)$$

IV. System Description

Simulations are carried in VPI Transmission maker 9.1 and MATLAB r2015a. The simulation setup is shown in Fig.4 and system parameters are listed in Table 1.

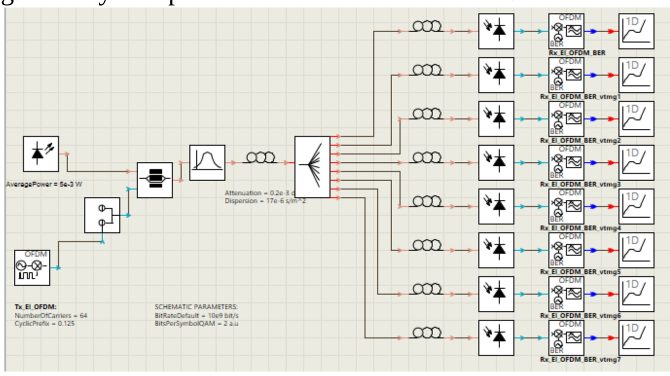

Fig.4. OFDM PON System Setup

An OFDM PON system of bit rate 10 Gb/s is simulated. At transmitter side, data is generated using pseudo- random binary sequence (PRBS) generator which is then mapped using a quadrature-amplitude modulation(QAM) encoder. The information stream is then parsed into 64 data subcarriers, inverse fast Fourier transform (IFFT) processor will process this information.

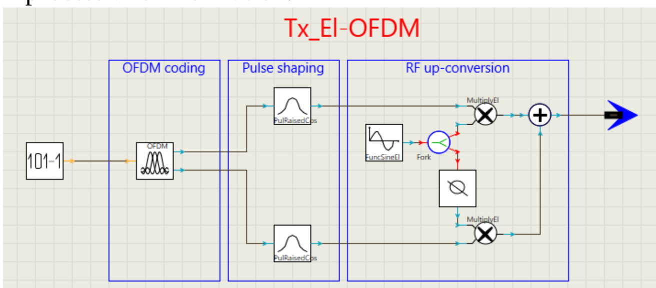

Fig.5. OFDM Transmitter

To ensure correct data recovery, a cyclic prefix(CP) of 12.5 % is added. This generated electrical QAM OFDM signal is modulated using a MZM in combination of CW laser. Laser has linewidth of 1 MHz and average power of 5 mW. The wavelength of carrier wave is 1550 nm.

Optical channel consists of two segments of Single mode

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fiber (SMF), x_1 length of SMF is followed by a 1:8 splitter and finally a section of SMF of length x_2 as shown in Fig.1.

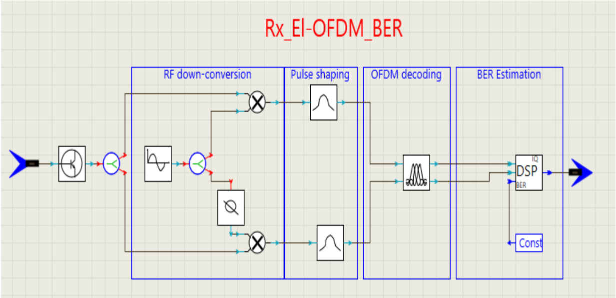

Fig.6. OFDM Receiver

The receiver side consists of a photo detector to convert optical signal to electrical signal. After removing CP from received signal, it is passed through FFT module. The signal is then processed through MATLAB module. ANN-NLE will equalise the signal. Equalised signal is passed through QAM decoder and BER is calculated to evaluate system performance.

Table 1: OFDM Transceiver Parameters

Parameters	**Values**	**Unit**
Number of subcarriers	64	-
Average Power	5	mW
Laser Wavelength	1550	nm
Cyclic Prefix	12.5	%
Bit rate	10	Gbps
Coding	4QAM	-
Dispersion	17	ps/nm/km
Fiber attenuation	0.2	dB/km
Dispersion Slope	0.08	$ps/km/nm^2$
Kerr non-linearity coefficient	2.6×10^{-20}	m^2/W
Photo detector	PIN	-
ADC/DAC quantization bits	10	-

V. Results and Discussion

Non-linearity mitigation capability has been assessed based on BER of the system. Fig.7 shows BER vs transmission distance curve for 10 Gbps 4QAM OFDM PON system with and without using ANN-NLE. It is shown that BER of the system has been reduced by using ANN-NLE. The effect of ANN-NLE can also be seen in Fig.8 which depicts the constellation diagram of received signal at transmission distance of 52 Km. It was observed that ANN-NLE has the ability to concentrate constellation points, thus reducing the symbol dispersion.

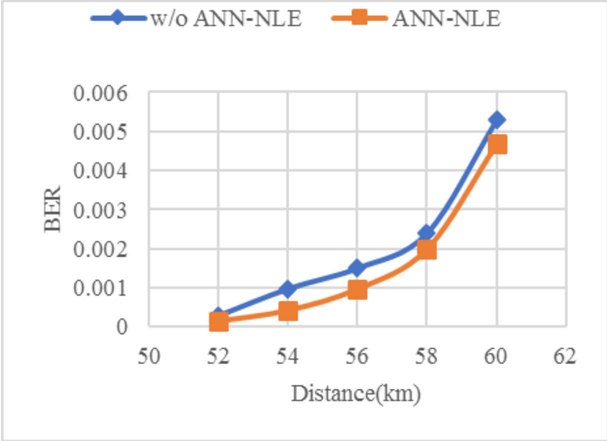

Fig.7. BER vs transmission distance

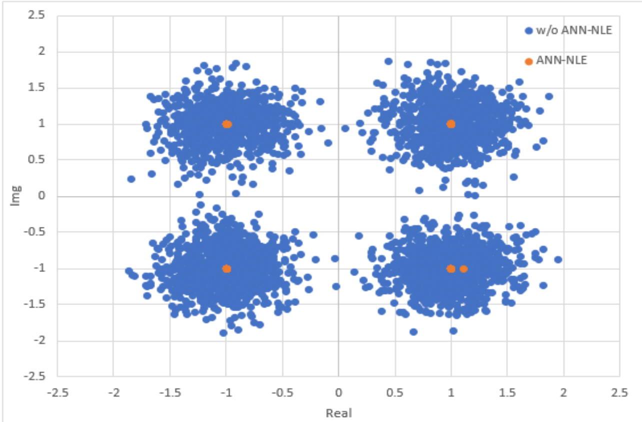

Fig.8. Received 4 -QAM constellation diagram at 52 Km

VI. Conclusion

In this paper, we have presented ANN-NLE for 10 Gbps OFDM PON system. It has been shown that, in a system based on ANN-NLE, BER is reduced which results in better performance of the system.

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